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REVIEW ARTICLE

Massage and Performance Recovery: A Meta-Analytical Review

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Abstract

Background Post-exercise massage is one of the most frequently applied interventions to enhance recovery of athletes. However, evidence to support the efficacy of massage for performance recovery is scarce. Moreover, it has not yet been concluded under which conditions massage is effective.

Objective The objective of this study was to perform a systematic review and meta-analysis of the available literature on massage for performance recovery.

Methods We conducted a structured literature search and located 22 randomized controlled trials. These were analysed with respect to performance effects and various characteristics of the study design (type and duration of massage, type of exercise and performance test, duration of recovery period, training status of subjects).

Results Of the 22 studies, 5 used techniques of automated massage (e.g. vibration), while the other 17 used classic manual massage. A tendency was found for shorter massage (5–12 min) to have larger effects (+6.6 %, $g = 0.34$) than massage lasting more than 12 min (+1.0 %, $g = 0.06$). The effects were larger for short-term recovery of up to 10 min (+7.9 %, $g = 0.45$) than for recovery periods of more than 20 min (+2.4 %, $g = 0.08$). Although after high-intensity mixed exercise, massage yielded medium positive effects (+14.4 %, $g = 0.61$), the effects after strength exercise (+3.9 %, $g = 0.18$) and endurance exercise (+1.3 %, $g = 0.12$) were smaller. Moreover, a tendency was found for untrained subjects to benefit more from massage (+6.5 %, $g = 0.23$) than trained athletes (+2.3 %, $g = 0.17$).

Conclusion The effects of massage on performance recovery are rather small and partly unclear, but can be relevant under appropriate circumstances (short-term recovery after intensive mixed training). However, it remains questionable if the limited effects justify the widespread use of massage as a recovery intervention in competitive athletes.

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Key Points

Although post-exercise massage is a frequently applied recovery tool, its efficacy for performance recovery and the underlying physiological mechanisms are unclear.

This meta-analysis investigated the effects of massage on performance recovery and suggests that although the average effects were negligible in total, massage can be effective if the recovery interval is short (up to 10 min). The average effects were larger for intensive mixed exercise than for strength and endurance exercise, and massage appeared to be more effective for untrained subjects than for athletes.

On average, the effects of massage on performance recovery are limited but can be relevant under certain circumstances.

1 Introduction

During training periods and competition, professional athletes can be exposed to high physical and psychological stresses. It is of great importance that they recover as quickly as possible to be able to perform at their best over longer periods of time. Therefore, athletes and coaches are searching for effective strategies to speed up post-exercise recovery and restore performance. Besides cooling [1], sauna [2], compression [3] or active recovery [4], a recovery strategy frequently used by athletes is massage.

Massage is defined as "mechanical manipulation of body tissues with rhythmical pressure and stroking for the purpose of promoting health and well-being" [5], and it is used for recovery purposes, preparation prior to exercise, and prevention and rehabilitation of injuries [6]. The most commonly used kind of massage in training and competition is the so-called classic Western massage or Swedish massage. Here, techniques such as effleurage (sliding movements), petrissage (tissue kneading or pressing), friction (pressure application), tapotement (rapid striking) and vibration are applied for a total duration of typically 10–30 min [5, 7]. Practically relevant alternatives include technically assisted vibration massage [8, 9], underwater water-jet massage [10], acupressure [11] and connective tissue massage [12].

Various potential mechanisms of massage have been discussed in the literature, including biomechanical, physiological, neurological and psychological effects [7]. Massage is believed to relieve muscle tension; reduce muscle pain, swelling and spasm; improve flexibility and range of motion; increase muscle blood flow; and enhance clearance of substances such as blood lactate or creatine kinase [13]. So far, only limited evidence has been found for these mechanisms, with the exception of an improved psychophysiological response, leading to increased relaxation [7]. In a recent study using muscle biopsies, however, Crane et al. [14] observed that massage was effective in reducing muscle inflammation by attenuating cytokine production.

As quick restoration of performance is the most relevant aspect of potential recovery strategies for competitive athletes, and as there may be limited time available for such measures, there is a need for scientific clarification of whether and under which circumstances massage may be an effective means of improving recovery after exercise. Numerous review articles analysing the results of studies with the aim of enhancing post-exercise recovery by massage interventions have been published in recent years [6, 7, 13, 15–17]. The general consensus is that although massage is a popular and frequently used recovery modality among athletes [5, 18], its effects on the recovery of performance (which is the most relevant issue for competitive athletes) are rather small and equivocal. The existing reviews have a rather narrative character and did not evaluate the respective studies using a structured meta-analytic approach. Although such a procedure is affected by the diversities in design and protocols present in the respective massage studies (e.g. different massage techniques, different types of exercise and performance tests, different recovery times) [13], a meta-analysis of existing studies, including aspects of study design, may help to elucidate whether and under which conditions (e.g. type of exercise, duration of recovery period) post-exercise massage can speed up the recovery of performance [1].

Therefore, a meta-analytical review was conducted to give an overview of the current scientific literature in the field of massage for performance recovery purposes and its effects on subsequent performance. To this end, the efficacy of massage was evaluated with regard to various methodological aspects of the investigated studies.

2 Methods

A literature search was undertaken for articles published through December 2014, using different sets of nine keywords ['massage', 'sports', 'performance', 'recovery', 'exercise', 'delayed onset muscle soreness' (DOMS), 'effleurage', 'petrissage', 'vibration'] combined by Boolean logic ('AND', 'OR'). The following databases were used for research: PubMed, ISI Web of Science, Allied and Complementary Medicine Database (AMED), Cochrane

Database of Systematic Reviews and Excerpta Medica Database (Embase). Moreover, key primary and review articles were citation tracked. From 1123 screened abstracts, 57 potentially suitable articles were identified.

2.1 Selection Criteria

The obtained articles were evaluated with respect to their suitability and significance for the desired context on the basis of various criteria. A study was included only if it was published in an internationally peer-reviewed scientific journal and if it fulfilled the following requirements:

1. A massage intervention had to be performed. Here, any kind of massage was included, e.g. classic Western massage, vibration or water-jet massage (drop-outs 6).
2. The massage intervention had to be performed for recovery purposes, i.e. after intensive exercise (drop-outs 11).
3. A plausible measurement of physical performance before and after the intervention had to be performed, as only under these circumstances could the effect of massage on performance be quantified. Studies evaluating the effects of massage only on physiological markers were excluded (drop-outs 18).
4. A control condition with a passive recovery protocol had to exist, with the subjects either acting as their own controls (a randomized crossover design) or being randomly divided into an intervention group and a control group (drop-outs 0).

Figure 1 shows the flow chart of the selection process. Finally, 22 remaining studies were analysed.

2.2 Classification and Quality Assessment of the Studies

For further analyses, studies were classified into different categories with respect to the following criteria:

1. Type of massage (manual or automated massage)
2. Duration of massage (5–6, 8–12, 15–20, ≥30 min)
3. Time between exercise and post-test (5–10 min, 20–35 min, 1–6 h, 24 h, 48 h, 72 h, 96 h, >96 h)
4. Type of performance investigated pre- and post-exercise (endurance, strength, sprint or jump)
5. Type of exercise used to induce fatigue (endurance, strength, mixed)
6. Training status of the subjects [untrained (subjects not exercising on a regular basis), active (physically active but not competitive subjects) or competitive (subjects regularly competing in sporting events)].

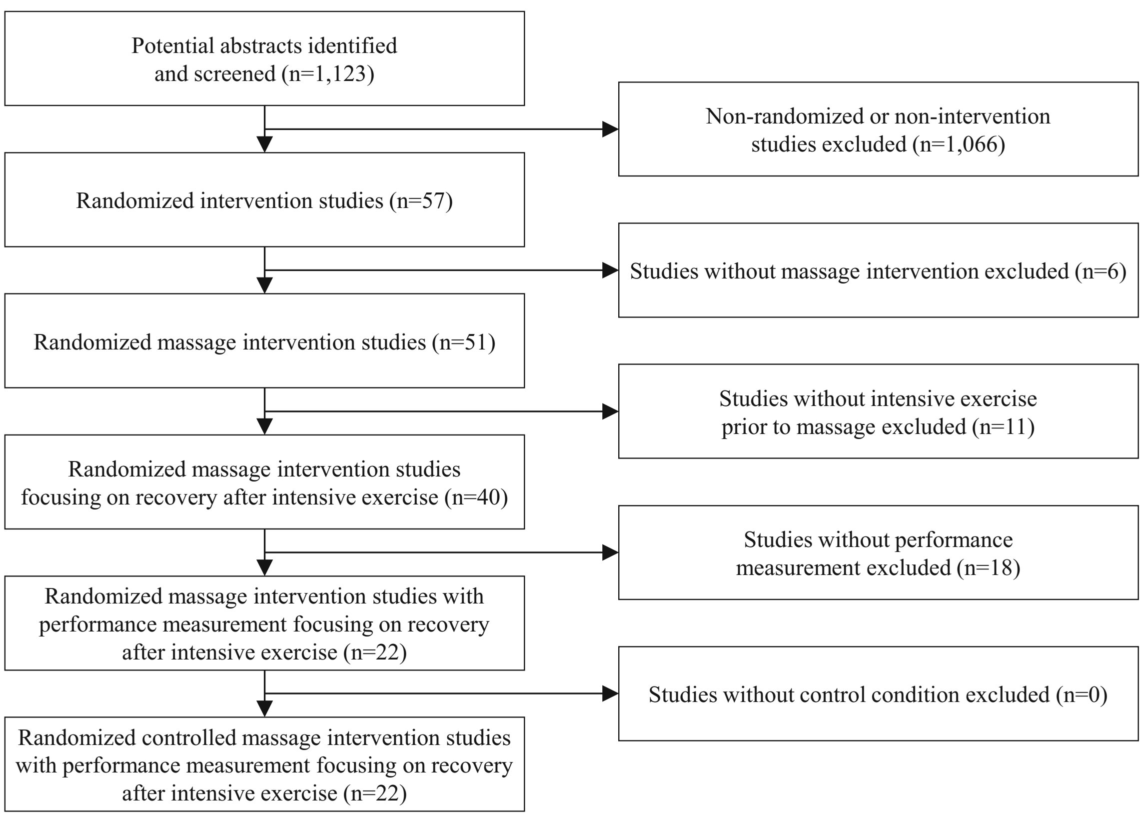

Fig. 1 Summary of the study selection process

In the statistical analysis, several studies were included more than once—for instance, if several post-tests were conducted (e.g. after 24 and 48 h) or if several types of performance were investigated. If more than one parameter was assessed for a certain type of performance, the most relevant indicator was chosen (e.g. mean power instead of peak power for cycling sprints).

For quality assessment of the studies, the Cochrane risk-of-bias tool [19, 20] was used.

2.3 Statistical Analysis and Assessment of Effect Sizes

A standardized form was used to extract all relevant data and key methodological details from the studies. Relative changes in performance (pre- versus post-) for the massage condition and the control condition were calculated for each study. By subtracting the two values, the net effect of massage on performance recovery was calculated.

Effect sizes (Hedges' g values) were calculated using the following formula:

$$g = c_P \left[\frac{(M_{\text{post,massage}} - M_{\text{pre,massage}}) - (M_{\text{post,control}} - M_{\text{pre,control}})}{\text{SD}_{\text{pre}}} \right]$$

with $M_{\text{pre,massage}}$, $M_{\text{post,massage}}$, $M_{\text{pre,control}}$ and $M_{\text{post,control}}$ being the respective mean values of performance (pre-/post-, massage/control), the pooled pre-test standard deviation (SD_{pre}) and a bias factor (c_P) to adjust for small sample sizes [21]. This method was selected as it has been recommended for effect size calculation of controlled pre-/post- study designs in meta-analyses based on simulation results [21]. Negative effects (performance impairments due to massage) are denoted by a minus sign. Effect size variances and 95 % confidence intervals were calculated as described by Borenstein et al. [22]. For the crossover studies, an intra-individual correlation coefficient of 0.9 was used, based on values reported in the studies [23–25].

If more than one parameter was assessed for a certain type of performance, a combined effect was calculated by averaging the relative change and the effect size, and calculating the combined effect size variance [22]. Here, a correlation coefficient of 0.9 was assumed, based on literature values [26, 27].

The overall outcomes for the analysed conditions were assessed by calculating inverse-variance-weighted g averages [22]. For 12 of the 22 studies, more than one outcome was included in the analysis, either because several post-tests were conducted (e.g. after 24 and 48 h) or because several types of performance were investigated. In these cases, the respective outcomes were combined as described above, assuming correlation coefficients of 0.9 for combining different time points [23–25] and 0.6 for combining different types of performance [27–32].

Data for all single studies, as well as weighted average values, are presented in forest plots. The magnitude of g was categorized according to the following scale [33]: <0.20, negligible effect; 0.20–0.49, small effect; 0.50–0.79, moderate effect; ≥ 0.80, large effect. Values are reported with 95 % confidence intervals to express the uncertainty of the true effect. Effect sizes can be interpreted as clear evidence for the benefit of massage if the average and 95 % confidence interval are above zero.

3 Results

Twenty-two studies that met all inclusion criteria, with a total number of 270 subjects, were identified. Overviews of these studies are provided in Table 1 and Electronic Supplementary Material Table S1 (the latter includes pre- and post-test scores), and the calculated effect sizes are presented in Figs. 2, 3, 4, 5, 6. Over all studies, the weighted average performance change due to massage was +3.3 % and the weighted average effect size was $g = 0.19$. Thirteen studies showed only positive (albeit partly very small) effects of massage on performance recovery. In five studies, positive effects were found for some target parameters, but negative effects were found for others. The remaining four studies found only negative performance effects.

The quality assessment using the Cochrane risk-of-bias tool [19] revealed a similar risk of bias for most of the studies. Almost all studies had a low risk of selection bias, as they explicitly stated that allocation of the subjects was done on a random basis. No information on subject allocation was provided by Hemmings et al. [34], while Zelikovski et al. [35] divided their subjects into two groups but did not explicitly mention randomization. The risk of bias in these two studies was therefore classified as unclear. Because of the nature of the massage intervention, blinding of subjects was not possible; therefore, the risk of performance bias was high in all studies. Only Mancinelli et al. [36] stated that the examiners were blinded during outcome assessment, indicating a low risk of detection bias. None of the other authors provided any information on examiner blinding. Regarding attrition bias, three studies reported on drop-outs ($n = 1$ [9], $n = 3$ [37] and $n = 2$ [38]), while no information on withdrawals could be extracted from the other studies. Finally, ten studies used a familiarization session prior to the examination [9, 23, 24, 34, 37, 39–43]; in 11 studies, the subjects were asked to refrain from strenuous exercise prior to the examination period [9, 24, 25, 34, 35, 37, 38, 44–47]; five studies mentioned diet control [9, 35, 37, 44, 45]; and three studies explicitly

Table 1 Overview of the studies included in this meta-analysis

Study	Subjects (male/female)	Exercise to provoke exhaustion	Time between exercise and massage	Massage intervention	Time between massage and post-test	Performance measurement	Effects
Endurance performance							
Lane and Wenger, 2004 [45]	10 (10/0), active	Endurance: 18 min intermittent cycling sprint	0 min	15 min manual massage (legs), registered massage therapist	24 h	Endurance: Work during 18 min intermittent cycling sprint	Post 24 h: +1.0 % ($g = 0.06$)
Monedero and Donne, 2000 [41]	18 (18/0) competitive cyclists	Endurance: 5 km cycling TT	0 min	15 min manual massage (legs), certified masseur	5 min	Endurance: 5 km cycling TT	Post 20 min: +0.6 % ($g = 0.11$)
Rinder and Sutherland, 1995 [56]	20 (13/7), untrained	Mixed: Leg extensions, cycling and ski squats until exhaustion	0 min	6 min manual massage (legs), no information provided on therapist experience	0 min	Endurance: Maximum number of leg extensions at 50 % 1RM	Post 6 min: +15.2 % ($g = 0.62$)
Jump performance							
Delextrat et al., 2012 [37]	16 (8/8), competitive basketball players	Endurance: 25 min basketball match	0 min	30 min manual massage (legs), qualified massage therapist with five years experience as a sports massage practitioner	24 h	Jump: CMJ height	Post 24 h: +3.3 % ($g = 0.31$)
Farr et al., 2002 [39]	8 (8/0), active	Endurance: 40 min downhill walk	2 h	30 min manual massage (one leg, other leg as control), trained masseur	22 h	Jump: Vertical jump height (% of baseline)	Post 24 h: −4.0 % ($g = -0.33$)
					70 h		Post 72 h: +1.6 % ($g = 0.11$)
					118 h		Post 120 h: +0.3 % ($g = 0.02$)
Jönhagen et al., 2004 [38]	16 (8/8), active	Strength: 300 eccentric quadriceps contractions	10 min	3 × 12 min manual massage (one leg, other leg a control), repeated daily, experienced sport physical therapist	0 min	Jump: 1-leg long jump	Post 48 h: +0.2 % ($g = 0.01$)
Mancinelli et al., 2006 [36]	11+11[a] (0/22), competitive basketball/ volleyball players	Mixed: 3 days intense strength training and drills	0 min	17 min manual massage (legs), licensed massage therapist with 3 years of experience as general massage practitioner	3 min	Jump: Vertical jump height	Post 20 min: +4.5 % ($g = 0.41$)
Sprint performance							
Ali Rasooli et al., 2012 [44]	17 (17/0), competitive swimmers	Endurance: 200 m swimming	0 min	10 min manual massage (whole body), masseur	0 min	Sprint: 200 m swimming	Post 10 min: +4.3 % ($g = 0.44$)

Table 1 continued

Study	Subjects (male/female)	Exercise to provoke exhaustion	Time between exercise and massage	Massage intervention	Time between massage and post-test	Performance measurement	Effects
Delextrat et al., 2012 [37]	16 (8/8), competitive basketball players	Endurance: 25 min basketball match	0 min	30 min manual massage (legs), qualified massage therapist with five years experience as a sports massage practitioner	24 h	Sprint: 10 × 30 m time	Post 24 h: –0.3 % (g = –0.03)
Mancinelli et al., 2006 [36]	11+11[a] (0/22), competitive basketball/volleyball players	Mixed: 3 days intense strength training and drills	0 min	17 min manual massage (legs), licensed massage therapist with 3 years of experience as general massage practitioner	3 min	Sprint: Shuttle run (30 m)	Post 20 min: +4.5 % (g = 0.60)
Ogai et al., 2008 [46]	11 (0/11), active	Sprint: 3 min intermittent cycling sprint	5 min	10 min manual massage (legs), skilled and experienced therapist	20 min	Sprint: 3 min intermittent cycling sprint	Post 35 min: +4.2 % (g = 0.28)
Strength performance							
Dawson et al., 2004 [53]	12 (8/4), competitive runners	Endurance: Half-marathon race	0 min	4 × 30 min manual massage (one leg, other leg as control), repeated after each post-test, registered massage therapist trained in sports massage	24 h 72 h 96 h 72 h	Strength: Quadriceps/hamstrings peak torque	Post 24 h: −0.3 % (g = 0.00) Post 96 h: −1.6 % (g = −0.18) Post 192 h: −3.8 % (g = −0.28) Post 264 h: −3.8 % (g = −0.28)
Farr et al., 2002 [39]	8 (8/0), active	Endurance: 40 min downhill walk	2 h	30 min manual massage (one leg, other leg as control), trained masseur	22 h 70 h 118 h	Strength: Knee extensor isometric and isokinetic (60°/s) strength (% of baseline)	Post 24 h: +5.0 % (g = 0.46) Post 72 h: +0.3 % (g = 0.03) Post 120 h: +2.3 % (g = 0.23)
Hemmings et al., 2000 [34]	8 (8/0), competitive boxers	Endurance: 5 × 2 min boxing (400 punches total)	0 min	20 min manual massage (whole body), qualified sports massage therapist	40 min	Strength: Punching force	Post 1 h: −0.1 % (g = −0.01)
Hilbert et al., 2003 [40]	9 + 9[a] (?/?[b]), untrained	Strength: 6 × 10 eccentric hamstring contractions	2 h	20 min manual massage (leg), senior physical therapy student	4 h 22 h 46 h	Strength: Hamstrings peak torque	Post 6 h: 3.5 % (g = −0.07) Post 24 h: −1.0 % (g = 0.01) Post 48 h: +1.7 % (g = 0.10)

Table 1 continued

Study	Subjects (male/female)	Exercise to provoke exhaustion	Time between exercise and massage	Massage intervention	Time between massage and post-test	Performance measurement	Effects
Jönhagen et al., 2004 [38]	16 (8/8), active	Strength: 300 eccentric quadriceps contractions	10 min	3 × 12 min manual massage (one leg, other leg a control), repeated daily, experienced sport physical therapist	0 min	Strength: Quadriceps isokinetic strength	Post 48 h: +3.3 % ($g = 0.15$)
Sykaras et al., 2003 [42]	12 (0/12), competitive Tae Kwon Do athletes	Strength: 6 × 10 concentric/eccentric quadriceps contractions	0 min	6 × 2 min manual massage (legs), performed after each exercise set, experienced therapist	3 min	Strength: Quadriceps concentric and eccentric peak torque	Post 5 min: +14.1 % ($g = 0.86$)
Tiidus and Shoemaker, 1995 [43]	9 (4/5), untrained	Strength: 7 × 20 eccentric quadriceps contractions	1 h	4 × 10 min manual massage (one leg, other leg as control), repeated daily, registered massage therapist	23 h	Strength: Quadriceps peak torque at 0°/s, 60°/s and 180°/s (% of baseline)	Post 24 h: +2.9 % ($g = 0.10$)
					23 h		Post 48 h: +1.7 % ($g = 0.06$)
					23 h		Post 72 h: +2.9 % ($g = 0.11$)
					23 h		Post 96 h: +5.5 % ($g = 0.26$)
Weber et al., 1994 [47]	10 + 10[a] (0/20), untrained	Strength: Eccentric elbow contraction until exhaustion	0 min	8 min manual massage (arm), no information provided on therapist experience	24 h	Strength: Elbow flexor MVIC and peak torque at 60°/s	Post 24 h: +6.7 % ($g = 0.45$)
					48 h		Post 48 h: +10.5 % ($g = 0.68$)
Young et al., 2005 [55]	12 (12/0), untrained	Strength: 1 min MVIC of thumb adductors	0 min	5 min manual massage (hand), experienced osteopath	0 min	Strength: Thumb adductor isometric strength	Post 5 min: −1.8 % ($g = -0.07$)

Table 1 continued

Study	Subjects (male/female)	Exercise to provoke exhaustion	Time between exercise and massage	Massage intervention	Time between massage and post-test	Performance measurement	Effects
Zainuddin et al., 2005 [25]	10 (5/5), untrained	Strength: 10 × 6 eccentric elbow flexor contractions	3 h	10 min manual massage (one arm, other arm as control), professional masseuse who had been working for an Australian football club for several years	21 h 45 h 69 h 93 h 165 h 237 h 333 h	Strength: Elbow peak torque at 0°/s (% of baseline), 30°/s and 300°/s	Post 24 h: +4.8 % ($g = 0.07$) Post 48 h: +5.3 % ($g = 0.07$) Post 72 h: +7.8 % ($g = 0.09$) Post 96 h: +10.5 % ($g = 0.22$) Post 168 h: +5.2 % ($g = 0.09$) Post 240 h: +7.4 % ($g = 0.15$) Post 336 h: +5.1 % ($g = 0.10$)
Automated massage							
Cafarelli et al., 1990 [23]	12 (12/0), active	Strength: Quadriceps MVC until exhaustion	0 min	2 × 4 min vibration massage (legs), separated by performance test	1 min 1 min	Strength: Quadriceps MVC during exercise (% of MVC superimposed by electrical stimulation)	Post 5 min: ±0.0 % ($g = -0.01$) Post 10 min: +1.2 % ($g = 0.01$)
Edge et al., 2009 [9]	9 (9/0), competitive runners	Endurance: 3 km TT, 8 × 400 m (running)	0 min	30 min vibration massage (whole body)	24 h	Endurance: 3 km running TT	Post 24 h: −0.2 % (g=–0.03)

Table 1 continued

Study	Subjects (male/female)	Exercise to provoke exhaustion	Time between exercise and massage	Massage intervention	Time between massage and post-test	Performance measurement	Effects
Lau and Nosaka, 2011 [24]	15 (15/0), untrained	Strength: 10 × 6 eccentric elbow contractions	30 min	5 × 30 min vibration massage (upper body), repeated daily for a total of 5 days	30 min	Strength: Elbow isometric strength (% of baseline)	Post 1 h: +4.9 % ($g = 0.33$)
					24 h		Post 24 h: +8.7 % ($g = 0.49$)
					48 h		Post 48 h: +6.4 % ($g = 0.44$)
					72 h		Post 72 h: +4.5 % ($g = 0.37$)
					96 h		Post 96 h: +6.7 % ($g = 0.48$)
					120 h		Post 120 h: −3.4 % (g=–0.24)
					168 h		Post 168 h: +1.5 % ($g = 0.10$)
Viitasalo et al., 1995 [10]	14 (8/6), competitive track and field athletes	Mixed: 5 intensive training sessions in 3 days (strength, technique, jump, strength, speed)	30 min	3 × 20 min warm underwater water-jet massage (whole body), repeated daily	12 h	Jump: Drop and rebound jump height	Post 12 h: +6.1 % ($g = 0.36$)
					20 h		Post 20 h: −5.3 % ($g = -0.36$)
					36 h		Post 36 h: +3.6 % ($g = 0.22$)
					12 h	Strength: Leg extensor isometric strength	Post 12 h: +17.2 % ($g = 0.62$)
					20 h		Post 20 h: −3.0 % ($g = -0.11$)
					36 h		Post 36 h: −2.1 % ($g = -0.08$)
Zelikovski et al, 1993 [35]	11 (11/0), active	Endurance: Cycling at 80 % VO_{2peak} until exhaustion	0 min	20 min pneumatic massage (legs)	0 min	Endurance: Time to exhaustion during cycling exercise protocol	Post 20 min: +24.6 % ($g = 3.06$)

1RM 1-repetition maximum, *CMJ* counter movement jump, *MVC* maximal voluntary contraction, *MVIC* maximal voluntary isometric contraction, *TT* time trial, VO_{2peak} peak oxygen uptake

[a] Parallel group study (first number: subjects in massage group, second number: subjects in control group)

[b] Male and female volunteers (no information on sex distribution provided)

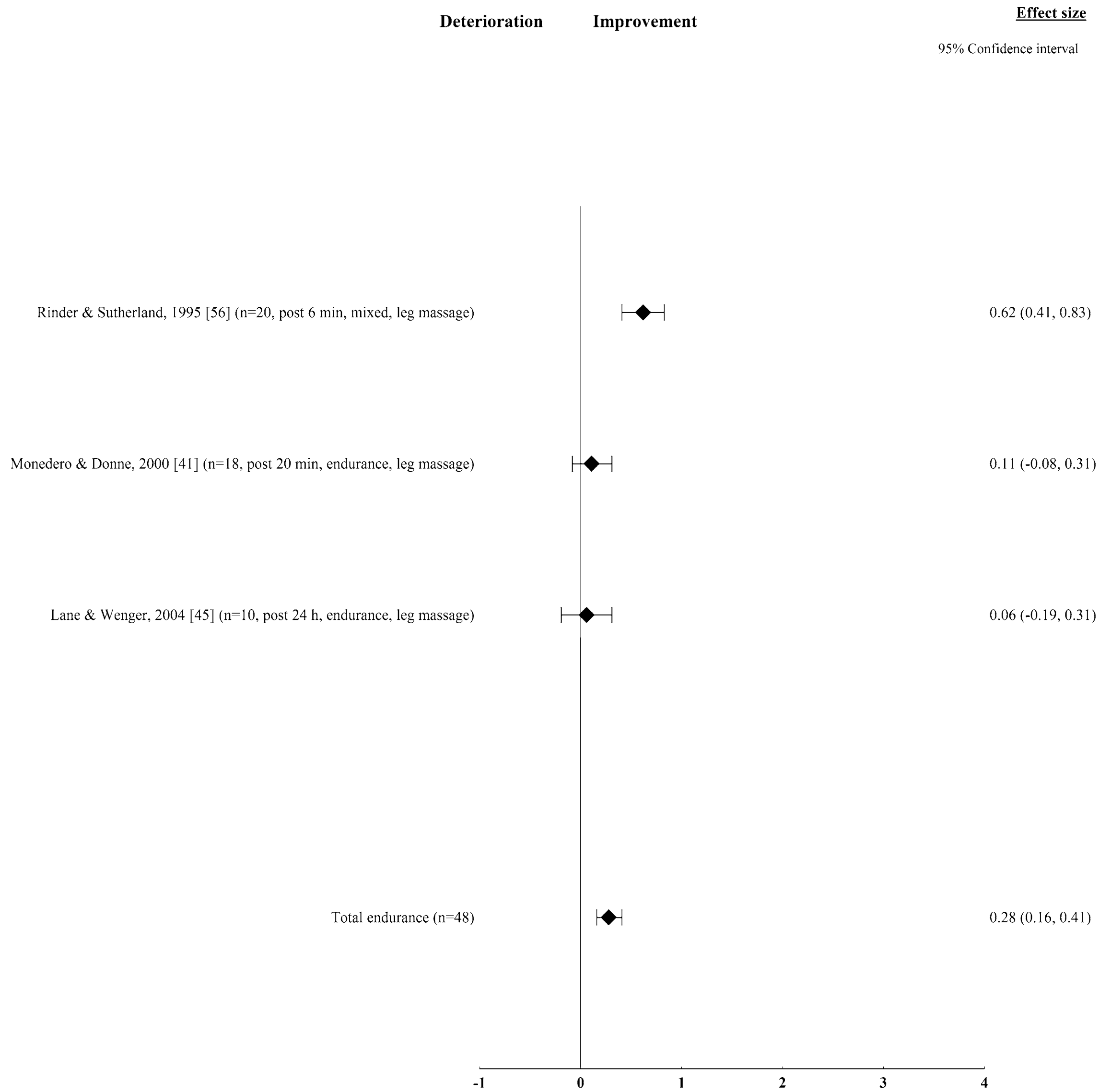

Fig. 2 Effects of post-exercise manual massage on recovery of endurance performance. For each study, the following information is included in *parentheses*: number of subjects, timing of post-test, type of exercise to induce fatigue, type of massage. The studies are ordered by increasing duration between exercise and post-test

stated that the protocols were conducted at the same time of the day in both conditions [9, 44, 45].

In conclusion, none of the studies included in this meta-analysis was considered to have a high risk of bias, apart from the high risk of performance bias inevitable for this type of study.

Of the 22 studies, 17 used classic massage (typically a combination of effleurage and petrissage, sometimes accompanied by vibration [36], friction [25, 42, 44, 45] or tapotement [40, 41]), usually done by a trained physiotherapist (average performance change: +3.5 %, $g = 0.19$). Three studies [9, 23, 24] applied vibration massage using an automated commercial device (+1.8 %, $g = 0.11$). In one study [10], warm underwater water-jet massage was used (+2.8 %, $g = 0.11$). In another study [35], massage was applied by means of a modified intermittent sequential pneumatic device (+24.6 %, $g = 3.06$). For further classification of the studies into categories, only studies using manual massage were considered.

For those 17 studies, there was a tendency towards larger effects for shorter massage durations. For 5–6 min of massage (two studies), as well as for 8–12 min of massage (six studies), clear positive effects were found, on average (+7.8 %, $g = 0.32$, and +6.1 %, $g = 0.35$, respectively). For longer massage durations of 15–20 min (six studies) and $\geq$30 min (five studies), only unclear and negligible effects were observed (+0.9 %, $g = 0.08$, and +1.1 %, $g = 0.06$, respectively).

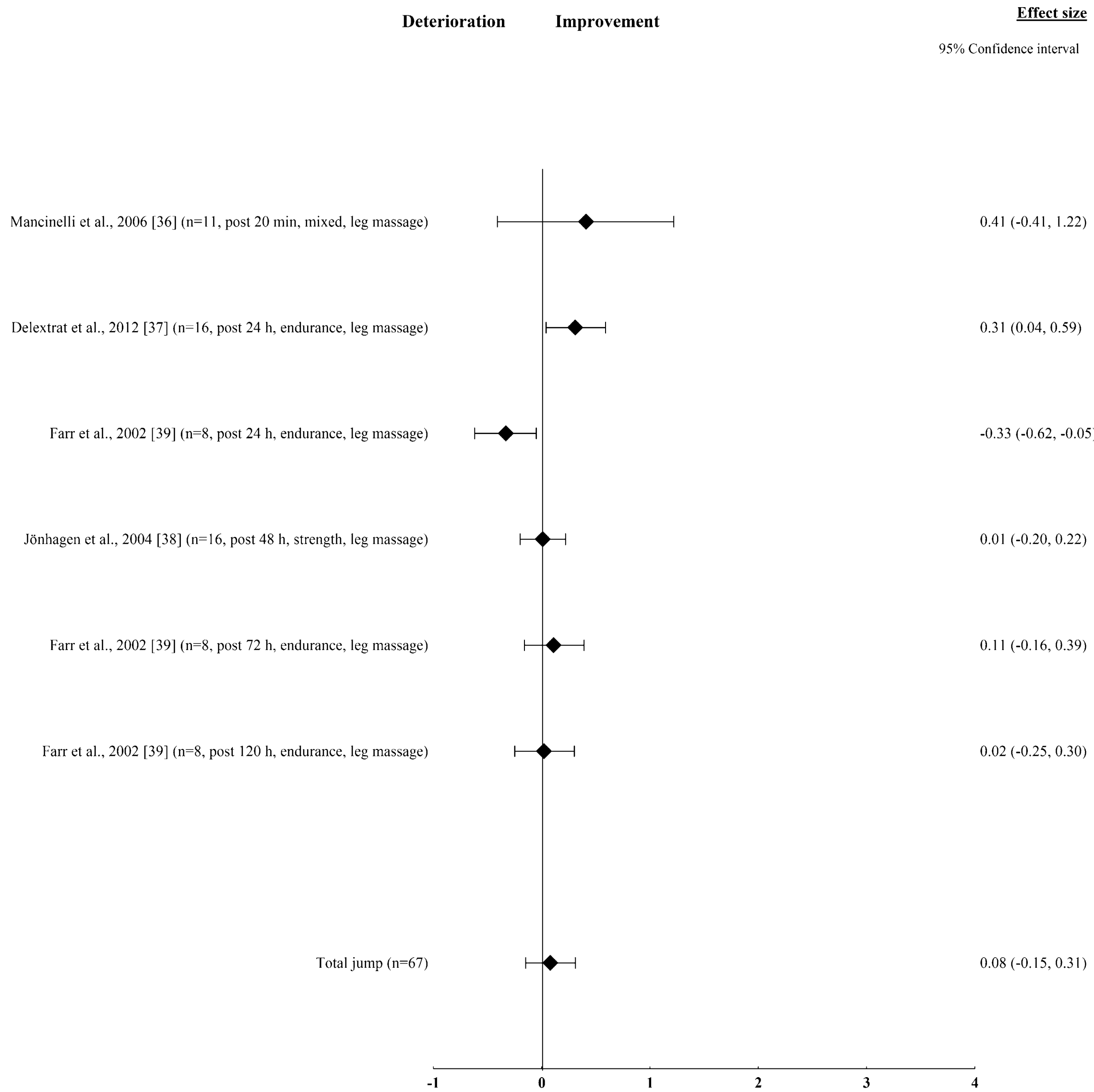

Fig. 3 Effects of post-exercise manual massage on recovery of jump performance. For each study, the following information is included in *parentheses*: number of subjects, timing of post-test, type of exercise to induce fatigue, type of massage. The studies are ordered by increasing duration between exercise and post-test

Considering the time between the exercise and the post-test, massage appeared to be most effective for short-term recovery (5–10 min), with the post-test being performed directly after the massage intervention (four studies, +7.9 %, $g = 0.45$). For longer recovery periods of 20–35 min (three studies, +2.1 %, $g = 0.19$), 1–6 h (two studies, −0.4 %, $g = -0.01$), 24 h (eight studies, +1.7 %, $g = 0.07$), 48 h (five studies, +2.8 %, $g = 0.08$), 72 h (three studies, +3.9 %, $g = 0.09$), 96 h (three studies, +4.6 %, $g = 0.09$) and more than 96 h (three studies, +1.1 %, $g = -0.02$), the average effects were unclear and negligible.

With respect to the type of performance investigated, the largest effects were found for endurance (three studies, +6.0 %, $g = 0.28$) and sprints (four studies, +3.1 %, $g = 0.28$). The majority of studies focused on strength performance (ten studies, +2.9 %, $g = 0.13$). For jump performance (four studies, +0.9 %, $g = 0.08$), only unclear, negligible average effects were detected.

Regarding the type of exercise conducted to induce fatigue, the best results were found for mixed exercise (two studies, +14.4 %, $g = 0.61$). Massage performed after strength exercise (seven studies, +3.9 %, $g = 0.18$) and endurance exercise (eight studies, +1.3 %, $g = 0.12$) had only negligible effects.

Finally, the studies were grouped with respect to the training status of the subjects. While massage had clear positive effects for untrained subjects (six studies, +6.5 %,

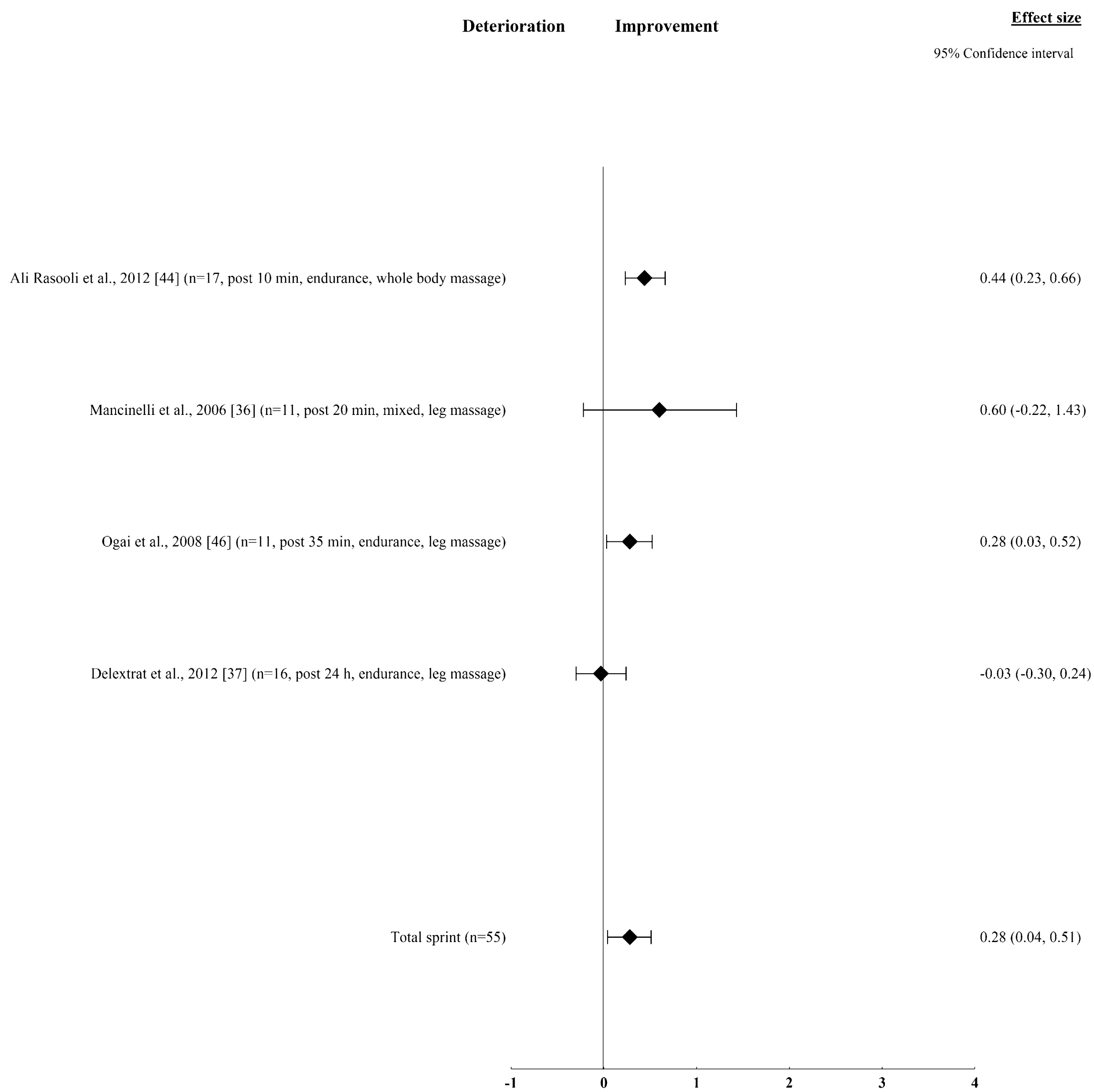

Fig. 4 Effects of post-exercise manual massage on recovery of sprint performance. For each study, the following information is included in *parentheses*: number of subjects, timing of post-test, type of exercise to induce fatigue, type of massage. The studies are ordered by increasing duration between exercise and post-test

$g = 0.23$), the average performance improvements were smaller for trained athletes (active subjects: four studies, +1.9 %, $g = 0.12$; competitive subjects: seven studies, +2.5 %, $g = 0.21$). However, the average effect size for competitive subjects was similar to that for untrained subjects.

4 Discussion

The average effect size of $g = 0.19$ across all studies indicates that, on average, only negligible effects on performance recovery can be expected from massage. However, the average relative performance improvement found in the studies was 3.3 %. Hopkins et al. [48] defined the smallest worthwhile enhancement (i.e. the minimum improvement making a certain strategy worthwhile) as the value increasing the chance of victory for an athlete by 10 %. For half-marathon and marathon races, they calculated values of ~1 %; for shorter distances including sprints, they found values of ~0.5 % [48, 49]. This shows that although the effect sizes were rather small from a purely statistical point of view, when inter-individual variability was taken into account, the results suggested that the average improvements in performance were within a range that was relevant for competitive athletes.

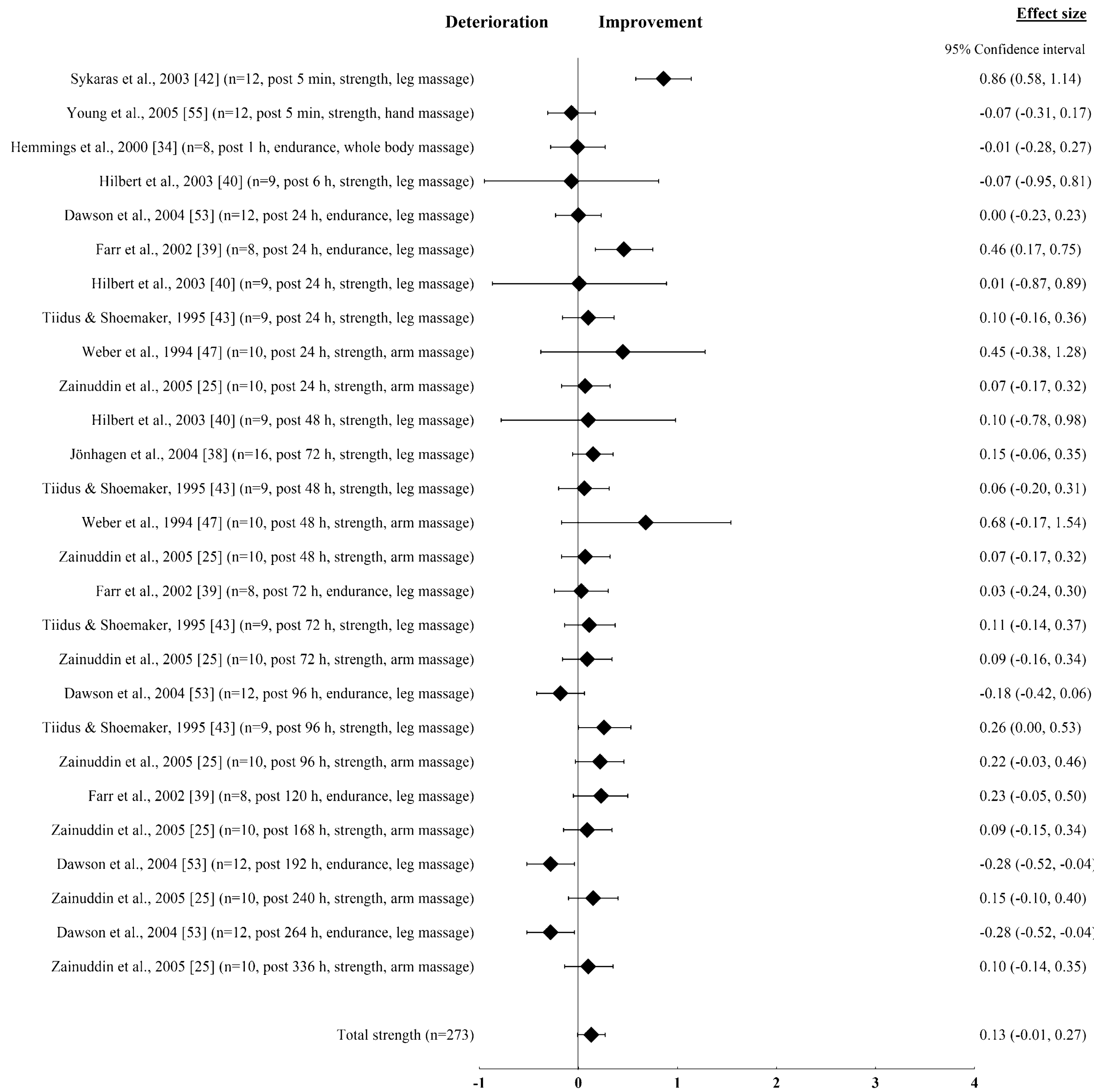

Fig. 5 Effects of post-exercise manual massage on recovery of strength performance. For each study, the following information is included in *parentheses*: number of subjects, timing of post-test, type of exercise to induce fatigue, type of massage. The studies are ordered by increasing duration between exercise and post-test

For further analysis and grouping, only studies using manual massage were considered, as the small number of other massage studies made grouping not worthwhile. Notably, the effect size of 3.06 found for the one study that used pneumatic massage [35] was much larger than those for all other studies (which had effect sizes ranging from −0.19 to 0.86). Therefore, if that study had been grouped with the other studies, it would have distorted the analysis.

4.1 Manual Massage

For the 17 studies using manual massage, a weighted average effect size of 0.19 was found. The average relative performance improvement was 3.5 %, being in a range clearly higher than Hopkins' "smallest worthwhile enhancement" [48, 49]. One of the main aims of this meta-analysis was to elucidate under which conditions a massage intervention might be most promising to speed up recovery.

4.1.1 *Duration and Timing of Massage and Recovery Period*

A tendency towards larger effects for shorter massage durations was observed. The largest effects were found for short massage interventions of 5–12 min, while massage protocols lasting 15 min or more showed hardly any effect at all. It is possible that this tendency was due to a potential detrimental effect of prolonged massage on subsequent

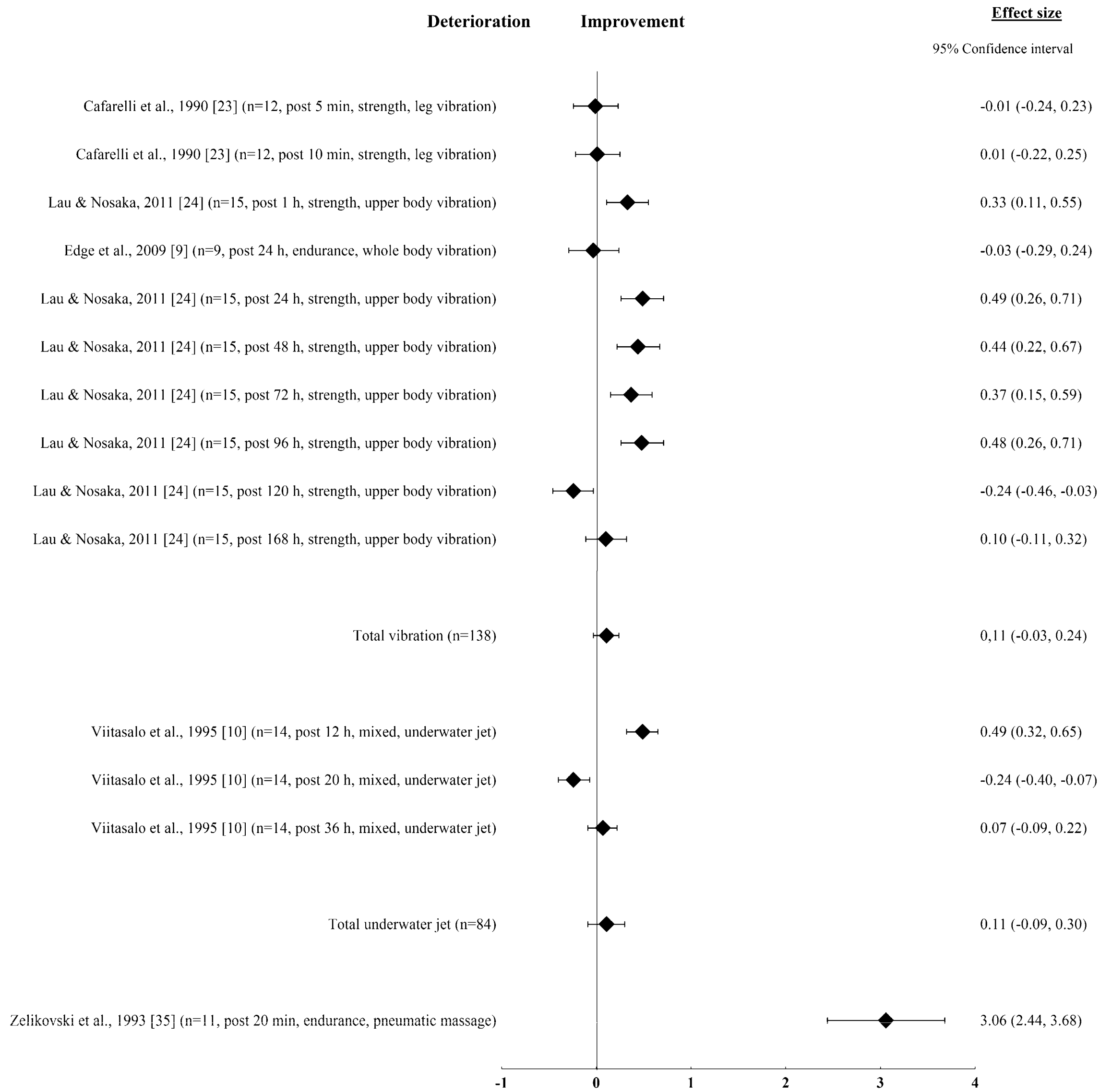

Fig. 6 Effects of post-exercise automated massage (vibration, underwater water-jet and pneumatic) on recovery of performance. For each study, the following information is included in *parentheses*: number of subjects, timing of post-test, type of exercise to induce fatigue, type of massage. The studies are ordered by increasing duration between exercise and post-test

performance, as suggested by some authors [50, 51]. However, those authors investigated massage interventions immediately prior to exercise. With the exception of the study by Jönhagen et al. [38], in all studies included in the present analysis that used massage durations of 30 min and more, the subjects performed the post-tests at least 1 day after the massage intervention. Therefore, in these studies, a 'pre-massage' effect on the post-test was unlikely. In contrast, several studies applying shorter massage durations used shorter recovery periods between massage and post-test, as well. It is therefore possible that the larger effects found for short massage durations were associated with the shorter interval between massage and post-test than with the actual massage duration.

It is worth mentioning that almost all massage interventions targeted only the exercising muscles for the whole duration of the massage. However, in the study by Hemmings et al. [34], who investigated punching force in boxers, the massage was focused on the affected body region (shoulders and arms) for only 10 min, and the remaining 10 min was focused on the back and the legs.

Regarding the duration between exercise and post-test, a tendency towards increasing effects of massage for shorter recovery periods was observed. For very short recovery periods of 5–10 min, with the post-test taking place immediately after the intervention, an average effect size of $g = 0.45$ was found, with a large average performance improvement of 7.9 %. The average effects for recovery periods of 1 h and longer were unclear and negligible despite partly relevant average performance improvements of up to 3.9 and 4.6 % being found for 72 and 96 h, respectively. The reason why these values are larger than the performance improvements after 24 h (1.7 %) and 48 h (2.8 %) is that certain studies finding only small effects [37, 40, 45] did not assess performance after more than 48 h, whereas Zainuddin et al. [25], who found relatively large improvements, evaluated performance also after 72 and 96 h. As the studies varied strongly with respect to the protocols they used, this might have contributed to a distortion of the results. Also, the findings by Zainuddin et al. [25] were weighted more strongly for 72 and 96 h than for 24 and 48 h, as the total number of included studies was smaller for the former. It should be mentioned that Weber et al. [47], who found relatively large effects of massage, investigated performance only after 24 and 48 h, in contrast to the observations described above. However, because of the parallel-group design used in this study and the corresponding higher variance, the study had a smaller weight in the analysis. Moreover, it should be noted that also after a very long recovery period of 10 days, a performance improvement due to massage of +7.4 % ($g = 0.15$) was found in one study [25], which is hardly compatible with physiological considerations and was possibly due to other interfering factors.

With respect to the duration between massage and post-test, clear positive effects were found only for very short intervals. Seven studies did the post-test immediately (0–5 min) after the massage intervention (+5.1 %, $g = 0.30$), three after 20 min to 4 h (+2.0 %, $g = 0.14$) and eight on the next day or later (+1.8 %, $g = 0.06$). These results suggest that there are almost only acute effects of massage on performance. Going one step further, it is even possible that massage did not improve the actual recovery process at all, and that the positive effects on performance could have been solely due to 'pre-massage' effects [52] and might have disappeared after a few hours. This could also explain the results found in the study by Ogai et al. [46], where post-test performance after massage was even better than at baseline. The hypothesis that massage mainly has acute effects on performance is also plausible, considering that its physiological mechanisms are mostly unclear, and the benefits might instead be based on psychological effects [7]. In fact, positive psychological effects on perceived recovery, pain and mood have been reported by several studies [25, 34, 36, 37, 39, 40, 46, 53]. It is likely that such effects are strongest immediately after massage and might have contributed to the observed performance improvements.

Unfortunately, to date, no study has investigated both short-term effects (after a few minutes) and long-term effects (after 24 h or more) of massage on performance at the same time. Such an investigation would help to clarify if massage actually has a noteworthy beneficial effect on recovery, or if its effects are instead based on acute, possibly psychological 'pre-massage' effects. Moreover, another possibility to determine the influence of psychological effects could be to investigate electrical muscle stimulation in comparison with voluntary muscle contraction. This was not done in any of the studies we analysed.

Taking a closer look at the eight studies with a break of at least 1 day between massage and post-test, the four studies with the massage intervention directly (0–10 min) after the exercise showed no effects at all, on average (0.1 %, $g = 0.01$), while the other four studies (with a break of 1–3 h between exercise and massage) found a negligible average effect size but a relevant average performance improvement (3.6 %, $g = 0.11$). Although those results were unclear, it can be speculated that in order to obtain sustained effects of massage, a break for a few hours should be included between exercise and massage. If this is true, the benefit of the break might be explained by the potentially different responses of the body in the exhausted state immediately post-exercise, compared with the cooled-down state a few hours later. This speculation is in line with the findings by Smith et al. [54], who suggested that massage should preferably be administered 2 h after eccentric exercise to most effectively disrupt the accumulation of neutrophils in the area of injury, and thereby reduce DOMS as well as creatine kinase levels. However, definite conclusions are difficult to draw, especially as the number of studies is limited. Further studies would be needed, directly evaluating the effects of immediate versus delayed application of massage within the same study design.

In summary, it can be suggested that short massage durations of 5–12 min should preferably be used, as apparently no additional effects can be expected from prolonged massage. Shorter massage durations also have the advantage that more athletes can be treated by one physiotherapist/masseur. Massage seems to be most beneficial when applied to enhance short-term recovery. However, it is possible that, in this case, the positive effects are at least partly due to short-term 'pre-massage' effects than actual enhancement of the recovery process. For recovery periods of several hours or days, the average effects were smaller, but some studies still found relevant performance improvements due to massage.

4.1.2 Type of Performance

Ten studies investigated the effects of massage on strength performance, while endurance, jump and sprint performance were tested in only three and four studies, respectively. A reason for this might be that massage is expected to be most effective for strength recovery. However, the average effects on strength were negligible and slightly unclear. Only Sykaras et al. [42] found a clear, medium-to-large positive effect of massage. A possible reason is that this was the only study to have the massage administered not only after exercise but also during 2 min breaks in a 6 × 10 repetition strength training setting. Moreover, in contrast to almost all other studies on strength performance, short-term recovery (5 min), with the post-test taking place immediately after massage, was investigated; therefore, the psychological effects might have been more pronounced. The only other study with a similar setting was the one by Young et al. [55], who found no effects on short-term recovery of the thumb adductors. It is possible that massage of such a small muscle is less effective than massage of the knee extensors, as was done by Sykaras et al. [42].

The largest average effects of massage were found for recovery of endurance and sprint performance. However, when looking more closely at the studies investigating endurance performance, it becomes evident that only in one of them was a relevant effect (+15.2 %, $g = 0.62$) on performance observed [56], while the two other studies found only unclear and negligible effects [41, 45]. A possible reason for the relatively large effect found by Rinder and Sutherland [56] was the open-ended protocol (maximal number of leg extensions) they used for performance evaluation. It is likely that on a percentage basis, such a protocol leads to larger performance improvements than time trials. Moreover, open-ended protocols are more sensitive to motivational influences [57], which is particularly relevant, as the study was conducted with untrained individuals. Another difference was that Rinder and Sutherland [56] used a 'mechanistic' approach with an exercise programme far removed from normal training protocols, aiming to cause considerable muscle fatigue (leg extensions, cycling and ski squats until exhaustion). In contrast, Monedero and Donne [41] and Lane and Wenger [45] used endurance exercise protocols closer to typical training or competition, considering that endurance athletes are typically fatigued because of endurance exercise.

With regard to the effects of massage on the different types of performance, differences in the time course of recovery also have to be considered. Andersson et al. [58] investigated the time course of post-match performance recovery in female soccer players without any recovery intervention and found that while sprint performance recovered rather quickly (within 5 h), recovery of strength performance (27–51 h) and jump performance (>69 h) took more time. Of the four studies investigating sprint performance, three used an exercise-to-post-test interval of 10–35 min, finding relevant performance improvements (4.2–4.5 %, $g = 0.28$–0.60) [36, 44, 46]. In the one study with a longer exercise-to-post-test interval of 24 h, Delextrat et al. [37] did not find any changes in sprint performance but did find a small effect on jump performance. They suggested that this finding might have been due to the fact that 24 h was a sufficiently long period for sprint performance, but not for jump performance, to recover even without intervention. Therefore, massage may be an effective means of speeding up sprint performance recovery if the recovery period is rather short.

Apart from the study by Delextrat et al. [37], three other studies [36, 38, 39] assessed different types of performance within one study. Mancinelli et al. [36] used a 20 min recovery period and found the same percentage improvement but a larger effect size for sprint performance (+4.5 %, $g = 0.60$) than for jump performance (+4.5 %, $g = 0.41$). For longer exercise-to-post-test intervals of 24–120 h, Farr et al. [39] found small positive effects of massage on strength performance (+2.5 %, $g = 0.24$), whereas the effects on jump performance were negligible (−0.7 %, $g = -0.07$). This might indicate that for longer recovery periods, massage could be more effective for strength recovery than for jump performance. This tendency was also observed in the study by Jönhagen et al. [38], although the effects on both strength (+3.3 %, $g = 0.15$) and jump performance (+0.2 %, $g = 0.01$) after 48 h were negligible.

To sum up, the largest average effects were found for endurance and sprint exercise, but, especially for endurance, these results should be interpreted cautiously, as the number of available studies was limited and only one of them showed a clear positive effect. The effects on strength and jump performance were negligible and unclear.

4.1.3 Type of Fatigue-Inducing Exercise

In the studies using endurance exercise to induce fatigue, only negligible effects of massage were found, on average (+1.3 %, $g = 0.12$). This suggests that massage is of little benefit for endurance athletes, who are mainly interested in fast recovery after strenuous endurance-type exercise. However, it should be noted that in some studies that used endurance exercise to induce fatigue, by the time of the post-test the subjects had already fully recovered to baseline levels even without any recovery intervention [37, 39, 53], indicating that the exercise was not severe enough to induce fatigue. This did not occur in any of the studies that used strength or mixed exercise. After removal of those studies from the analysis, a small and clear positive effect (+2.2 %, $g = 0.20$) was found for recovery after endurance exercise.

As in the endurance situation, athletes performing strength exercise are typically interested in fast recovery of strength performance. In all studies using strength exercise to induce fatigue, only strength tests were done to evaluate performance (with the exception of one study, which also investigated jump performance [38]). For recovery of strength performance after strength exercise, massage appears to have a small positive effect (+4.5 %, $g = 0.20$).

On average, slightly larger effects were observed after strength exercise than after endurance exercise. Even larger effects were found in the two studies that used very intensive mixed exercise (3 days of intense strength training/drills [36] and combined strength/cycling training [56]). A possible explanation is that massage might be more effective on a muscular level [14], while having less influence on cardiovascular fatigue, as it typically occurs after endurance exercise. It is worth noting that in all studies using endurance exercise to induce fatigue, the exercise protocol was realistic and relevant for competitive athletes (e.g. 200 m swimming [44] or a half-marathon race [53]), whereas the studies using strength exercise usually had a rather 'mechanistic' character. While those protocols still had some practical relevance for athletes (e.*g*. strength training), they appeared to have been selected in order to provoke severe muscular fatigue (e.*g*. 300 eccentric quadriceps contractions [38]).

In summary, the largest effects of massage were found after intensive mixed-type exercise. However, this type of exercise was investigated in only two studies. Marginal small effects can also be expected for endurance athletes (if the exercise is sufficiently intense) and for athletes interested in recovery of strength performance after strength exercise.

4.1.4 Training Status

With respect to the subjects' training status, the largest relative performance improvements due to massage were found for untrained subjects. A possible reason for this observation is that massage might be rather effective on a psychological basis, including reduction of DOMS and muscle pain [7]. Therefore, the larger performance gains found in untrained individuals could at least partly be due to motivation rather than to actual recovery. On the other hand, as trained athletes are less susceptible to DOMS than untrained subjects [59], motivational aspects—and thus the performance improvements to be expected from massage—may be smaller for this population.

However, looking at the corresponding effect sizes, similar values were found for untrained and competitive subjects, both indicating a small, but clear, positive effect. In fact, the only study finding large positive effects of manual massage (+14.1 %, $g = 0.86$) was conducted in elite athletes [42]. Therefore, while (on a percentage basis) massage seems to be most effective for untrained subjects, it is possible that even elite athletes can benefit from post-exercise massage.

4.2 Automated Massage

Five studies were identified that used some kind of technically aided massage: three studies used vibration massage [9, 23, 24], one study applied warm underwater water-jet massage [10] and one study used a modified intermittent sequential pneumatic device [35].

4.2.1 Vibration Massage

Three studies included in this meta-analysis used vibration massage [9, 23, 24]. Cafarelli et al. [23] found no effects of leg vibration using a hand-held device on quadriceps strength recovery. A similar device was used by Lau and Nosaka [24], but they investigated strength performance of the arms rather than the legs. Small positive effects of vibration for a period of up to 4 days after exercise were found in their study. Edge et al. [9], who used a whole-body vibration massage to enhance endurance recovery, did not find any effects on performance. All groups speculated that vibration massage facilitates recovery through improvement of removal of metabolites, a local increase in blood flow and stimulation of sensory receptors. However, neither Edge et al. [9] nor Lau and Nosaka [24] found any significant effects of vibration on blood lactate, creatine kinase or C-reactive protein levels, whereas Cafarelli et al. [23] did not record any parameters to elucidate whether the proposed mechanisms were at work.

Because of the limited number of studies, it can only be speculated why Lau and Nosaka [24] found small positive effects of vibration, while Cafarelli et al. [23] and Edge et al. [9] did not observe any such effects. It is possible that the vibration duration (2 × 4 min) used by Cafarelli et al. [23] was too short to induce any effects, in comparison with the 5 × 30 min used by Lau and Nosaka [24]. Edge et al. [9], on the other hand, used a longer intervention of 30 min but investigated endurance exercise, while Lau and Nosaka [24] examined the effects on strength exercise. Moreover, Lau and Nosaka [24] were the only ones to use untrained subjects, and (as with manual massage) vibration might be more effective in this population because of possible psychological effects. However, further research would be necessary to clarify whether and under what conditions vibration treatment could be an effective means of enhancing recovery.

4.2.2 Water-Jet Massage

Viitasalo et al. [10] examined the effects of a daily 20 min warm underwater water-jet massage on strength and jump performance recovery after five standardized intensive training sessions (strength, technique, jump, strength and speed). The average effects were unclear and negligible ($g = 0.11$), but on one occasion (12 h post-exercise), a large improvement of isometric leg strength was found (+17.2 %, $g = 0.62$). Notably, the results for the three different points in time that were investigated differed considerably. While the effects after 12 h were clearly positive, a clear negative effect was found after 20 h. The effects after 36 h were negligible and unclear. As no further studies on water-jet massage are available, it is difficult to draw any conclusions from this observation. Regarding potential mechanisms, significantly higher creatine kinase and myoglobin levels were found in the serum in the massage condition, suggesting increased leakage of proteins from the cells to the blood. The authors speculated that this increased leakage could be a sign of improved transport, favouring decreased accumulation of muscle-originating compounds in the interstitial space and thereby enhancing recovery [10].

During the intervention, the subjects were immersed in ~37 °C warm water. Therefore, it was not clear if the observed effects on performance and blood parameters were due to the actual massage intervention or were at least partly caused by either the water temperature or hydrostatic pressure [60]. As water immersion (especially cold and contrast water) may have positive effects on recovery [1, 61, 62], water-jet massage could be an interesting means of combining two recovery interventions in order to maximize effects. However, further studies—preferably also testing water-jet massage in cold water—would be required to clarify if water-jet massage represents a worthwhile recovery intervention.

4.2.3 Pneumatic Massage

Zelikovski et al. [35] investigated the effects of a 20 min leg treatment using a modified intermittent sequential pneumatic device on the recovery of endurance performance (open-ended cycling test). A strong improvement in performance due to the pneumatic massage was found (for the massage condition, the time to exhaustion dropped only from 10.9 to 8.7 min, in comparison with a much larger decline from 11.6 to 6.4 min in the control condition). The underlying mechanisms could not be clarified. The authors hypothesized that pneumatic massage might enhance the removal of metabolites from the blood, prevent the formation and accumulation of fluid in the interstitial space, and have positive psychological effects. However, suitable parameters either were not recorded or (in the case of blood parameters) showed no significant differences [35].

One reason for the large (24.6 %) relative performance improvement could be the open-ended nature of the test protocol. In the only other study using a similar performance parameter (the number of submaximal repetitions until exhaustion), a large (15.2 %) relative performance improvement was also observed [56]. On the other hand, it has been demonstrated that open-ended tests show higher baseline variability than, for example, the average power output during a time-trial protocol [57]. This is in contrast to the large effect size (3.06) observed by Zelikovski et al. [35], as high baseline variability should lead to smaller effect sizes.

Despite the apparent success of pneumatic massage, no further studies using similar protocols have been conducted to verify the results. Wiener et al. [63] conducted a study using a similar device to investigate the effects on recovery after 10 min of treadmill walking. On the basis of electromyographic (EMG) data, they concluded that pneumatic treatment improved muscle contractile capacity. However, no actual performance parameters (e.g. maximal isometric strength) were assessed in that study.

4.3 Practical Recommendations

In summary, it is somewhat surprising how frequently post-exercise massage is used as a recovery intervention, although its efficacy for performance recovery is rather limited and unclear. One of the aims of the present analysis was to clarify why the results from the different studies were rather equivocal and which aspects of the study design seemed to favour beneficial effects of massage, in order to provide recommendations for athletes and coaches, as well as for scientists planning to conduct further research in this field [62].

4.3.1 Recommendations for Athletes and Coaches

The results of the present analysis suggest that a massage duration of 5–12 min appears to be sufficient to maximize effects. Massage seems to be most effective if the recovery period is relatively short (lasting a few minutes) and if it is preceded by intense, maximal strength or mixed-type exercise. However, the exercise protocols used in many of the studies investigating such exercise were designed to provoke as much fatigue as possible, rather than simulating competitive situations. On the other hand, massage appears to be of smaller benefit after endurance-type exercise, which is practically relevant for different sports, including long-distance running [53], cycling [41] or team sports [37]. Notably, the only study investigating massage after an actual endurance competition (a half-marathon race) [53] showed unclear negative effects (–2.4 %, $g = -0.19$) and thereby the poorest results of all studies included in this meta-analysis.

The largest effects of massage were found when it was administered immediately before the post-test, suggesting that massage might have a short-term ‘pre-massage’ effect on subsequent performance, rather than actually speeding up recovery. While being an important question for future research, this discrimination might be less relevant for athletes during competition, as their primary aim is to optimize momentary performance. However, during intensive training periods, athletes are particularly interested in enhancing medium- to long-term recovery over several days or weeks. Here, massage was found to be less effective.

Another aspect to be considered by athletes and coaches is that massage showed the largest effects in untrained subjects, while the benefits for competitive and elite athletes were smaller. Therefore, it is questionable if the large efforts that are often made to organize post-exercise massage interventions for athletes are justifiable. However, even for competitive athletes, the average effects exceeded Hopkins’ smallest worthwhile enhancement [48] and were thus in a relevant range.

As the number of high-quality studies on massage is limited, the conclusions drawn above should be treated cautiously. Further studies would be necessary to confirm the results of this meta-analysis. Moreover, even if the available evidence for the physiological effects of massage is limited [7, 14], several authors have suggested positive psychological effects on perceived recovery [34, 36, 37, 39, 40, 46, 53]. As psychological aspects play an important role in most sports, the fact that an athlete ‘feels better’ after receiving a massage might be sufficient to justify its use despite the absence of measurable physiological benefits. Also, the almost complete absence of side effects might be in favour of such recovery-supporting interventions.

The weighted average effect size for performance recovery across all studies was $g = 0.19$. In a recent meta-analysis focusing on the effects of cooling on performance recovery, a larger average effect size of $g = 0.28$ was found [1]. Therefore, in order to optimize performance recovery, the use of other modalities, such as cooling, should also be considered, either instead of or in combination with massage. However, in this context, further studies are required to support athletes and coaches in their search for individually optimized recovery strategies. Also, there is certainly a need for investigations elucidating the interaction between different recovery interventions (e.g. blood flow–enhancing massage versus cooling, which potentially leads to the opposite perfusion effect).

4.3.2 Recommendations for Researchers

Despite the widespread use of massage, relatively few studies have focused on the effects of massage on performance recovery. Therefore, further research is necessary to determine the conditions in which massage is most beneficial for athletes. Given the large number of variable methodological factors, the optimum design would be a series of studies using a standardized protocol (i.e. using the same exercise, massage protocol, performance tests, etc.), varying only one parameter in each study. This might help to identify the optimum conditions for a massage intervention. Outcome measures should include actual parameters of performance (preferably several), as those are most relevant for competitive athletes. Additional parameters (e.g. blood samples, questionnaires) could help to elucidate potential physiological and psychological mechanisms of massage.

Researchers should use a ‘proper’ control condition, i.e. comparing a massage-only intervention with a passive-rest condition. Some studies have combined massage with techniques such as stretching [64] or compression [65], making it difficult to identify the effects of the actual massage intervention. In addition, there have been ‘mechanistic’ studies that applied massage to only one leg or arm, using the contralateral side as a control [25, 38, 39, 43, 53]. As massage may also work at a systemic whole-body level, Ernst [16] suggested that such designs should be avoided. To allow conclusions to be drawn on studies with competitive athletes as the main target population, only trained subjects should be used, as responses to recovery strategies might differ depending on the training status [59, 62, 66]. Moreover, while the type of exercise to be used depends on the specific research question, use of exercise protocols that are sufficiently intensive to provoke fatigue—and that resemble actual, relevant situations in training and competition—is recommended.

While the efficacy of a single massage intervention seems to be limited, it is possible that regular massage over a longer period—for instance, a whole season—may have larger effects on performance. So far, no longitudinal studies on the efficacy of massage for performance recovery over a longer period have been conducted. Moreover, only a few studies have focused on the type and quality of the applied massage. Moraska [67] observed that the psychological effects of massage depended on the physiotherapist’s level of education. In most of the studies in this meta-analysis, some information on the therapists was provided, but not enough to allow analysis of the influence of their education level on the effects of massage. The identification of an optimum combination of massage techniques (effleurage, petrissage, etc.) remains an open question. Similarly, relatively few studies have investigated the effects of automated massage, such as pneumatic massage. Given the partly promising results, more research is required to clarify if such interventions can be effective recovery tools.

4.4 Limitations

It is acknowledged that the present analysis suffered from some limitations. For some categories, the number of available studies was limited. While the clarity of the evidence for the benefit of massage could be estimated by calculating effect sizes with 95 % confidence intervals, it is acknowledged that definite conclusions could only be drawn within the narrow scope of the study designs investigated in the respective articles, and these conclusions cannot be generalized—for instance, to other sports.

Also, as different types of performance tests were used, it was difficult to directly compare the effects of massage between the studies. Percentage improvements in performance might not be a suitable means, as they seem to depend on the type of test (e.g. an open-ended test versus a time trial). For this reason, effect sizes were calculated to obtain a measure of the effects independent of the inter-test variability.

Many of the included studies investigated effects on performance by using different tests at several points in time (for instance, six outcomes were included by Farr et al. [39]), while others conducted only one post-test [34, 41, 42, 45, 46, 55]. In order to avoid distortion of the analysis by bias towards the studies with more than one outcome, we used inverse-variance weighting to compensate for correlations between multiple outcomes from the same study, as recommended by Borenstein et al. [22]. However, as exact correlation coefficients between the outcomes could not be determined, they could only be estimated on the basis of literature values. For instance, the correlation between different performance tests (e.*g*. jumps versus sprints) was estimated on the basis of studies comparing (baseline) performance tests [27–32]. It is acknowledged that the correlation between—for example—jump and sprint performance recovery after exercise is not necessarily equal to the correlation between jump and sprint baseline performance, as, for instance, differences in the time course of recovery, as observed by Andersson et al. [58], are neglected. Nevertheless, these inaccuracies were expected to have only a small influence on the main results of the present analysis.

5 Conclusion

Although massage is frequently applied as a post-exercise intervention among athletes, its average effects in terms of performance recovery are rather small, and the underlying mechanisms are unclear. Because of the limited number of studies and their varying protocols, only cautious conclusions can be drawn. For the first time, the present analysis provides some hints and recommendations about the conditions in which a post-exercise massage intervention might be of greatest benefit for athletes.

Massage seems to be most effective for short recovery periods of up to 10 min. As this implies only a short break between the intervention and the subsequent post-test, it is possible that a large portion of the observed effects were short-term 'pre-massage' effects (for instance, psychological effects) rather than actual enhancement of recovery from the previous exercise bout. Massage was more effective for recovery from intensive mixed-type exercise than for recovery after endurance exercise. A treatment duration of 5–12 min appears to be sufficient to maximize the effects. The efficacy of massage seems to also depend on training status, since the largest effects were found in untrained subjects. Therefore, the question remains as to whether the widespread use of post-exercise massage for competitive athletes is justified. In this context, it has to be noted that massage may also play a role in injury prevention and rehabilitation of athletes. While this topic was not the focus of the current analysis, the evidence for massage in injury prevention appears to be rather small [6].

Of the 22 studies included in this meta-analysis, the only one to show a clear, large effect used an automated, pneumatic form of massage [35]. Unfortunately, no further studies on performance recovery using such a device have been conducted.

Further research into the efficacy of massage as part of post-exercise recovery strategies is necessary. The present meta-analysis has identified some open questions and provides recommendations for future studies.

Compliance with Ethical Standards

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Conflicts of interest Wigand Poppendieck, Melissa Wegmann, Alexander Ferrauti, Michael Kellmann, Mark Pfeiffer and Tim Meyer declare that they have no conflicts of interest that are relevant to the content of this review.

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