Le YH[1], Kohl M[2], von Stengel S[1], Uder M[1], Kemmler W[1,3]

Effectiveness and Safety of Whole-Body Electromyostimulation on Musculoskeletal Diseases in Middle Aged-Older Adults – A Systematic Review

Wirksamkeit und Sicherheit der Ganzkörper-Elektromyostimulation auf muskuloskeletale Größen bei Menschen in mittlerem bis hohem Lebensalter – eine systematische Übersicht

REVIEW

ACCEPTED: March 2024

PUBLISHED ONLINE: April 2024

Le YH, Kohl M, von Stengel S, Uder M, Kemmler W. Effectiveness and safety of whole-body electromyostimulation on musculoskeletal diseases in middle aged-older adults – A systematic review. Dtsch Z Sportmed. 2024; 75: 41-48. doi:10.5960/dzsm.2024.590

1. UNIVERSITY HOSPITAL ERLANGEN, *Institute of Radiology, Erlangen, Germany*
2. UNIVERSITY OF FURTWANGEN, *Department of Medical and Life Sciences, Schwenningen, Germany*
3. FRIEDRICH-ALEXANDER UNIVERSITY OF ERLANGEN-NÜRNBERG, *Institute of Medical Physics, Erlangen, Germany*

Summary

- **Whole-Body electromyostimulation (WB-EMS)** is a time-effective, joint-friendly and consistently supervised exercise training technology particularly attractive to address health-related outcomes in middle-age to older adults. The present systematic review aims to summarize WB-EMS effects on musculoskeletal diseases and conditions in corresponding non-athletic cohorts.
- **A systematic search** in five electronic databases, two study registers and a hand search in Google Scholar without language restrictions up to March 2023 was conducted. We included only peer reviewed clinical trials and intervention studies on WB-EMS with non-athletic adult cohorts averaging 45 years and older addressing musculoskeletal diseases and conditions. Case reports, review articles, editorials, conference abstracts, or theses were not considered.
- **Nineteen research projects** with 22 articles focusing on the effect of WB-EMS on musculoskeletal diseases and conditions were identified. In summary high evidence for positive effects were reported for non-specific chronic low back pain and sarcopenia. Moderate evidence was provided for positive effects on knee osteoarthritis and non-significant positive effects on osteopenia. While two out of eight studies reported minor increases of biomarkers related to rhabdomyolysis, one study reported a single case of mild rhabdomyolysis after a WB-EMS session. No study reported clinically relevant adverse effects.
- **In summary,** we have provided further evidence for predominately positive effects of WB-EMS on musculoskeletal diseases and conditions along with a lack of clinically relevant adverse effects related to WB-EMS application in middle-aged and older cohorts.

KEY WORDS:
WB-EMS, Neuromuscular Electromyostimulation, Complaints, Cohorts, Training

Objective

Whole-body electrostimulation (WB-EMS) is an ever more popular innovative training method capable to stimulate multiple and large muscle areas simultaneously, but with dedicated intensity per electrode. Due to its time effective, joint friendly and consistently supervised character (1, 2) WB-EMS might be an adequate solution to address health related outcomes in middle-age to older adults. This might particularly refer to outcomes related with musculoskeletal diseases. Considering the limited resources of exercise studies including trials on WB-EMS, it is crucial to identify and summarize prevalent evidence provided by WB-EMS literature in order to enhance the efficiency of future research. Therefore the present systematic review aims to summarize WB-EMS effects on musculoskeletal diseases and conditions in middle aged and older non-athletic people.

Methods

The full search strategy and proceeding were outlined in a recently published evidence map on WB-EMS (3). Briefly five electronic databases (Medline [PubMed], The Cochrane Central Register of Controlled Trials [CENTRAL], Cumulative Index to Nursing & Allied Health [CINAHL via Ebsco Host], SPORTDiscus (via Ebsco Host), Physiotherapy Evidence Database [PEDro]) and two study registers (Clinical trial.gov and the WHO's International Clinical Trials Registry Platform [ICTRP]) published from their incentives up to 6th March 2023 were searched without language restrictions. To identify additional study reports, we hand-searched Google Scholar. Of note, the comprehensive search on WB-EMS (figure 1) described above was considered as a database for more detailed review articles. Thus, in the present article we focus on the more specified eligibility criteria listed below (figure 1).

Selection Process

Titles, abstracts and full texts were independently screened by two reviewers (YHL, WK) according to the pre-specified eligibility criteria (3).

CORRESPONDING ADDRESS:
Wolfgang Kemmler, Prof. Dr.
Institute of Medical Physics and Institute of Radiology, Friedrich-Alexander-University of Erlangen-Nürnberg (FAU)
Henkestrasse 91, 91052 Erlangen
: wolfgang.kemmler@fau.de

Table 1

Publication, study, and participant characteristics of the included studies. CG=control group; m=men, NRCT=non-randomized controlled trial; RCT=randomized controlled trial; w=women; methodological quality according to PEDro (maximum of 10 score points). [1]=baseline training status: untrained (UT)=no regular exercise; moderate (MT)=1 session per week, well-trained (WT)=2-3 sessions per week.

	AUTHOR, PROJECT	YEAR	COUNTRY (CODE)	STUDY-DESIGN	TOTAL SAMPLE SIZE (N)	GENDER	AGE (YEARS)	TRAINING-STATUS[1]	METHODO-LOGICAL QUALITY
1	Amaro-Gahete (5)	2019	ESP	RCT	89	m+w	53±5	UT	6
2	Blöckl et al. (6)	2022	GER	NRCT	28	m+w	80±4	UT	4
3	Fritzsche et al. (7)	2010	GER	No CG	15	m+w	56±16	UT	2
4	Kemmler/von Stengel TEST III-Project (8, 9, 10)	2015	GER	RCT	76	m+w	>70	UT	7
5	Kemmler et al. Formosa-Project (11, 35)	2016	GER	RCT	75	w	77±4	UT	8
6	Kemmler et al. FranSO-Project (12, 13)	2017	GER	RCT	100	m	77±5	MT	8
7	Kim et al. (14)	2020	KOR	RCT	25	w	71±3	UT	6
8	Konrad et al. (15)	2020	GER	NRCT	128	m+w	56±14	UT	2
9	Micke et al. (16)	2021	GER	RCT	240	m+w	40-70	MT	8
10	Müllerova et al. (17)	2022	CZE	RCT	21	w	63±2	UT	4
11	Park et al. (18)	2021	Kor	RCT	81	w	61-79	UT	7
12	Reverter-Masia (19)	2020	ESP	RCT	34	w	61±4	UT	7
13	Reljic el al. (20)	2022	GER	RCT	118	m+w	53±11	MT	6
14	Sanchez-Infante et al. (21)	2020	ESP	RCT	28	w	40-60	MT	6
15	Schink et al. (22)	2018	GER	NRCT	31	m+w	55±15	UT	3
16	Silvestri et al. (23)	2023	ITA	NRCT	52	m+w	43-81	UT	3
17	Teschler et al. (24)	2021	GER	NRCT	134	m+w	56±8	UT	7
18	Vacoulikova et al. (25)	2021	CZE	RCT	63	w	60-65	UT	4
19	Weissenfels et al. (26)	2018	GER	RCT	60	w	57±7	UT	8

Eligibility Criteria

The eligibility criteria applied for the present systematic review were categorized according to PICO.

Study design: We included clinical trials and intervention studies with or without control groups. Review articles, case reports, editorials, conference abstracts, letters, or theses (doctoral, master, bachelor) were not considered.

Population: Sedentary to non-athletic adult cohorts with an average age of 45 years and older were included. Athletes or sport-students were excluded; recreational sportsmen were accepted.

Comparators: Type or even presence of a control group was not considered an eligibility criteria.

Intervention: We only included studies that applied WB-EMS according to the present definition (1)

Outcomes: For the present review, we included eligible studies that focused on musculoskeletal diseases and conditions according to International Statistical Classification of Diseases and Related Health Problems (ICD-10 GM).

Data Items

A Microsoft Excel table modified for the present research topic was used to extract relevant data of the included studies. The table was structured in publication characteristics, study characteristics and intervention characteristics. Musculoskeletal diseases and conditions considered as outcomes were classified according to ICD-10 GM. We further recorded whether the outcome was defined (or considered) as primary or main study outcomes or secondary/subordinate study endpoints by the authors. Adverse effects related to the WB-EMS intervention were also recorded. Adverse effects were defined as any untoward medical occurrence, unintended disease or injury, or any untoward clinical signs, including an abnormal laboratory finding related to the WB-EMS application.

Quality Assessment

Risk of bias was classified by YHL and WK using the Physiotherapy Evidence Database (PEDro) Scale Risk of Bias Tool (4) specifically dedicated to physiotherapy/exercise studies.

Data Synthesis

Results are displayed for all studies in tables that listed publication and study characteristics, exercise and stimulation characteristics and cohort and participant characteristics. Bubble charts with 4 dimensions were created to provide a rapid overview (figure 2).

Results

The comprehensive search (figure 1) finally identified 19 projects with 22 articles that focus on musculoskeletal diseases and conditions and corresponding adverse effects (5-26).

Publication, Study and Participant characteristics

Table 1 displays publication and study characteristics of the included trials. Seventeen studies out of 13 projects were RCTs, five studies were non-randomized controlled study and one intervention study (7) establish no CG (table 1). The number of participants per study arm vary between 11 (17) and 80 (16). The methodologic quality according to PEDro (table 1) vary between 2 and 8 score points. Individuals age ranged from 40 (16) to 91 (6). Most study cohorts were untrained (no frequent exercise) at baseline, four study cohorts can be considered moderately trained (table 2). About half of the cohorts were in average predominantly or exclusively overweight (i.e. mean value BMI ≥25 kg/m²).

Intervention Characteristics

Table 2 shows the intervention characteristics of the studies. Superimposed WB-EMS (i.e. intensive exercises supported by moderate impulse-intensity) or combined WB-EMS and conventional exercise programs (e.g. one session/week WB-EMS and one session/week resistance exercise) was applied in five studies (table 3). Intervention length of the closely supervised trials vary between 4 weeks (24) and 12 months (8, 27). Training frequency vary from 1 to 3 sessions/week of predominately 20 min/session. All studies used low frequency impulse programs (7-85 Hz) with impulse width between 300-400 µs. The predominately intermitted WB-EMS protocols schedules 4-6 s of impulse and 2-4 s of impulse break (table 2). Drop-out rates vary from 0% to 59% between the projects/studies, attendance rate average between 77% and 100% (table 2).

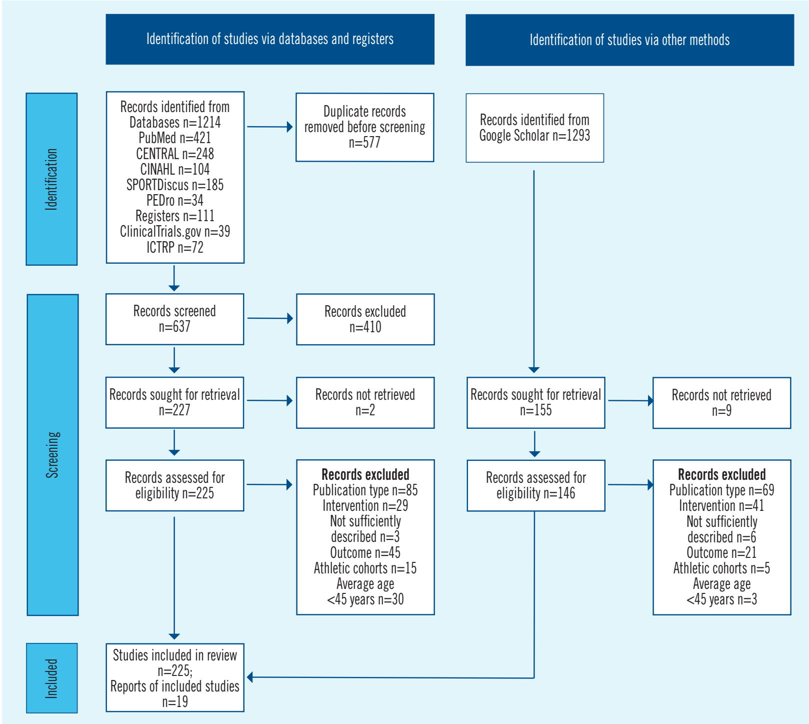

Figure 1

Flow diagram of search process according to PRISMA.

Diseases of the Musculoskeletal System

Osteoarthritis: One combined WB-EMS/isometric exercise trial (18) focused on early knee osteoarthritis in older women applying the Knee Injury and Osteoarthritis Outcome Score (KOOS). The study reported positive effects on all KOOS categories (pain, symptoms, activity of daily living (ADL), sport and recreation and knee related quality of life), maximum isokinetic strength of the leg flexor and extensors and inflammatory biomarkers (IL-6, TNFα, CRP, Resistin) compared to a non-training control. Significant more favorable effects on KOOS pain, symptoms, ADL and IL-6 compared to isometric exercise alone indicate the relevance of WB-EMS within the exercise protocol.

Non-specific chronic low back pain (NCLBP) was addressed as a primary outcome by four trials (15, 16, 23, 26) applying the visual analogue scale (VAS) (23) or the numeric rating scale (NRS 10/11) (15, 16, 26). All the studies consistently reported significant positive effects on NCLBP. In this context, Micke et al. reported similar effects of WB-EMS, whole-body vibration and back specific resistance exercise on NCLBP. Konrad et al. (15) and Silvestri et al. (23) additionally reported positive effects on the Oswestry Disability Index. In summary thus, evidence for WB-EMS induced positive effects on non-specific chronic low back pain is very high.

Sarcopenia, recently included in the ICD-10 (M62.5) was addressed as a primary outcome by two studies (11, 12) in sarcopenic men or women 70 years+. Both studies reported significant effects on the Sarcopenia Z-Score that summarizes morphometric and functional sarcopenia criteria (i.e. gait speed, handgrip strength), compared to control. In detail, effects on muscle mass parameters were more pronounced compared to functional parameters. After 4 weeks of WB-EMS, Teschler et al. (24) reported significant effects on chair rise test but not on handgrip strength in older people with sarcopenia compared to control. One WB-EMS-study in lean older women (9) that addressed morphometric (i.e. ASMM, SMI) and functional parameters (strength, power, muscle-function) related to present sarcopenia definitions determined positive effects compared with a control group that exercised with lower volume and intensity.

Osteoporosis: Bone mineral density (BMD) or bone mineral content (BMC) as determined by dual energy x-ray absorptiometry (DXA) i.e. outcomes dedicated to Osteoporosis were determined by five studies (5, 8, 17, 21, 25). Two studies included only women with osteopenia and considered BMD changes as the primary study outcome (8, 25). Unfortunately only von Stengel et al. (8) determined BMD at the lumbar spine and femoral neck/total hip region of interest i.e. sites relevant for osteoporosis diagnostics. In parallel, only the 12-month protocol of Stengel et al. (8) exceed the duration a of bone remodeling cycle (6-7 months; (29)) considered as the primary mechanism of bone adaptation in adults. In summary, von Stengel reported positive WB-EMS effects on lumbar spine BMD (p=.051) while only negligible effects were observed for total hip BMD compared to a semi-active control group. Apart from BMD, no study so far focus on changes of biomarkers of bone metabolism.

Outcomes related to rhabdomyolysis were determined by several studies. Changes of creatine-kinase, myoglobin and other markers of muscle damage were reported by eight of the included studies (6, 7, 13, 14, 19, 20, 22, 24). Two trials (19, 30) reported significant post-intervention CK raises. However, the increases reported were far below the 5fold increase of CK-levels considered as the threshold of rhabdomyolysis. While the clinical relevance of minor longitudinal CK changes is not clear, there is considerable evidence for severe rhabdomyolysis after too intense WB-EMS (31) particularly in novice applicants (32). Blöckl et al. (6) that closely monitor CK-kinetics (15min, 48h and 72h post EMS) after 1, 3 and 8 weeks reported CK-peaks consistently below 300 IE/l in frail older people. In contrast Fritzsche et al. (7) reported one case of mild rhabdomyolysis (2770 IE/l CK) after acute WB-EMS in a patient with chron- ›

Table 2

Exercise and impulse characteristics of the included studies. [1]=varying impulse frequency and impulse width; [2]=first session, second session/week with continuous impulse.

	AUTHOR, PROJECT	SUPER-IMPOSED?	ACTIVE MODE?	INTER-VENTION LENGTH (MONTHS)	VOLUME/ WEEK (SESSIONS X DURATION	IMPULSE-FREQUENCY (HZ)	IMPULSE-WIDTH (µs)	IMPULSE-LENGTH (s)/ IMPULSE-BREAK (s)	WB-EMS DROP-OUT (%)	ADHERENCE (%)
1	Amaro-Gahete et al. (5)	yes	yes	3	2x20-33	15-20/ [1] 35-75	200-400	6-4	17	99
2	Blöckl et al. (6)	no	yes	2	1-1.5x20	85	350	6-4	14	88
3	Fritzsche et al. (7)	no	yes	6	2x20	80	300	4-4	0	n.g.
4	Kemmler/von Stengel TEST III-Project (8-10)	no	yes	12	1.5x20	85	350	6-4	16	79
5	Kemmler et al. Formosa-Project (11, 36)	no	yes	6	1x20	85	350	4-4	10	89
6	Kemmler et al. FranSO-Project (12, 13).	no	yes	4	1.5x20	85	350	4-4	9	91
7	Kim et al. (14)	yes	yes	2	3x40	85	350	6-4	13	n.g.
8	Konrad et al. (15)	no	yes	1.5	1x20	85	350	4-4	27	85
9	Micke et al. (16)	no	yes	3	1x20	85	350	6-4	9	92
10	Müllerova et al. (17)	no	yes	2.5	1x20	85	350	4-4	18	n.g.
11	Park et al. (18)	yes	yes	2.5	2x20	7 or 55	150-350	6-4	6	93
12	Reverter-Masia (19)	yes	yes	2	3x20	85	350	6-4	7	92
13	Reljic el al. (20)	no	yes	3	2 x20	85	350	6-4	23	93
14	Sanchez-Infante et al. (21)	yes	yes	2	1x20	10 or 85	350	8-4 [2]	0	100
15	Schink et al. (22)	no	yes	3	2 x20	85	350	6-4	59	77
16	Silvestri et al. (23)	no	yes	2	2x20	85	350	6-4	23	91
17	Teschler et al. (24)	no	yes	1	1.5 x20	85	350	4-4	9	98
18	Vacoulikova et al. (25)	no	yes	2.5	1 x20	85	350	4-4	18	100
19	Weissenfels et al. (26)	no	yes	3	1x20	85	350	6-4	7	93

ic heart failure. Albeit the authors determined no clinical sign of rhabdomyolyses apart from muscular soreness, and similar high CK peaks were reported after heavy resistance exercise, researchers should address the issue of rhabdomyolysis by closely following the present guideline on WB-EMS application (33).

Adverse effects: While one study failed to report adverse effects (17) and did not respond to our queries, no project/study reported injuries or negative musculoskeletal side effects apart from temporary muscular soreness after WB-EMS application. Nevertheless, the case of mild rhabdomyolyses after acute WB-EMS application (7), although without clinical significance constitutes an abnormal laboratory finding and can thus be regarded as an adverse effect.

Discussion

The present systematic review summarized the effect of WB-EMS intervention studies on musculoskeletal conditions and diseases in middle-aged to older adults. In summary, with some exception for osteopenia, we observe significant positive effects on core outcomes of musculoskeletal diseases and conditions addressed by WB-EMS trials so far. This positive result however does not refer to biomarkers related to rhabdomyolysis. Reviewing the studies considerable evidence for positive evidence is particularly provided for NCLBP and sarcopenia (figure 2). Osteopenia was addressed by five studies, however, due to the short interventions of four studies, at least the fully amount of mineralized bone might not be reached (29). Nevertheless, the 12 month study of von Stengel (8) that addressed BMD as the primary outcome in osteopenic, postmenopausal women provided considerable evidence for a however limited effect of non-superimposed WB-EMS on BMD. In parallel, the only study that addressed osteoarthritis so far (18), provided high evidence for favorable effects of (superimposed) WB-EMS on outcomes related to OA of the knee. Finally, several studies provided evidence for missing or minor longitudinal changes of CK and related biomarkers. While the clinical relevance of small increases of resting CK is unknown, one of the included studies reported a single case of mild rhabdomyolysis post WB-EMS, however without clinical signs. The finding of exceptionally high CK (and myoglobin) levels is not unique (31). Teschler et al. (32), reported an average 117fold in CK-increase reflecting excessively high impulse intensity applied in novice users. Although the authors reported a very pronounced repeated bout effect after 10 weeks once weekly WB-EMS with CK levels in the range of resistance exercise, it is well known that rhabdomyolysis is a potential side effect after too intense and/or frequent WB-EMS application.

Regarding the limited resources of WB-EMS research and the presently provided positive evidence, we conclude that the area of outcomes related to musculoskeletal diseases or conditions could not be considered as an evidence gap (3, 34) – although advanced evidence in some details is welcome. Our review confirmed the rating that WB-EMS can be considered as a safe training technology, at least when applied with "common sense" (33). This particular refers to the low risk of musculoskeletal injuries and complaints due to low mechanical demands, at least when applying non-superimposed WB-EMS programs. Speculative, another reason for the lack of clinical adverse effect might have been the close and consistent supervision of the WB-EMS session ensured by all the trials.

Some features and limitations of this evidence map might be irritating for the reader. (a) The present systematic review on musculoskeletal diseases, conditions and adverse effects is based on a comprehensive evidence map on outcomes addressed by WB-EMS and Belt Electrode-Skeletal Muscle Electrical Stimulation (B-SES) (34). In this publication, we deal with a narrower topic while adding effects to the number of studies gathered by the evidence map. (b) In this publication we focus on peer reviewed articles. We included randomized controlled trials or controlled trial with and without control group. The latter feature, however, aggravate the proper classification of the methodologic quality by the PEDro-Score (4). (c) Another limitation is the frequently missing prioritization of the study outcomes. Many trials failed to define a hierarchy of outcomes or do not state that the given article focus on a secondary outcome of the project. This reduces the plausibility of the analysis and contributes to publication bias. (d) The studies applied widely comparable stimulation protocols (table 2). While this aspect facilitates the interpretation of the result, it indicates the low enthusiasm in the field to evaluate NMES protocols that differ from the standard protocols presently applied in the vast majority scientific and commercial settings (3).

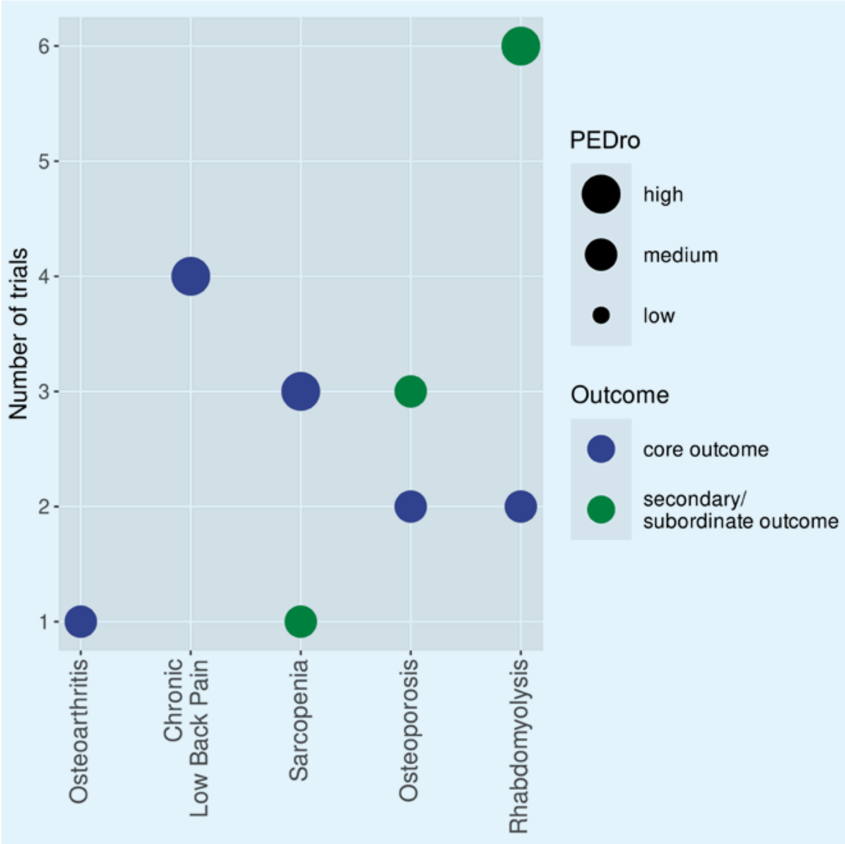

Figure 2

Musculoskeletal outcome addressed by WB-EMS trials. The y-axis indicate the number of studies of the given outcome category. The x-axis presents the outcome categories and the color of the bubble represents if the given outcomes were addressed as core outcomes (i.e. primary outcome, blue) or secondary/ subordinate outcomes (green). PEDro=Physiotherapy Evidence Database (4).

Conclusion

The present work revealed varying effects of WB-EMS on different musculoskeletal diseases and conditions. While high evidence for positive WB-EMS effects was provided for sarcopenia and, in particular, non-specific chronic low back pain, moderate evidence for suboptimum effects on BMD particularly at the proximal femur region of interest – at least after purebred (i.e. non-superimposed) WB-EMS exists . Due to the low mechanical demands of non-superimposed WB-EMS musculoskeletal injuries or complaints can be widely excluded, nevertheless negative side effects related to rhabdomyolysis should be prevented by closely respecting present guidelines and contraindications for WB-EMS application. This particularly includes the consistent and close supervision of the WB-EMS session by dedicated trainers.

Conflict of Interest

The authors have no conflict of interest.

Acknowledgement

We thank all authors that have provided missing data. The present work was performed in (partial) fulfilment of the requirements for obtaining the degree "Dr. med dent. for the first author (Yen Hai Le).

Summary Box

Whole-body Electromyostimulation (WB-EMS) is a time-saving, joint-sparing and consistently monitored exercise technology that is particularly attractive for improving health-related outcomes in middle-aged and older adults. The present systematic review aims to summarize the effects of WB-EMS on musculoskeletal diseases and conditions in matched non-athletic cohorts.

Nineteen research projects with 22 articles were identified that addressed the effect of WB-EMS on musculoskeletal diseases and conditions. In summary, a high level of evidence was found for positive effects on non-specific chronic low back pain and sarcopenia. Moderate evidence was presented for positive effects on knee osteoarthritis and non-significant positive effects on osteopenia. The field of research needs to be further developed.

References

(1) **Kemmler W, Kleinoder H, Fröhlich M.** Editorial: Whole-Body Electromyostimulation: A Training Technology to Improve Health and Performance in Humans? Front Physiol. 2020; 11: 523. doi:10.3389/fphys.2020.00523

(2) **Kemmler W, Kleinoder H, Fröhlich M.** Editorial: Whole-body electromyostimulation: A training technology to improve health and performance in humans? Volume II. Front Physiol. 2022; 13: 972011. doi:10.3389/fphys.2022.972011

(3) **Beier M, Schoene D, Kohl M, von Stengel S, Uder M, Kemmler W.** Non-athletic cohorts enrolled in longitudinal whole-body electromyostimulation trials - An evidence map. Sensors (Basel). 2024; 24: 972. doi:10.3390/s24030972

(4) **Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M.** Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther. 2003; 83: 713-721. doi:10.1093/ptj/83.8.713

(5) **Amaro-Gahete FJ, De-la OA, Jurado-Fasoli L, Ruiz JR, Castillo MJ, Gutierrez A.** Effects of different exercise training programs on body composition: A randomized control trial. Scand J Med Sci Sports. 2019; 29: 968-979. doi:10.1111/sms.13414

(6) **Bloeckl J, Raps S, Weineck M, Kob R, Bertsch T, Kemmler W, Schoene D.** Feasibility and Safety of Whole-Body Electromyostimulation in Frail Older People-A Pilot Trial. Front Physiol. 2022; 13: 856681. doi:10.3389/fphys.2022.856681

(7) **Fritzsche D, Fruend A, Schenk S, Mellwig KP, Kleinöder H, Gummert J, Horstkotte D.** Elektromyostimulation (EMS) bei kardiologischen Patienten. Wird das EMS-Training bedeutsam für die Sekundärprävention? Herz. 2010; 35: 34-40. doi:10.1007/s00059-010-3268-8

(8) **von Stengel S, Bebenek M, Engelke K, Kemmler W.** Whole-Body Electromyostimulation to Fight Osteopenia in Elderly Females: The Randomized Controlled Training and Electrostimulation Trial (TEST-III). J Osteoporos. 2015; 2015: 643520. doi:10.1155/2015/643520

(9) **Kemmler W, Bebenek M, Engelke K, von Stengel S.** Impact of whole-body electromyostimulation on body composition in elderly women at risk for sarcopenia: the Training and ElectroStimulation Trial (TEST-III). Age (Dordr). 2014; 36: 395-406. doi:10.1007/s11357-013-9575-2

(10) **Kemmler W, Engelke K, Von Stengel S.** Ganzkörper-Elektromyostimulation zur Prävention der Sarkopenie bei einem älteren Risikokollektiv [Effects of Whole-Body-Electromyostimulation on Sarcopenia in Lean, Elderly Sedentary Women. The TEST-III Study]. Die TEST-III Studie. Dtsch Z Sportmed. 2012; 63: 343-350. doi:10.5960/dzsm.2012.044

(11) **Kemmler W, Teschler M, Weissenfels A, Bebenek M, von Stengel S, Kohl M, Freiberger E, Goisser S, Jakob F, Sieber C, Engelke K.** Whole-body electromyostimulation to fight sarcopenic obesity in community-dwelling older women at risk. Resultsof the randomized controlled FORMOsA-sarcopenic obesity study. Osteoporos Int. 2016; 27: 3261-3270. doi:10.1007/s00198-016-3662-z

(12) **Kemmler W, Weissenfels A, Teschler M, Willert S, Bebenek M, Shojaa M, Kohl M, Freiberger E, Sieber C, von Stengel S.** Whole-body Electromyostimulation and protein supplementation favorably affect Sarcopenic Obesity in community-dwelling older men at risk. The Randomized Controlled FranSO Study. Clin Interv Aging. 2017; 12: 1503-1513. doi:10.2147/CIA.S137987

(13) **Kemmler W, von Stengel S, Kohl M, Rohleder N, Bertsch T, Sieber CC, Freiberger E, Kob R.**Safety of a Combined WB-EMS and High-Protein Diet Intervention in Sarcopenic Obese Elderly Men. Clin Interv Aging. 2020; 15: 953-967. doi:10.2147/CIA.S248868

(14) **Kim J, Jee Y.** EMS-effect of Exercises with Music on Fatness and Biomarkers of Obese Elderly Women. Medicina (Kaunas). 2020; 56: 158. doi:10.3390/medicina56040158

(15) **Konrad KL, Baeyens JP, Birkenmaier C, Ranker AH, Widmann J, Leukert J, Wenisch L, Kraft E, Jansson V, Wegener B.** The effects of whole-body electromyostimulation (WB-EMS) in comparison to a multimodal treatment concept in patients with non-specific chronic back pain—A prospective clinical intervention study. PLoS One. 2020; 15: e0236780. doi:10.1371/journal.pone.0236780

(16) **Micke F, Weissenfels A, Wirtz N, von Stengel S, Dörmann U, Kohl M, Kleinöder H, Donath L, Kemmler W.** Similar Pain Intensity Reductions and Trunk Strength Improvements following Whole-Body Electromyostimulation vs. Whole-Body Vibration vs. Conventional Back-Strengthening Training in Chronic Non-specific Low Back Pain Patients: A 3-armed randomized controlled trial. Front Physiol. 2021; 13: 664991. doi:10.3389/fphys.2021.664991

(17) **Müllerová M, Vaculíková P, Potúcková A, Struhár I, Balousová DN.** Impact of Whole-Body Electromyostimulation and Resistance Training Programme on Strength Parameters and Body Composition in Group of Elderly Women at Risk of Sarcopenia. Studia sportiva. 2022; 16: 292-304. doi:10.5817/StS2022-2-29

(18) **Park S, Min S, Park SH, Yoo J, Jee YS.** Influence of Isometric Exercise Combined With Electromyostimulation on Inflammatory Cytokine Levels, Muscle Strength, and Knee Joint Function in Elderly Women With Early Knee Osteoarthritis. Front Physiol. 2021; 12: 688260. doi:10.3389/fphys.2021.688260

(19) **Reverter-Masia J, Pano-Rodriguez A, Beltran-Garrido JV, Lecube A, Sánchez E, Hernández-González V.** Effect of a Training Program on Hepatic Fat Content and Cardiometabolic Risk in Postmenopausal Women: The Randomized Controlled Trial. Appl Sci (Basel). 2021; 11: 6409. doi:10.3390/app11146409

(20) **Reljic D, Herrmann HJ, Neurath MF, Zopf Y.** Iron Beats Electricity: Resistance Training but Not Whole-Body Electromyostimulation Improves Cardiometabolic Health in Obese Metabolic Syndrome Patients during Caloric Restriction-A Randomized-Controlled Study. Nutrients. 2021; 13: 1640. doi:10.3390/nu13051640

(21) **Sánchez-Infante J, Bravo-Sáncheza A, Abiánb P, Estebana P, Jimeneza J, Abián-Vicén J.** The influence of whole-body electromyostimulation training in middle-aged women. Isokinet Exerc Sci. 2020; 28: 365-374. doi:10.3233/IES-202113

(22) **Schink K, Reljic D, Herrmann HJ, Meyer J, Mackensen A, Neurath MF, Zopf Y.** Whole-Body Electromyostimulation Combined With Individualized Nutritional Support Improves Body Composition in Patients With Hematological Malignancies - A Pilot Study. Front Physiol. 2018; 9: 1808. doi:10.3389/fphys.2018.01808

(23) **Silvestri A, Ruscello B, Rosazza C, Briotti G, Gabrielli PR, Tudisco C, D'Ottavio S.** Acute Effects of Whole-Body Electrostimulation Combined with Stretching on Lower Back Pain. Int J Sports Med. 2023; 44: 820-829. doi:10.1055/a-2080-2018

(24) **Teschler M, Heimer M, Schmitz B, Kemmler W, Mooren FC.** Four weeks of electromyostimulation improves muscle function and strength in sarcopenic patients: a three-arm parallel randomized trial. J Cachexia Sarcopenia Muscle. 2021; 12: 843-854. doi:10.1002/jcsm.12717

(25) **VACULÍKOVÁ, P, KAZDOVÁ A, BALOUSOVÁ DN, KOTKOVÁ M, STRUHÁR I.** Impact of Whole-Body Electromyostimulation and Resistance Training on Bone Mineral Density in women at risk for Osteopororosis. IJPESS. 2022: 69-79. doi:10.51846/the-sky.v0i0.2075

(26) **Weissenfels A, Teschler M, Willert S, Hettchen M, Fröhlich M, Kleinöder H, Kohl M, von Stengel S, Kemmler W.** Effects of whole-body electromyostimulation on chronic nonspecific low back pain in adults: a randomized controlled study. J Pain Res. 2018; 11: 1949-1957. doi:10.2147/JPR.S164904

(27) **Kemmler W, von Stengel S.** Whole-body electromyostimulation as a means to impact muscle mass and abdominal body fat in lean, sedentary, older female adults: subanalysis of the TEST-III trial. Clin Interv Aging. 2013; 8: 1353-1364. doi:10.2147/CIA.S52337

(28) **Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinková E, Vandewoude M, Zamboni M; European Working Group on Sarcopenia in Older People.** Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age Ageing. 2010; 39: 412-423. doi:10.1093/ageing/afq034

(29) **Eriksen EF.** Cellular mechanisms of bone remodeling. Rev Endocr Metab Disord. 2010; 11: 219-227. doi:10.1007/s11154-010-9153-1

(30) **Schink K, Herrmann HJ, Schwappacher R, Meyer J, Orlemann T, Waldmann E, Wullich B, Kahlmeyer A, Fietkau R, Lubgan D, Beckmann MW, Hack C, Kemmler W, Siebler J, Neurath MF, Zopf Y.** Effects of whole-body electromyostimulation combined with individualized nutritional support on body composition in patients with advanced cancer: a controlled pilot trial. BMC Cancer. 2018; 18: 886. doi:10.1186/s12885-018-4790-y

(31) **Stollberger C, Finsterer J.** Side effects of and contraindications for whole-body electro-myo-stimulation: a viewpoint. BMJ Open Sport Exerc Med. 2019; 5: e000619. doi:10.1136/bmjsem-2019-000619

(32) **Teschler M, Weissenfels A, Bebenek M, et al.** Very high creatine kinase CK levels after WB_EMS. Are there implications for health. Int J Clin Exp Med. 2016; 9: 22841-22850.

(33) **Kemmler W, Fröhlich M, Ludwig O, Eifler C, von Stengel S, Willert S, Teschler M, Weissenfels A, Kleinöder H, Micke F, Wirtz N, Zinner C, Filipovic A, Wegener B, Berger J, Evangelista A, D'Ottavio S, Sara JDS, Lerman A, Perez de Arrilucea Le Floc'h UA, Carle-Calo A, Guitierrez A, Amaro-Gahete FJ.** Position statement and updated international guideline for safe and effective whole-body electromyostimulation training-the need for common sense in WB-EMS application. Front Physiol. 2023; 14: 1174103. doi:10.3389/fphys.2023.1174103

(34) **Le YE, Schoene D, Kohl M, von Stengel S, Uder M, Kemmler W.** Outcomes addressed by longitudinal whole-body electromyostimulation trials in middle aged-older adults - An evidence map. Front Physiol. 2023; accepted for publication.

(35) **Kemmler W, von Stengel S, Teschler M, Weissenfels A, Bebenek, Kohl M, Freiberger E, Bollheimer C, Goisser S, Sieber C, Seefried L, Jakob F, Engelke K.** Ganzkörper-Elektromyostimulation und Sarcopenic Obesity. Ergebnisse der randomisierten kontrollierten FORMOsASarcopenic Obesity Studie. Osteologie. 2016; 25: 204-211. doi:10.1055/s-0037-1619018

(36) **Kemmler W, von Stengel S.** Alternative Exercise Technologies to Fight against Sarcopenia at Old Age: A Series of Studies and Review. J Aging Res. 2012; 2012: 109013. doi:10.1155/2012/109013