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REVIEW

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Health efficacy of electrically operated automated massage on muscle properties, peripheral circulation, and physio-psychological variables: a narrative review

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Abstract

Manual massage, commonly used by healthy individuals for well-being, is an ancient practice requiring the intervention of a trained and experienced physiotherapist. On the other hand, automated massage is carried out by machines or modalities without or with minimal control of a human operator. In the present review, we provide a literature analysis to gather the effects of automated massage on muscle properties, peripheral circulation and psychophysiological variables as reported through psychometric and neurophysiological evaluations of each modality ranging from massage beds and whole-body vibrations to robotic massage. A computerized search was performed in Google Scholar, PubMed, and ResearchGate using selected key search terms, and the relevant data were extracted. The findings of this review indicate that for vibration massage, whole-body vibration exposure with relatively lower frequency and magnitude can be safely and effectively used to induce improvements in peripheral circulation. As for massage chair and mechanical bed massage, while most studies report on positive changes, the lack of strong clinical evidence renders these findings largely inconclusive. As for robotic massage, we discuss whether technological advances and collaborative robots might reconcile active and passive 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: Automated massage, Muscle properties, Peripheral circulation, Robotic massage

1 Introduction

Time spent in both work and recreational activities by modern day people have drastically shifted toward longer durations spent in sedentary positions and such habits, over the last decades, have had detrimental effect on our lives. The effects are nonetheless furthered and aggravated through overuse of computers and smartphone alike, which consequently lead toward postural deformity, neck and shoulder pain as evidenced by research, and when prolonged and recurred, these habits gradually degrade our overall health. Fortunately, massage techniques had been in practice in many cultures throughout human history as a means to prevent such disorders. However, while generally accepted and appreciated, manual massage has largely been considered a companion treatment rather than a therapeutic intervention per se. Massage targets soft tissue such as muscles, tendons and facias. Conventionally, manually applied massage is imparted on these aforementioned structures as the masseuse or physiotherapist performs several maneuvers including effleurage, kneading, static or slide pressures, but also light and deep pressures. They are likely to involve biomechanical, physiological, neurological and psychological mechanisms, although these empirical attributions are not always confirmed by scientific data [54]. Delivering manual massage requires a trained physiotherapist/individual and such interventions are difficult to scale up given that only one individual can tend to a single patient at a time. Furthermore, while the benefits of massage in literature is extensively demonstrated for individuals with or without motor disorders, manual massage interventions still remain rather time-consuming and expensive. Additionally, some researchers have indicated that effectiveness of manually administered massage may degrade as the physiotherapist tend to exhaust with successive interventions [43].

Earlier studies on the efficacy of massage have encompassed several physiological and physical parameters such as heart rate variability [7], blood pressure [1, 16] as well as cognitive abilities such as psychological record, mental operation [4, 5, 24, 39], and neural activity [8]. The outcomes of these studies have been indicated that massage therapy could be beneficial in relieving not only physical stress such as chronic lower back pain and headache [6, 51], but also psychological stress induced from anxiety [9, 35] and depression [13]. However, decades of independent attempts have not been able to unearth the underlying mechanism of massage therapy. Nevertheless, the massage therapy research has been suggestive of two possible mechanisms of effect. The first one describes about activation of parasympathetic nervous system via massage, which in turn lowers blood pressure, heart rate and muscle fatigue and subsequently promotes muscle oxygenation [11, 12, 36]. The other theory suggests that the effect of massage is linked to activation of the sympathetic nervous system.

Commercially, a great deal of electrically operated massage devices is available at consumer market. These devices include automated massage chair, mechanical massage beds, vibration mattresses, pneumatic-air massage, robotic massage modalities, and so on. The present paper provides a synthesis of the experimental evidence of automated massage on the human body as per reported in preceding studies. Additionally, we look into robotic massage solutions and their prospective development in assisting classical massage with more interactive and proactive modes to deliver optimal massage experience to end user. The literature review was conducted using three search engines: Google Scholar, PubMed, and ResearchGate, and restricted to only papers on English language. The search involved sets of inclusion and exclusion criteria. A total of 79 articles including the keywords: "automated massage," "vibration massage," "mechanical massage," and "robotic massage" were reviewed, and finally 45 articles were retained.

2 Effects of muscle properties

Two studies investigated on the effect of mechanical bed massage on lower back muscle fatigue, strength, and recovery. In one study by Zhong et al. [52], the researchers induced muscle fatigue through reverse sit ups in prone position followed by mechanical bed massage and evaluated back muscle endurance immediately, and 24 h after the intervention. The sample for this study comprised entirely of athletes. In another study by Do-Kim et al. [21], trunk extension (TE) was used as an index for back muscle fatigue. In addition to TE, the group also recorded EMG signals to analyze the strength of erector spinae muscles. However, Do-Kim et al. [21] had incorporated heating to the mechanical bed massage intervention to examine the combined effect. Zhong et al. [52] reported no statistically significant difference in back muscle extension (BME) between massage and control group. The study noted the slower rate of decline in BME in massage group, which they associated with increased blood flow and elimination of metabolites, but the evidence was not conclusive. On the other hand, Do-Kim et al. reported a significant improvement in TE and EMG signal after combined application of massage with heating as an indicator of improved flexibility and strength in back muscles.

The potential for vibration-based massage therapy to aid recovery from exercise-induced muscle stiffness has also been studied. Imtiyaz et al. [19] and Pournot et al. [44], in two separate studies, investigated the effect of vibro-massage in treating stiffness of the biceps brachii muscle generated from weighted loading. Pournot et al. massaged the subject's biceps 5 min after exercise and 5 min after recovery period. They used the one arm as control/passive arm and evaluated the shear elastic modulus (SEM) of the other arm after massage. Their study lacked to observe any positive impact of vibration on SEM, and therefore, on muscle stiffness. Furthermore, Imityaz et al. compared the effect of vibration to manual massage and reported increased rate of recovery in groups receiving vibration massage as indicated by lowered level of blood serum LDH (lactate dehydronase). However, the study also reported absence of any significant difference between massage group and vibration group on ROM (range of motion) and level of CK (creatine kinase). In another study by Anna et al. [65], the effect of lower limb vibration on cyclist is documented. In this study, the authors applied vibration for 60 min after exercise, and reported a gradual decrease in blood lactate level as well as significant difference in other biochemical markers (IL-6, Mb, MMP-2) in experimental groups after intervention. Both Imtiyaz et al. and Anna et al. had varied time points in collection of blood samples ranging from 1 to 72 h after intervention.

Hiraiwa et al. [18] explored the possibility of robotic massage to treat masseter muscle stiffness in a controlled clinical study. The study population constituted patients suffering from either unilateral or bilateral myofascial pain stemming from masseter muscle stiffness. In this controlled study, the treatment duration ranged from 4 to 12 weeks and authors reported significant reduction in muscle stiffness in the treatment group. Only one study by Durkin et al. [9] involved conducting massage through mechanically designed chair on a car seat. In this study, the authors separately evaluated different massage system integrated to the car seat and found no statistically significant difference.

The Waseda Asahi Oral-Rehabilitation Robot 1 (WASO-1), developed by the Waseda University and Asahi Roentgen Company, aimed at recovery of temporomandibular disorders. The authors approach to unilateral and bilateral temporomandibular disorder was targeted to a specific population, highly technical and very expensive. Other studies on investigating the robotic massage effects on masseter and temporal muscles had varying degrees of pressure exerted, which ranged from 100 g to 1.5 kg per square area [2, 3, 20, 23, 46, 60]. The most effective outcome was derived at approx. 800 g on small facial muscles. The authors further reported that the robotic massage decreased muscle pain and promoted functional motor recovery in patients. Another study by Luo and Chang [30] showed that patients had improved muscle activity after undergoing multi-finger robotic massage. However, the validity of these experimental results remains questionable due to the small sample sizes and complex study designs. Despite the autonomy of these robotic devices and lack of intervention by the physiotherapist, the robotic massages still do not allow for individualization of massage. The robots were designed to follow respective preprogrammed massage commands and did not incorporate a pain threshold for applied pressure considering patient morphology. Instead, like manual massage techniques, the patients had to assume a passive position when receiving massage [55](Table 1).

3 Effects on peripheral circulation

A summary characterizing the interventional protocol of different massage modalities on blood circulation is given in Table 2. The larger segment of these studies involve vibrational massage focused on whole-body vibration (WBV). In addition, the electrically operated chair and air-cuff-based massage has also been reported (Table 3).

Variability in terms of exposure session and duration to WBV is stark in the reported studies. Several studies had multiple bouts within the same session. Intra-session variation in exposure from WBV ranged up to 15 min [47]. While some studies were relatively short term, the duration for long-term intervention ranged from 2 weeks [34] to 12 weeks [32]. In these longitudinal studies, there were up to three intervention session each week of the study period. Differences with regard to vibrational intensity for the WBV interventions ranged from 26 to 44 Hz with a median exposure of ≤ 30 Hz. All but one study was randomized controlled and, in that study, the exact location of vibrational massage has not been reported. In addition to measuring blood flow, Menendez et al. [33] and Sonza et al. [47] reported on the skin temperature measurements at both baseline and post-intervention. In both cases, an infrared thermography-based temperature measurement was taken on the lower extremity. While Menendez et al. [33] reported on positive changes to side-altering vibration massage, the effect of vertical synchronized WBV according to the other studies, have no significant changes to circulation. However, Mitchel et al. [34] did not report on vertically synchronized vibration. Sonza et al. [47] and Menendez et al. [33] reported on significant alterations in peripheral circulation at vibrational stimulus between 25 and 30 Hz compared to lower intensities. However, Manimmanakorn et. al. and Mitchel et al.[32, 34] did not observe any significant improvement in terms of long-term intervention with vibrational massage. There are several methodical limitations observed in these studies. Vibrational apparatus for all studies either imparted side-altering or vertical vibration. Given that intensity of the vibrational stimulus in side-altering vibration can change the impact of WBV due to the variability in foot positioning or distance between feet on the vibrational platform, the lack of reporting on these details in almost all studies create some ambiguity

Table 1 Effects of mechanical and automated massage on muscle properties

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Mechanical bed massage									
Do Kim et al. [21]	RCT	15 males (age = 26.2 ± 2.68 years) 13 females (age = 18.6 ± 1.1 years)	NR		20 min	NR	2 groups: CON & EG	TE, EMG, HRV, EEG, STAI, VAS-10	Post-intervention: *TE*: CM↑ > SM↑ > CON *EMG*: CM↑ > SM↑ > CON
Zhong et al. [52]	RCT	Athletes: EG: 6 males (age = 20.2 ± 0.6 years) CON: 6 males (age = 18.6 ± 1.1 years)	NR	Lower back	20 min Kneading	NR	2 groups: CON & EG	VAS-10, HRV, BME	Immediately post-intervention: BME: EG↓ > CON ↓ 24 h post-intervention: BME: EG↑ > CON ↑
Vibration massage									
Imtiaz et al. [19]	RCT	45 females	NR	–	(EG1) 5 min vibration (50 Hz) on biceps brachii before eccentric exercise (EG2) 15 min manual massage	NR	3 groups: EG1, EG2 & CON	VAS-10 for muscle soreness, ROM, MIF, 1RM and Blood serum levels: LDH & CK	VAS: vibration group significantly less than the massage group after 24 h ROM: both vibration and massage group significantly lower than CON after 48 h and 72 h MIF: NS between 3 groups 1RM: significant difference between vibration and massage group during pre- and 48 h after exercise LDH: vibration group significantly lesser than CON after 48 h CK: NS between vibration and massage group, but significant difference compared to CON after 48 h

Table 1 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Pournot et al. [44]	–	6 males and 5 females (age = 38 ± 9 years)	NR	–	10 min vibration (frequency 55 Hz) on one arm at 5 min post-exercise and 5 min post-recovery. Other arm remained at passive rest	NR	–	Shear elastic modulus of biceps brachii muscle with SSI	Shear elastic modulus: Post-exercise: passive arm↑ > massage arm↑ Post-recovery: massage arm↓ > passive arm↓ Baseline values were significantly lower for both arms
Anna et al.56	RCT Crossover (after 2 weeks)	20 male cyclists (age = 22 ± 2.5 years)	NR	–	60 min of lower limb vibration massage at low-medium frequency and variable pulse sequence	NR	2 groups: EG & CON	Biochemicalmarkers in blood: LA, IL-6, Mb, MMP-2	LA ↓ at 15th, 30th and 60th mins of massage IL-6, Mb, MMP-2: EG significantly differed from CON at 1 h and 24 h after massage
Robotic massage									
Koga et al. [23]	CT	11 healthy	WAO-1	Masseter and temporalis	1 session of effleurage or petrissage for 1–5 min	1–10 N (Newton)	2 groups: EG1: robotic EG2: manual	Skin temperature, size of masseter muscle	Both groups: Temperature ↑ Muscle size ↑
Ishi et al. [20]	CCT	18 healthy	WAO-1	Masseter and temporalis	1 session of effleurage or petrissage for 2 min	5 N	2 groups: EG1: robotic EG2: manual	Skin temperature, Width of masseter muscle	Both groups: Temperature ↑ Muscle width ↑
Ariji et al. [60]	CCT	16 healthy and 2 with TMJ disorder	WAO-1	Masseter and temporalis	7 bouts each 1 min of effleurage or petrissage. Total 3 sessions in 2 weeks	12 N	Applied intensity-based groups	VAS-10, masseter stiffness index	Group 6–10 N: VAS score ↑ Masseter stiffness index ↑

Table 1 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Solis et al. [46]	CT	12 healthy	WAO-1 & WAO-1R	Masseter and temporalis	1 session of effleurage or petrissage for 1 min	12 N	2 robotic massage groups EG1: WAO-1 EG2: WAO-1R	Masseter thickness, skin temperature	EG2 > EG1: Muscle thickness ↑ NS temperature
Ariji et al. [2]	CT	15 with TMJ disorder	WAO-1	Masseter and temporalis	7–10 bouts for 1 min. 3 times a week for 6 weeks	8–12 N	2 groups EG1: Unilateral EG2: bilateral	Masseter thickness, VAS-10	Both groups: Thickness ↓ VAS score ↑
Luo et al. [30]	RCT	5 healthy	Multi-finger robot hand	Shoulder	1 session of kneading for 10 min	1–20 N	3 groups EG1: manual EG2: robotic hand CON	Muscle activity	EG1 & EG2: Muscle activity ↓
Ariji et al. [3]	RT	41 with temporomandibular disorder	WAO-1	Masseter and temporalis	7 bouts for 1 min. 5 times every 2 weeks for 12 weeks	6 -14 N	2 groups EG1: effective EG2: ineffective	Muscle thickness VAS-10	Symptomatic muscle thickness ↓ VAS score ↑

RT randomized trial, *CT* clinical trial, *CCT* controlled clinical trial, *RCT* randomized control trial, *VAS* visual analogue scale, *HRV* heart rate variability, *BME* back muscle endurance, *EG* experimental group, *CON* control group, ↑ = increased ↓ = decreased, *NS* no significant difference ($p > 0.05$), *TE* trunk extension, *EMG* electromyogram, *EEG* electroencephalogram, *STAI* state anxiety inventory, *SAM* self-assessment manakin, *SM* single massage group, *CM* massage + heating (combined massage) group, *LA* blood lactate concentration, *IL-6* Interleukin 6 (cytokine), *Mb*: myoglobin, *MMP-2* metalloproteinase 2, *SSI* supersonic shear wave imaging, *ROM* range of motion, *MIF* maximal isometric force, *1RM*, *LDH* lactate dehydrogenase, *CK* creatine kinase, *NIRS* near infrared spectroscopy, *MVC* maximal voluntary contraction, *WAO-1R* Waseda Asahi Oral Rehabilitation Robot

Table 2 Effects of mechanical and automated massage on blood circulation

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Vibration massage									
Taspinar et al. [48]	RCT, double blinded	15 healthy females (age = 21.47 ± 1.06 years)	NR	Triceps Surae (lower extremity)	1 session each: 30 min MRT 1 week later manual massage by kneading and stroking	NR	3 groups: EG1: MRT EG2: manual CON	Using DUS at left popliteal artery and post-tibial artery: BF, artery diameter, BV	EG1 > EG2: BF significantly increased
Sonza et al. [47]	Quasi-experimental	Healthy subjects 11 males and 13 females (age = 26.4 ± 4.1 years)	NR	NR	Total 4 sessions 4 bout/session. 1 session per day Each bout 15 min long	Vibration frequency = 31, 35, 40, 44 Hz	–	Taken at each mins during 15 min of intervention and 10 min following intervention: ST (using IT at thighs, knees, lower legs, feet)	Significant decrease in ST during and after vibration massage
Menendez et al. [33]	RCT	13 healthy males (age = 21 ± 21.5 years)	NR	Right popliteal fossa	Total 4 sessions with 1 session/day 10 bouts/session. Each bout 1 min long. 1 min rest between bouts	Vibration frequency = 26 Hz	–	Taken at baseline, at rests during intervention and at each mins for 5 min following intervention: BF (using DUS at right Popliteal fossa) ST (using IT at left Gastrocnemius)	BF: Significant increase in MBV and PBV during intervention ST: NS

Table 2 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Mitchel et al. [34]	CCT	Willes Ekibon disease patients EG: 7 males and 4 females (age = 54.7 ± 12.5 years) CON: 7 males and 4 females (age = 53.6 ± 10.4 years)	NR	Dorsum of the right foot	Total 6 sessions with 3 sessions/week for 2 weeks 10 bouts/session. Each bout 30 s long and 1 min rest between bouts	Vibration frequency = 30–40 Hz	2 groups: EG: WBV CON	Taken at baseline and 2 weeks after completion of intervention: BF (using LDI at dorsum of right foot)	NS
Manimmanakorn et al. [32]	RCT	Diabetic patients EG: 7 males and 10 females (age = 60.9 ± 11.2 years) CON: 6 males and 13 females (age = 63.9 ± 4.9 years)	NR	Right mid-popliteal fossa	Total 36 sessions 3 sessions/week for 12 weeks 2 sets of 6 bouts. Each bout 1 min long and 20 s rest between bouts	Vibration frequency = 30–40 Hz	2 groups: EG: WBV CON	Taken at baseline and after 12 weeks: BF (using DUS at right mid-popliteal fossa)	In EG: NS in reduction in PSV Significant decrease in EDV
Pulse-synchronized air cuff massage									
Tochikubo et al. [49]	–	19 males and 36 females (age = 34.4 ± 12.7 years)	NR		Single session 15 min active PS-AM preceded and followed by 15 min pre-PS-AM and 15 min post-PS-AM relaxation	–	2 groups: Males and Females	Taken before, during and after PS-AM: BF(using LDF), BP and HR (using ECG)	For both males and females: BF: significant increase only during PS-AM BP: NS HR: Significant increase in HF only during PS-AM

CCT clinical trial, *RCT* randomized controlled trial, *BF* blood flow, *ST* skin temperature, *DUS* doppler ultrasound, *PSV* peak systolic velocity, *EDV* end diastolic velocity, *WBV* whole-body vibration, *LDI* laser Doppler imaging, *MBV* mean blood velocity, *PBV* peak blood velocity, *SBF* skin blood flow, *MRT* matrix rhythm therapy, *PS-AM* pulse-synchronized air-cuff massage, *LDF* laser Doppler flowmeter, *HF* high frequency component of heart rate variability, *NR* not reported, *NS* not significant

Table 3 Effects of mechanical and automated massage on psycho-physiological variables

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Massage chair									
Zullino et al. [53]	RT	Healthy 5 males and 5 females (age = 35.6 ± 7.9 years)	NR	NR	5 min of no massage followed by 3 different massages: Roll-stretch, shiatsu and beat—5 min each. No rest in-between	NR	–	STAI, SAM, EMG (gastrocnemius and frontalis), skin temperature and conductance	Significant difference found compared to no massage condition: SAM valence: roll-stretch and shiatsu EMG (gastrocnemius): roll-stretch and shiatsu Conductance: shiatsu and beat Temperature: roll-stretch and shiatsu
Muller et al. [38]	RCT	93 participants	–	NR	3 sessions each week for 8 weeks by each group Each session 15 min	NR	5 groups: G1—massage and mental training (n = 19) G2—massage (n = 19) G3—mental training (n = 19) G4—pause (n = 19) G5—CON (n = 17)	SSP with sub-scales: STA PSTA, SS, SD and D	After 8 weeks STA: only G2 changed SS: only G1 tended to change NS found with PSTA, SD and D subscales with all 5 groups

Table 3 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Muller et al. [37]	RCT	93 participants	–		3 sessions each week for 8 weeks by each group Each session 15 min	NR	5 groups: G1—massage and mental training (n = 19) G2—massage (n = 19) G3—mental training (n = 19) G4—pause (n = 19) G5—CON (n = 17)	Taken at baseline, after 4 weeks and after 8 weeks—3 times: HR, BP, Fingertip temperature	HR: Significant differences: After 4th week: G5 < G3 < G2 < G1 < G4 After 8th week: G3 < G2 < G5 < G4 < G1 SBP: NS between groups Significant decrease within each group after 4th week DBP: After 4th week: only G2 & G3 NS between groups after 8 weeks Temperature: After 4th week: G2 & G3 significantly decreased After 8th week: only G2 increased; other groups unchanged
Lee et al. [25]	–	186 healthy subjects (age = 18–27 years)	–	full body	Single group pre-test and post-test design MCT 20 min including squeezing, shiatsu, kneading, tapping, punching, vibration and heating	NR	–	Questionnaires (pre- and post-test): (i) Marteau and Bekker's (1992) [62] measure of anxiety and (ii) an index of tranquillity	Post-massage anxiety < pre-massage anxiety, with a decrease of -1.04 Post-massage tranquillity > pre-massage tranquillity, with an increase of + 1.04

Table 3 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Lim et al. [27]	RCT, single crossover	25 subjects	–		All participants received each treatment once Each session 20 min 1 treatment a day for up to 3 weeks with 1 day interval between treatments Treatment A = CON TreatmentB = MCT Treatment C = MCT + binaural beats	NR	3 treatment groups	Pre- and post-treatment data collection (i) Cognitive test (memory and attention): d2-test digit span test Corsi block-tapping test Picture recognition test Face recognition test (ii) EEG (indices for mental fatigue inducing test)	EEG: (i) theta/beta index: treatment C significantly reduced mental fatigue compared to A & B. NS between A & B treatments (ii) theta + alpha/beta index: marginally significant reduction in treatment C compared to A & B Cognitive test (significant improvement post-treatment): (i) d2-test: only B & C (ii) digit span test: only C (iii) Corsi block-tapping test: NS between A, B&C (iv) Picture recognition test: only C (v) Face recognition test: only B & C

Table 3 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Willeke et al. [50]	RCT	69 females and 24 males (age = 47.6 ± 9.84 years)	–		3 sessions each week over 8 weeks for each group Each session 15 min Massage techniques NR	NR	5 groups: G1—massage and mental training (n = 19) G2—massage (n = 19) G3—mental training (n = 19) G4—pause (n = 19) G5—CON (n = 17)	Taken at baseline, after 4 weeks and after 8 weeks—3 times: HRV (using ECG) and Cortisol (blood sample) Taken only at baseline: SBP	*HRV*: NS between groups at baseline NS within each group after 4 weeks and 8 weeks *Cortisol*: Only G2 showed significant ↓ between 4 and 8th week *Correlation of SBP with HRV and Cortisol*: (i) ↓ G2 HRV (suggesting lower SBP = stronger increase in HRV) (ii) ↑ G3 cortisol (lower SBP = less decrease in cortisol)
Seung Kim et al. [22]	–	EG1: 13 males and 14 females (age = 48.40 ± 9.52 years) EG2: 15 males and 16 females (age = 38.84 ± 9.68 years)	–	lower back	Each group 6 sessions in 3 weeks Each session 20 min EG1: 5 min USM + 5 min of TENS + 5 min ICT + 5 min hot pack application EG2: 3 min of constant stretching + 5 min of vibration and stroke mode + 40℃ heating	NR	2 groups: EG1: Physical therapy (PT) EG2: Massage chair therapy (MCT)	Taken at baseline, after 1, 2 and 3 weeks after intervention—4 times: VAS, MPQ, FRI	Both PT and MCT group showed improvement after 3 weeks according to VAS, MPQ and FRI scores
Mechanical bed massage									

Table 3 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Lee et al. [26]	–	139 subjects: 131 females and 8 males	–	L5-S1	Massage with heating at 50–55℃ for 40 min Treatment duration weeks Treated 5 times/week	NR	–	At baseline, after 2 weeks and after 4 weeks: HRV, cortisol, Norepinephrine and SSR	Compared to baseline: *HRV*: significant changes after 2 weeks, but NS after 4 weeks *Cortisol*: significant decrease after 2 weeks, NS after 4 weeks *Norepinephrine*: significant decrease after 4 weeks *SSR*: significant changes after 2 and 4 weeks
Do Kim et al. [21]	RCT	15 males (age = 26.2 ± 2.68 years) 13 females (age = 18.6 ± 1.1 years)	–	–	20 min	NR	2 groups: CON & EG	TE, EMG, HRV, EEG, STAI, VAS-10	*HRV*: SM↓ > CON, CM↓ > CON and NS between SM & CM *EEG (alpha and beta)*: CM↓ *STAI*: CON↓ > SM↓ > CM↓ *VAS*: CON↓ > SM↓, CON↓ > CM↓ and NS between SM & CM
Zhong et al. [52]	RCT	Athletes: EG: 6 males (age = 20.2 ± 0.6 years) CON: 6 males (age = 18.6 ± 1.1 years)		Lower back	20 min Kneading	–	2 groups: CON & EG	VAS-10, HRV, BME	Immediately post-intervention: VAS: CON↑ > EG ↑ HRV: NS 24 h post-intervention: VAS: CON ↓ > EG ↓ HRV: NS
Vibration massage									
Yang et al.[67]	RCT	40 subjects	–	lower back (lumbar vertebrae)	Both EG and CON group 3 sessions/week Total duration:6 weeks	–	2 groups: 1. EG: WBV with lumbar stability training 2. CON: only lumbar stability training	VAS for chronic LBP	VAS score: EG > CON

Table 3 (continued)

Authors	Study design	Sample size	Apparatus model	Massage intervention			Groups	Outcome measures	Effects
				Targeted area	Technique and time	Intensity			
Wang et al. [66]	RCT	99 patients of Knee Osteoarthritis (age = 61.5 ± 9.1 years)	–	Knee	Both EG and CON group 5 sessions/week Total duration: 24 weeks	–	2 groups: 1.EG: WBV with QSE 2.CON: Only QSE	VAS for knee pain	
Ramalingam et al. [65]	RCT	100 males 2 groups of 50: 1. EG (age = 21.80 ± 1.62 years) 2. CON (age = 22.40 ± 1.98 years)	–	Muscles: gastrocnemius muscle and tibialis anterior	Vibration massage for 2 min activated at 30 min interval within 2 h treatment session	Frequency = 30 Hz	2 groups: EG & CON	Borg's scale measurement to assess comfort Scores recorded at 0th, 15th, 30th, 60th, 75th, 90th, 105th, and 120th min of the 2-h session	Significant progressive improvement in the calf region for EG compared to CON
Robotic massage									
Peng et al. [41]	–	1 healthy male	NR	Back muscles	Pushing, picking-up and kneading Session time NR	NR	–	HR, breathing rate, skin temperature	↓ HR NS: Breathing rate and temperature
Lei et al. [64]	CT	30 patients with lumber muscle strain	NR	Latissimus dorsi and erector spinae	Rolling, thumb kneading, pinching, pressing and vibrating Each technique 3 times with 5 min interval	NR	–	Lumber PPT Lumber strain VAS-10	↓ Lumber sensitivity ↓ Lumber strain

SBP systolic blood pressure, *DBP* diastolic blood pressure, *PT* physiotherapy, *MCT* massage chair therapy, *TENS* transcutaneous electrical nerve stimulation, *USM* ultrasound massage, *ICT* inferential current therapy, *VAS* visual analogue scale, *MPQ* McGill pain questionnaire, *FRI* functional rating index, *SSP* Swedish scale of personality (*STA* somatic trait anxiety, *PSTA* psychic trait anxiety, *SS* stress susceptibility, *SD* social desirability, *D* detachment), *LWMS* lightweight massage system, *sEMG* surface electromyography, *NS* no significant difference ($p > 0.05$), *SSR* sympathetic skin response, *VAT* vibro-acoustic therapy, *GSR* galvanic skin response, *QSE* quadriceps strengthening exercise, *OA* osteoarthritis, *LBP* lower back pain, *WBV* whole-body vibration in interpreting the findings. Furthermore, in some studies, the use of footwear by subjects has not been reported. Another limitation indicated by Mahbub et al. [58] is on the knee flexion whilst the subject is placed on the vibration platform. As suggested by Brooke-Wavell and Mansfield [59], assuming an extended knee on the platform may cause deleterious effect on the spine and cervical joints because the vibration transverses toward the vertebral column. The International Society of Musculoskeletal and Neuronal Interactions (ISMNI) recommended listing parameters such as frequency/amplitude and acceleration level while describing the vibration involving exposure of subjects to WBV (Rauch et al. [57]). However, most studies have reported vaguely on the measures of vibrational amplitude. Additionally, the placement of a transducer, which is used for measurement of vibrational intensity, is not reported accurately in majority of the studies. This unfortunately creates discrepancy in the reported vibrational parameters and raises implication of replicating the studies in the future. Furthermore, the available research works involving human exposure to WBV did not consider or discuss the recommendations of the international standard and in most cases, the adoption of safety limits when exposed to WBV is not clearly reported. Another limitation is the lack of reporting in environmental condition by the reviewed studies. As mentioned by Mahbub et al. [58], vascular response to vibration massage can change in accordance with differences in room temperature and therefore should be informed.

4 Effects on psycho-physiological variables

Majority of studies involving automated massage modalities have focused on the finding impact of these modalities in treating pain, discomfort, stress, and relaxation. The nature of outcomes measured in these studies is largely qualitative.

Kim et al. [22] studied the efficacy of mechanical massage chair therapy (MCT) in relieving chronic lower back pain. As compared to physiotherapy, the authors reported that MCT showed similar improvement in pain management where the result were based on a set of questionnaires. In a study by Lim et al. [27], the authors sought to find the effect of MCT with binaural beats by analyzing the electroencephalogram (EEG) and cognitive tests. Their study revealed a significant reduction in mental fatigue in patient as indicated by theta/beta as well as theta + alpha/beta indices in the treatment group for MCT combined with binaural beats. Moreover, there were significant improvement in cognition and memory for individuals who received MCT or MCT combined with binaural beats. Muller et al. [37, 38] and Willeke et al. [50] in three similar randomized controlled studies investigated if MCT and mental training could reduce stress and anxiety among office employees. Muller et al. in their initial study found a significant reduction in anxiety and stress susceptibility in groups which received MCT or MCT along with mental training. The results acquired from this study were largely based on questionnaires. Likewise, in their following study, Muller et al. measured the employee's heart rate, blood pressure and fingertip temperature. While they did not find any significant change in blood pressure and temperature, they reported that MCT combined with mental training induced reduction in heart rate over the course of the study. Surprisingly, in a very similar study by Willeke et al. [50] the authors could not find any significant change in heart rate variability (HRV). In contrast, they found a significant decrease in the blood cortisol levels in the MCT group. Furthermore, their study suggested a possible positive correlation of MCT with systolic blood pressure (SBP) and cortisol levels, and a negative correlation with HRV through a post hoc analysis. Another study by Lee et al. [25] on a relatively large number of subjects showed a decrease in the level of anxiety after MCT. However, their result being only from a single-subject measurement reduces its validity.

Franz et al. [68] explored the effects of a lightweight massage system (LWMS) integrated to a car seat on driver comfort and relaxation. Their experiment recounts reduced activity in trapezius muscle group, but no changes in rhomboideus muscle as measured with EMG. The authors relate such reduction in muscular activity as suggestive of decreased amount of stress due to mechanical massage.

Luo et al. [31] reported reduced delta and alpha power of electroencephalogram (EEG) frequency band after robotic hand massage. However, the evidence is weak as their study lacked a trial design and involved a very small sample size.

Two studies investigated the impact of mechanical bed massage on stress. While Do-Kim et al. [21] looked into physiological variables as HRV and EEG frequency band power, Lee et al. [26] also tracked changes in the biochemical markers of stress such as cortisol and norepinephrine. The study by Do-Kim et al. was a pre-test- and post-test-based trial design, contrary to Lee et al. who devised a treatment plan for 2 weeks and measured outcomes 2 weeks after the end of trial. Do-Kim et al. reported that automatic bed massage decreased HR and alpha–beta frequency power on EEG as well as improved scores on visual analogue scale (VAS) and state anxiety index (STAI). The study by Lee et al. had also showed a decrease in HRV, cortisol and norepinephrine levels, although the changes did not recur 2 weeks after the end of study for all parameters except for the norepinephrine level. Yang et al. [67] Wang et al. [66] and Ramalingam et al. [65] investigated the use of local vibration massage on pain management. The results were derived from questionnaires exhibited gradual improvement of pain perception throughout the study period.

In a recent review by Kerautret et al. [55] the authors discussed on the possibility of entirely autonomous massage modalities with ability to conciliate for both proactive and retroactive mode of motor control for user's massage experience. Earlier studies have largely involved highly technical and expensive robotic massage which may not be commercially feasible. However, in recent times there has been development of multiple automated massage modalities with added advantages of precision, availability, privacy and user choice. For instance, the iYU® Pro from Capsix Robotics, which started development in 2016, has complete autonomy and with aid of remote interface can switch from completely automated to user directed control for massage. However, further empirical evidence is required to conform to user safety and incurred benefits from such collaborative massage modalities. Safety is one of the prime issues, therefore, given the fact that with the freedom of use, the level of autonomy granted to massage robots can account for unwanted risk to users if pressure level or trajectories of massage and similar parameters are not adjusted prior to intervention, and subsequently monitored by attending professional. Lima et al. [63] have emphasized on the importance on the understanding of histological structure and physiological process to be accounted for during massage intervention. The issue is further complicated by the varying ergonomics of individuals in terms of muscle mass, personal preference in massage routine and possible presence of undiagnosed medical dysfunctionality. Therapeutic massage, hence, may never be complacent with only automated massage modalities and without involvement of the physiotherapist.

Automated massage modalities, from a preventive viewpoint may still be relevant when considering the importance of workload for physiotherapist and the limited medical resources available. Golovin et al. [61] suggest that such robotic massage modalities will provide an alternative means of assistance in cases when medical professionals are burdened with increased workload. In such cases these autonomous devices can administer simple massage techniques at a limited scale for preventive measures. Complex maneuvers such as stretching, strengthening and joint mobilization, which cannot be performed by robotic devices can be administer by a professional therapist, and thus providing compounding benefits. Hence, robotic massage can reduce risk of musculoskeletal injuries which occur from lack of joint mobilization and subsequently, improve well-being and health by allowing for regulated self-massage. It remains under scrutiny whether manual massage can be entirely substituted by its robotic counterpart. Even with the continuing advances in AI, it is questionable if physiotherapy can be robotized. Traditionally, manual massage therapy practice depends on feedback-based adjustment of manipulation of the patient's body by the therapist. The readjustment to ongoing feedback on the scar tissue ensures for treatment efficacy. Further studies on automated massage modalities are required and until then, mechanical apparatus such as massage chair and robots cannot be entirely integrated and therefore, remain another tool at the disposal of medical practitioners.

5 Conclusion

In this review of automated massage therapy, a range of massage modalities ranging from automated massage beds to robotic massage have been discussed pertaining to muscle properties, peripheral circulation and physio-psychological measures in different groups and health conditions. In many of these studies, a treatment or experimental group have been compared to a control group on basis of different types of psychological, physical, physiological and biochemical measures to evaluate massage effects. The studies have similarities and differences in terms of massage techniques involved such as kneading, rolling, and vibration. In almost all of these studies, massage has been shown to impart beneficial effects in both clinical and non-clinical experimental trials. It has been suggested that the beneficial effects incurred are induced from massage stimulation of pressure receptors on the body leading to enhanced vagal activity and reduced cortisol levels. However, in many cases, these effects are observed over a short period of time and/or involving small sample sizes. It is recommended that future studies look into the long-term effects of massage and design protocols conforming to international standards.

Abbreviations

TE: Trunk extension; SEM: Shear elastic modulus; CK: Creatine kinase; ROM: Range of motion; WASO-1: Waseda Asahi Oral-Rehabilitation Robot 1; RT: Randomized trial; CT: Clinical trial; CCT: Controlled clinical trial; RCT: Randomized control trial; VAS: Visual analogue scale; HRV: Heart rate variability; BME: Back muscle endurance; EG: Experimental group; CON: Control group; NS: No significant difference ($p > 0.05$); EMG: Electromyogram; EEG: Electroencephalogram; STAI: State anxiety inventory; SAM: Self-assessment manakin; SM: Single massage group; CM: Massage + heating (combined massage) group; LA: Blood lactate concentration; IL-6: Interleukin 6 (cytokine); Mb: Myoglobin; MMP-2: Metalloproteinase 2;

MIF: Maximal isometric force; LDH: Lactate dehydrogenase; NIRS: Near infrared spectroscopy; MVC: Maximal voluntary contraction; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; PT: Physiotherapy; MCT: Massage chair therapy; TENS: Transcutaneous electrical nerve stimulation; USM: Ultrasound massage; ICT: Inferential current therapy; MPQ: McGill pain questionnaire; FRI: Functional rating index; SSP: Swedish scale of personality; STA: Somatic trait anxiety; PSTA: Psychic trait anxiety; SS: Stress susceptibility; SD: Social desirability; D: Detachment; LWMS: Lightweight massage system; sEMG: Surface electromyography; SSR: Sympathetic skin response; GSR: Galvanic skin response; QSE: Quadriceps strengthening exercise; OA: Osteoarthritis; LBP: Lower back pain; WBV: Whole-body vibration.

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Authors' contributions
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