

# Outcomes Addressed by Longitudinal Whole-Body Electromyostimulation and Belt Electrode-Skeletal Muscle Electrical Stimulation Trials in Middle Aged-Older Adults - an Evidence Map

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## Abstract

**Introduction:** Due to its time-effective, joint friendly and highly customizable character whole-body-electromyostimulation (WB-EMS) is regarded as a feasible solution for a large variety of training issues. Not least for this reason WB-EMS research has increased considerably during the last few years. To identify gaps in research and summarize prevalent evidence we conducted an evidence map on outcomes addressed by WB-EMS trials in middle-aged to older, non-athletic adults so as to align future research more efficiently.

**Methods:** Based on a comprehensive systematic search in five databases and two study registers according to PRISMA, 54 projects published in 80 articles were ultimately identified as meeting our eligibility criteria.

**Results:** More than 90% of the studies reported outcomes related to the physical fitness or function domain. Body composition parameters were addressed by two thirds of the projects, however only 14 studies considered body composition as the primary outcome. Health-related outcomes addressed by WB-EMS trials as primary (or secondary/subordinate) outcomes included cancer/neoplasm ( $n=3$ , ( $n=4$ )), endocrine regulation ( $n=2$ , ( $n=6$ )), glucose metabolism ( $n=6$ , ( $n=9$ )), nervous system diseases ( $n=2$ ), cardiovascular system diseases ( $n=6$ , ( $16$ )), non-specific chronic low back pain ( $n=4$ ), osteopenia ( $n=2$ , ( $n=3$ )) and diseases of the renal system ( $n=1$ , ( $n=11$ )). Outcomes related to inflammation were addressed three times as a primary and 15 times as a secondary/subordinate outcome. Of importance, no studies reported clinically relevant adverse effects related to the WB-EMS intervention.

**Conclusion:** In summary, while considerable evidence on outcomes related to fitness/function and body composition is prevalent, evidence gaps of WB-EMS research were particular evident for diseases of the nervous and cerebrovascular system.

**Keywords:** Whole-Body Electrostimulation, Electromyostimulation, Health, Body Composition Fitness, Function

## 1. Introduction

Whole-body electrostimulation (WB-EMS) “defined as simultaneous application of electric stimuli via at least six current channels or participation of all major muscle groups, with a current impulse effective to trigger muscular adaptations is an ever more popular and innovative training method [1]. Due to its time effective, joint friendly, comprehensive and highly customizable character WB-EMS might be an adequate solution for various training issues [1,2]. In the last ten years a large number of articles

on WB-EMS effects on various outcomes have been published. Apart from cross-sectional studies and studies on the acute effect of WB-EMS, the vast majority of studies focus on the effect of longitudinal training interventions on given outcomes. So far, a large variety of performance-, function-, fitness- and health-related outcomes in athletic and particularly in non-athletic cohorts have been addressed [3]. Restricting the results to middle-age to older adults, i.e. the dominant area of WB-EMS application outcome domains addressed vary from muscle strength, endurance,

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flexibility, balance, body composition, chronic low-back pain, biomarkers of cardiovascular, cardiometabolic, neoplasm and inflammation, bone mineral density, intermuscular adipose tissue, vascular endothelial function, left ventricular function, through to quality of life, disability, pain, and sleep quality - to list just a few [4]. However, due to the rather stringent index of absolute or relative contraindications, a large variety of cohorts and corresponding outcomes were not adequately addressed by WB-EMS trials. In diametral contrast, Belt Electrode-Skeletal Muscle Electrical Stimulation (B-SES), a neuromuscular electrostimulation (NMES) technique that stimulates large muscle areas (i.e. gluteals and lower extremities) and can thus be considered as closely related to WB-EMS, focuses predominately on severe diseases and conditions [5]. Adding both NMES methods might increase the evidence for a wider applicability of WB-EMS on different outcomes. Considering the limited resources for WB-EMS and B-SES research, it is important to identify and summarize prevalent evidence provided by WB-EMS and related techniques in order to align future research more efficiently. An evidence map that listed the evidence, identify gaps, and provide results in a user-friendly format might be the appropriate tool to summarize research on WB-EMS and B-SES [6]. The present evidence map thus aimed to provide an overview of study outcomes addressed by WB-EMS and closely related techniques in middle aged and older non-athletic people.

## 2. Methods

Our evidence map based on a systematic review of the literature. Two researchers (YHL, DS or WK) searched 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]) for scientific literature published from launch up to 6th March 2023 were searched without language restrictions. Strategies were developed applying free text words as no database-specific key words (e.g. MeSH, Thesaurus) were identified. We piloted our search and found a good balance for maximizing sensitivity and precision by (a) constructing the search around the term whole-body electromyostimulation only and (b) searching the title and abstract fields only in PubMed, CINAHL and SPORTDiscus, excluding Medline hits in CINAHL and by applying the 'Trials' filter in CENTRAL. To identify additional study reports, we manually searched Google Scholar on the same date as the medical databases. The full strategies can be found in Supplemental S1 Table (Supplement). Of note, our comprehensive search on WB-EMS and related technologies was considered as a database for varying review articles, to which more specified eligibility criteria were covered in the more dedicated articles.

### a. Eligibility Criteria

#### i. Study Design

We included all types of longitudinal studies with an interventional

study designs, i.e. randomized or non-randomized clinical trials and intervention studies with or without control groups [7]. We also accepted articles on the same project that focus on the same cohort but other outcomes. Only peer reviewed research was considered. Review articles, case reports, editorials, conference abstracts, letters, and all kind of thesis were not considered.

#### ii. Population

Sedentary to non-athletic adult cohorts on average 45 years and older were included. Cohorts comprised of athletes or sport students were excluded but recreational sportsmen were accepted.

#### iii. Comparators

Type or even presence of a control group was not considered as an eligibility criterion.

#### iv. Intervention

We only included studies that applied Whole-Body Electromyostimulation (WB-EMS [1]) or other kinds of electromyostimulation able to stimulate large muscle areas ( $\geq 50\%$  of skeletal muscle mass) simultaneously. Studies that applied local EMS or focus on single muscle groups were not considered.

#### v. Outcomes

In the present analysis, we included eligible studies independently of the outcomes addressed. This includes outcomes related to physical fitness/function, health-related outcomes and safety aspects. Special emphasis was placed on adverse effects of WB-EMS application. We defined "adverse event" as any untoward medical occurrence, unintended disease or injury. Muscular soreness, discomfort with the stimulation, or increased CK values without clinical relevance were not considered adverse effects.

#### b. Selection process

Titles, abstracts and full texts were independently screened by two reviewers (YHL, WK) according to the pre-specified eligibility criteria. Disagreements were solved by discussion or with the help of a third reviewer (DS). Reasons for excluding ineligible studies were recorded. In the case of missing data or doubtful information, authors were contacted for a maximum of three times within a six-week period.

#### c. Data management

Search results were downloaded and imported to Endnote. Duplicates were identified and excluded based on the method proposed by Bramer et al. [8]. Title and abstract screening as well as full-text screening was conducted using Endnote.

#### d. Data items

A Microsoft Excel table applied in former studies and modified for the present research topic was used to extract relevant data of the included studies [9,10]. One author (WK) extracted study, participant, and intervention characteristics, two other authors (YHL and SvS) checked and confirmed the results. The table was

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structured in several domains.

Publication characteristics include information related to the study type, first author, year and country of the publication while study characteristics listed, for example, number of study arms, sample size in WB-EMS and control group, comparator (i.e. predominately sedentary control group or active control) and methodological quality of the studies.

Intervention characteristics include (1) mode of application, i.e. isolated WB-EMS or WB-EMS with voluntary movements that should not relevantly affect outcomes versus superimposed WB-EMS or exercise added to WB-EMS. (2) WB-EMS system including the corresponding manufacturers. (3) Duration of the application (in months), training frequency (sessions/week), length of the session (in min) (4) Details of the impulse protocol (i.e. impulse type (mono / bipolar), impulse frequency (in Hz), impulse breadth (in  $\mu$ s), impulse intensity, impulse application (continuous or intermitted impulse), length of the impulse phase (in s) and (if applicable) intermitted impulse break (in s). Due to the topic of the present evidence map, special emphasis was placed on outcome characteristics. Study endpoints were categorized in outcome domains (e.g. physical function/fitness) with subcategories (e.g. maximum strength, power) with specific regard to health-related outcomes. All adverse effects of the WB-EMS intervention were recorded independently of type (e.g. orthopedic, metabolic) or severity according to our definition listed above.

Diseases and conditions were classified according to the International Statistical Classification of Diseases and Related Health Problems (ICD-10 GM [11]). We also recorded whether the outcome was defined as the primary/main study outcomes or as secondary/subordinate study endpoints by the authors. To properly address this issue we carefully checked the article but also the study registration and databases where applicable. When several primary outcomes were specified by a study or project (e.g. we accepted the first three outcomes as main study outcomes [12]. In parallel, we accepted more than one primary outcome when the main outcome refers to a score composed of multiple outcomes (e.g. Sarcopenic Obesity).

Of importance, not completely in line with the character of the evidence map approach, we briefly address not only the number but also the results of projects/trials that reported adverse effects.

#### **e. Quality Assessment**

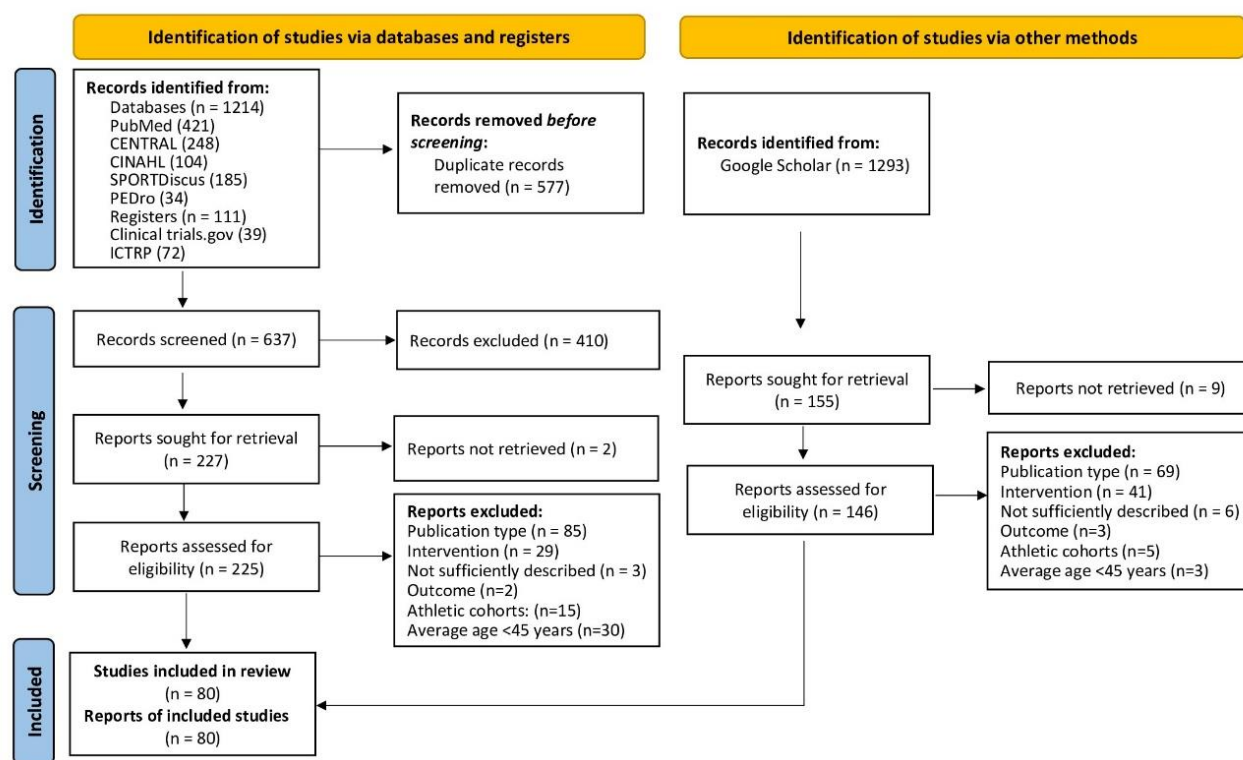
Eligible studies were assessed for risk of bias by two independent reviewers (YHL and WK) using the Physiotherapy Evidence Database (PEDro) Scale Risk of Bias Tool specifically dedicated to physiotherapy and/or exercise studies [13]. In case of inconsistencies, a third independent reviewer (SvS) made the decision. Studies with >7 score points were classified as high, 5-7 score points moderate and <5 score points as low methodological quality studies respectively [14].

#### **f. Data Synthesis**

Results are displayed for all studies in tables that display publication and study characteristics, exercise and stimulation characteristics and the cohort and participant characteristics of the included studies. To provide a quick overview, bubble charts with 4 dimensions were created with the y-axis indicating the number of studies of the given outcome category and the x-axis presenting the outcome categories and the color of the bubble represents if the given outcomes were addressed as core outcomes (i.e. primary outcome) or secondary/subordinate outcomes. In order to reliably estimate the latter aspect, two reviewers carefully checked the full text including methods, power calculations and statistical analysis but also study registration and online databases of the studies/projects – if available. Finally, the size of the bubble indicates the methodological quality according to PEDro. The largest size indicates at least one study of high methodological quality, the smallest size of the bubble chart represents at least one study of low methodological quality in the corresponding outcome category.

### **3. Results**

Of the 1103 records, 54 study projects published in 80 articles were ultimately included in the present evidence map (Fig 1) on outcomes addressed by WB-EMS studies with interventional study designs [7,12,15-93].



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: <http://www.prisma-statement.org/>

**Figure 1:** Flow Diagram of Search Process according to PRISMA

### a. Publication, Study and Participant Characteristics

Table 1 displays publication and study characteristics of the included projects/trials. Based on the 54 projects, the majority of the projects were designed as RCTs (Table 1). Fifteen projects applied non-randomized controlled study designs, the remaining six trials (WB-EMS: n=2, B-SES: n=4) applied a single group design without control group in an inpatient setting [27, 52, 55, 61, 82, 88]. The number of participants per study arm varies between three and 96 [63,78]. Twenty projects were conducted in Germany, 17 in Japan (all B-SES), 4 in Korea, and 3 in Spain, Italy and the Czech Republic each. About three quarters of the studies were published during the last 5 years (Table 1). The methodological quality according to PEDro (Table 1) varies between 3 and 8 score points.

Most projects included all genders, 26% focus on female and four

projects addressed male participants. The majority of the studies included cohorts largely independent of age. About half of the studies included participants 65 years and older, the youngest cohort was 49 years on average [20]. However, one study included also a few participants in their 20ies (e.g. [28]).

Most study cohorts (82%) were untrained (i.e. no frequent exercise prior to the study), six study cohorts can be considered as being moderately trained (1-2 sessions/week prior to the study) and one project included well trained (>2 sessions/week prior to the study) participants [36,37]. More than half of the cohorts were predominantly or exclusively overweight or obese (i.e. BMI mean  $\geq 25$  kg/m<sup>2</sup>). Seven projects focused on healthy cohort while the majority (87%) of projects addressed cohorts with diseases or conditions

	Author, project	year	country (code)	study-design	Number of study arms (n)	total sample size (n)	gender	age (years)	Body Mass Index (kg/m <sup>2</sup> ) <sup>1</sup>	training-status <sup>2</sup>	diseases/conditions	methodological quality <sup>5</sup>
1	FitAging-Project; Amaro-Gahete et al. [15-19, 23, 25, 32-34, 59]	2019	ESP	RCT	4	80-89	m+w	53 ± 5	26.8	untrained	no	6
2	Bellia et al. [20]	2020	ITA	RCT	2	25	m+w	49±7	40.1	moderate	yes	4
3	Blöckl et al. [21]	2022	GER	NRCT	2 <sup>2</sup>	28	m+w	80±4	26.2 <sup>3</sup>	untrained	yes	4
4	Bouty-Regard et al. [22]	2020	JPN	RCT	3	41	m+w	77±2	21.5	untrained	yes	6
5	DiCagno et al. [24]	2023	ITA	RCT	3	24	m+w	72±6	n.g.	untrained	yes	8
6	Evangelista et al. [26]	2021	BRA	RCT	2	30	m	75±7	n.g.	untrained	no	5
7	Fritzsche et al. [27]	2010	GER	No CG -	1	15	m+w	56±16	26.8	untrained	yes	2
8	Hamada et al. [28]	2023	JPN	NRCT	2	49	m+w	54±17	21.4	untrained	yes	3
9	Homma et al. [29]	2022	JPN	RCT	2	27	m+w	79±6	22.0	untrained	yes	5
10	Houdjijk et al. [30]	2022	NL	NRCT	4	75	m+w	45-75	31.8 <sup>4</sup>	untrained	yes	3
11	Imaoka et al. [31]	2022	JPN	RCT	2	49	m+w	64±7	24.2	untrained	yes	6
12	Kataoka et al. [35]	2019	JPN	RCT-	2	16	m+w	83±6	16.7	untrained	yes	5
13	TEST I Project; Kemmler et al. [36, 37, 39]	2010	GER	RCT	2	30	w	65±6	26.0	well-trained	yes	6
14	TEST II-Project; Kemmler et al. [37-39]	2012	GER	RCT	2	28	m	69±3	28.1	untrained	yes	5
15	TEST III-Project; Kemmler/von Stengel et al. [40-42, 91]	2015	GER	RCT	2	76	m+w	>70	34.6	untrained	yes	7
16	TEST III-Sub-Project; Kemmler et al. [42]	2013	GER	RCT	2	46	w	>70	22.1	untrained	yes	7
17	Formosa-Project; Kemmler et al. [43, 44, 93]	2016	GER	RCT	3	75	w	77±4	25.1	untrained	yes	8
18	FranSO-Project; Kemmler et al. [45-48, 109].	2017	GER	RCT	3	100	m	77±5	26.1	moderate	yes	8
19	Kim et al [49]	2020	KOR	RCT	2	25	w	71±3	30.9	untrained	yes	6
20	Konrad et al. [50]	2020	GER	NRCT	2	128	m+w	56±14	n.g.	untrained	yes	2
21	Lukashevich et al. [51]	2020	BLR	RCT	3	52	w	45-65	n.g.	untrained	yes	4
22	Matsumoto et al. [52]	2020	JPN	No CG-	1	4	m+w	66±6	24.0	untrained	yes	2
23	Matsuo et al. [53]	2022	JPN	NRCT	2	90	m+w	77±11	24.0	untrained	yes	4
24	Micke et al. [54]	2021	GER	RCT	3	240	m+w	40-70	26.3	moderate	yes	8
25	Mori et al. [55]	2020	JPN	NRCT	1	14	m	65±13	n.g.	untrained	yes	4
26	Müllerova et al. [56]	2022	CZE	RCT	2	21	w	63±2	26.6	untrained	no	4
27	Nakamura et al. [57]	2019	JPN	RCT	2	94	m+w	76±12	21.0	untrained	yes	4
28	Nakamura et al. [58]	2021	JPN	RCT	2	134	m+w	68±15	21.4	untrained	yes	5
29	Nejad et al. [60]	2021	IRN	RCT	5	50	w	60-70	28.2	untrained	no	3
30	Noguchi et al. [61]	2017	JPN	No CG-	1	8	m+w	69±10	n.g.	untrained	yes	1
31	Nonoyama et al. [62]	2022	JPN	NRCT	2	42	m+w	72-84	24.4	untrained	yes	3
32	Ochiai et al. [63]	2018	JPN	NRCT	2	6	m+w	60-90	n.g.	untrained	yes	3
33	Leida-Project; Pano-Rodriguez et al. [64, 65, 72]	2020	ESP	RCT	2	34	w	61±4	26.5	untrained	no	7
34	Park et al. [67]	2021	Kor	RCT	2	34	w	70±4	27.5	untrained	yes	7
35	Park et al. [66]	2021	Kor	RCT	3	81	w	61-79	24.4	untrained	yes	7
36	Park et al [68]	2023	Kor	RCT	4	60	w	≥65	25.4	Untrained	yes	7
37	MetS-Project; Reljic et al. [69-71]	2022	GER	RCT	4	29-118	m+w	53±11	37.2	moderate	yes	6
38	Sanchez-Infante et al. [74]	2020	ESP	RCT	2	28	w	40-60	25.5	moderate	no	6
39	Advanced cancer project; Schink et al. [75, 76]	2018	GER	NRCT	2	131	m+w	60±13	25.2	untrained	yes	3
40	Advanced cancer project; Schink et al. [77]	2018	GER	NRCT	2	31	m+w	55±15	25.4	untrained	yes	3
41	Advanced cancer project; Richter et al. [73]	2019	GER	NRCT	2	75	m+w	59±13	25.5	untrained	yes	4

42	Advanced cancer project; Schwappacher et al. [79]	2020	GER	NRCT	2	30	m+w	63±15	28.0	untrained	yes	3
43	Advanced cancer project, Schwappacher et al. [78]	2021	GER	NRCT	2	12	m+w	62±9	26.8	untrained	yes	3
44	Silvestri et al. [80]	2023	ITA	NRCT	2	52	m+w	43-81	24.6	untrained	yes	3
45	Suzuki et al. [81]	2018	JPN	RCT	2	29	w	66±10	23.2	untrained	no	4
46	Suzuki. et al. [82]	2018	JPN	No CG	1	12	m+w	65±7	23.7	untrained	yes	3
47	Tanaka et al. [83, 84]	2022	JPN	RCT	2	39	m+w	66±10	26.7	untrained	yes	7
48	Teschler et al. [12]	2021	GER	NRCT	3	134	m+w	56±8	36.2	untrained	yes	7
49	Tsurumi et al. [85]	2022	JPN	RCT	2	11	m+w	74±5	35.7	moderate	yes	5
50	Vacoulikova et al. [87]	2021	CZE	RCT	3	21	m+w	60-65	22.7	untrained	yes	4
51	Vacoulikova et al. [86]	2021	CZE	RCT	3	63	w	60-65	27.1	untrained	no	4
52	van Buuren et al. [89, 90]	2014	GER	NRCT	3	60	w	61±11	27.0	untrained	yes	4
53	van Buuren et al. [88]	2015	GER	No CG	1	15	m+w	62±4	29.7	untrained	yes	4
54	Weissenfels et al. [92]	2018	GER	RCT	2	60	w	57±7	22.2	untrained	yes	8

**Table 1: Publication, Study and Participant Characteristics of the Included Research Projects**

CG: control group; IS: Intervention study; m: men, n.a.: not applicable; NRCT: non-randomized controlled trial; RCT: randomized controlled trial; w: women; methodological quality according to PEDro (maximum of 10 score points)

<sup>1</sup> due to the approach of calculating BMI by body length and mass in case of missing BMI we do not list the SD here; <sup>2</sup> training status: untrained = no regular exercise; moderate = 1 session per week, well-trained = 2-3 sessions per week; <sup>3</sup> Blöckl et al.: BMI refer to “frail cohort”; <sup>4</sup> Houdjik et al: BMI refer to participants with non-insulin dependent diabetes; <sup>5</sup> according to PEDro

### b. Intervention Characteristics

Table 2 gives the intervention characteristics of the studies. Thirty-seven of the projects applied whole-body electromyostimulation (WB-EMS), 17 projects used Belt Electrode-Skeletal Muscle Electrical Stimulation (B-SES) that focuses on gluteal and/or lower extremity muscle stimulation applying 5-6 belt electrodes. Adjuvant or additional exercises (i.e. superimposed WB-EMS) with relevant effect on the primary study outcome or combined WB-EMS and conventional exercise programs were applied in about 20% of the projects. Nevertheless, apart from B-SES studies that focused on passive (i.e. without movements) EMS application, all WB-EMS studies conducted movements or exercises during the impulse phase.

The duration of the WB-EMS intervention varied considerably

from 10 days to 12 months [42,83,91]. Training frequency varied from 1 (e.g. [43,50,54]) to 7 sessions/week (e.g. [57,58,63]) of predominately 20-30 min duration/session. Only a few studies provided continuous impulse during the session, all the other trials exercised with intermitted WB-EMS protocols predominately with 4-6 s of impulse and 2-4 s of impulse break (Table 2) [35,85,95]. All but one study used low frequency impulse programs with impulse breadth of 200-400  $\mu$ s [51]. One project scheduled low impulse intensity, the remaining studies/projects reported moderate to high impulse intensities [43,44,93].

Apart from five projects that do not provide loss to follow-up rates, the remaining projects/studies reported drop-out rates of 0% to 59%. Projects/Studies that displayed attendance rate (83%) reported an average rate of 92±8%.

	Author	NEMS System	Isolated EMS?	Active mode?	Intervention length(months)	Sessions per week (n)	length of the session (min)	Impulse-frequency (Hz)	Impulse-width (µs)	Impulse-length (s)	Impulse-break (s)	WB-EMS Drop-out (%)	Adherence (%)	Adverse effects
1	FitAging-Project; Amaro-Gaehete et al. [15-19, 23, 25, 32-34, 59, 110]	WB-EMS <sup>1</sup>	no	yes	3	2	20 or 32.5	15-20 or 35-75	200 - 400	6	4	17	99	no
2	Bellia et al. [20]	WB-EMS	yes	yes	6	2	20	15 or 85	400	4 <sup>2</sup>	4	23	90	no
3	Blöckl et al. [21]	WB-EMS	yes	yes	2	1-1.5	20	85	350	6	4	14	88	no
4	Bouty-Regard et al. [22]	B-SES <sup>2</sup>	yes	n.g.	3	2	20	20	250	5	2	0	97	no
5	DiCagno et al. [24]	WB-EMS	yes	yes	3	2	20	7 or 85	350	4	4	0	100	no
6	Evangelista et al. [26]	WB-EMS	no	yes	1.5	2	20	85	350	4	2	33	100	no
7	Fritzsche et al. [27]	WB-EMS	yes	yes	6	2	20	80	300	4	4	0	n.g.	no
8	Hamada et al. [28]	B-SES	yes	yes	1	7(?)	20	20	250	5	2	12	71	no
9	Homma et al. [29]	B-SES	yes	no	3	3	40	20	250	5	2	29	100	no
10	Houdijk et al. [30]	WB-EMS	yes	yes	4	2	20	85	350	4	4	0	95	no
11	Imaoka et al. [31]	B-SES	yes	no	0.5	5	20	20	250	5	2	27	n.g.	no
12	Kataoka et al. [35]	B-SES	yes	no	3	3	20	4	250	1200		25	n.g.	no
13	TEST I Project; Kemmler et al. [36, 37]	WB-EMS	yes	yes	3.5	2	20	7 or 85	350	4	4	0	98	no
14	TEST II-Project; Kemmler et al. [37, 38]	WB-EMS	yes	yes	3.5	1.50	30	85	350	4	4	7	78	no
15	TEST-III-Project; Kemmler/von Stengel et al [39-41, 91]	WB-EMS	yes	yes	12	1.50	20	85	350	6	4	16	79	no
16	TEST III-Sub-Project; Kemmler et al. [42]	WB-EMS	yes	yes	12	1.50	20	85	350	6	4	16	79	no
17	Formosa-Project Kemmler et al. [43, 93]	WB-EMS	yes	yes	6	1	20	85	350	4	4	10	89	no
18	FranSO-Project; Kemmler et al. [45-48, 109].	WB-EMS	yes	yes	4	1.50	20	85	350	4	4	9	91	no
19	Kim et al. [49]	WB-EMS	no	yes	2	3	40	85	350	6	4	13	n.g.	no
20	Konrad et al. [50]	WB-EMS	yes	yes	1.5	1	20	85	350	4	4	27	85	no
21	Lukashevich et al. [51]	WB-EMS	no	yes	0.66	4	20	Up to 25000	Up to 5000	n.g.	n.g.	n.g.	n.g.	no
22	Matsumoto et al. [52]	B-SES	yes	no	1	5	20	20	250	5	2	n.g.	n.g.	no
23	Matsuo et al. [53]	B-SES	yes	n.g.	0.5	5	20	20	250	5	2	6	94	no
24	Micke et al. [54]	WB-EMS	yes	yes	3	1	20	85	350	6	4	9	92	no
25	Mori et al. [55]	B-SES	yes	n.g.	1.5	2	30	20	250	5	2	n.g.	n.g.	n.g.
26	Müllerova et al. [56]	WB-EMS	yes	yes	2.5	1	20	85	350	4	4	18	n.g.	n.g.
27	Nakamura et al. [57]	B-SES	yes	n.g.	0.5	7	20	20	250	5	2	55	100	no
28	Nakamura et al. [58]	B-SES	yes	n.g.	0.5	7	20	20	250	5	2	17	100	n.g.
29	Nejad et al. [60]	WB-EMS	no	yes	3	3	20	15-33 or 35-75	200 and 400	6	4	n.g.	n.g.	n.g.
30	Noguchi et al. [61]	B-SES	yes	n.g.	3	3	20	20	250	5	2	0	n.g.	no
31	Nonoyama et al. [62]	B-SES	yes	n.g.	1.30	5	30	20	250	5	2	n.g.	97	no
32	Ochiai et al. [63]	B-SES	yes	n.g.	1.10	7	20	20	250	5	2	0	n.g.	no
33	Leida-Project; Pano-Rodriguez et al. [64, 65, 72]	WB-EMS	no	yes	2.5	2	40	7 or 55	150 to 350	6	4	6	93	no
34	Park et al. [67]	WB-EMS	no	yes	1.5	3	40	80	n.g.	5	3	6	100	no
35	Park et al. [66]	WB-EMS	no	yes	2	3	20	85	350	6	4	7	92	no
36	Park et al. [68]	WB-EMS	no	yes	2	3	45	4	n.g.	2	2	3	97	no
37	MetS-Project; Reljic et al. [69-71]	WB-EMS	yes	yes	3	2	20	85	350	6	4	23	93	no
38	Sanchez-Infante et al. [74]	WB-EMS	no	yes	2	1	20	10 or 85	350	8/cont	4/cont.	0	100	no
39	Schink et al. [75, 76]	WB-EMS	yes	yes	3	2	20	85	350	6	4	40	87	no
40	Schink et al. [77]	WB-EMS	yes	yes	3	2	20	85	350	6	4	59	77	no
41	Richter et al. [73]	WB-EMS	yes	yes	3	2	20	85	350	6	4	19	88	no

42	Schwappacher et al. [79]	WB-EMS	yes	yes	3	2	20	85	350	6	4	n.g.	88	no
43	Schwappacher [78]	WB-EMS	yes	yes	3	2	20	85	350	6	4	n.g.	79	no
44	Silvestri et al. [80]	WB-EMS	yes	yes	2	2	20	85	350	6	4	23	91	no
45	Suzuki et al. [81]	B-SES	yes	n.g.	2	3	20	20	250	5	2	13	98	no
46	Suzuki. et al. [82]	B-SES	yes	no	3	3	30	20	250	5	2	0	n.g.	no
47	Tanaka et al. [83, 84]	B-SES	yes	no	0.30	5	35	20	250	5	2	25	86	no
48	Teschler et al. [12]	WB-EMS	yes	yes	1	1.50	20	85	350	4	4	9	98	no
49	Tsurumi et al. [85]	B-SES	yes	no	3	3	30	4	250	1200	0	27	n.g.	n.g.
50	Vacoulikova et al. [87]	WB-EMS	yes	yes	2.5	1	20	85	350	4	4	n.g.	81	no
51	Vacoulikova et al. [86]	WB-EMS	yes	yes	2.5	1	20	85	350	4	4	18	100	no
52	van Buuren et al. [89, 90]	WB-EMS	yes	yes	2.5	2	20	80	350	4	4	0	100	no
53	van Buuren et al. [88]	WB-EMS	yes	yes	2.5	2	20	80	350	4	4	0	100	no
54	Weissenfels et al. [92]	WB-EMS	yes	yes	3	1	20	85	350	6	4	7	93	no

**Table 2: Intervention Characteristics of the Included Research Projects**

<sup>1</sup> WB-EMS: simultaneous application of electric stimuli via at least six current channels or participation of all major muscle groups, with a current impulse effective to trigger muscular adaptations”[1]. In detail: large electrodes embedded in vest and cuffs were used to stimulate both thighs, upper arms, gluteals, lower back, upper back, latissimus area, abdomen and chest (stimulated area up to 2800 cm<sup>2</sup>)

<sup>2</sup> B-SES: We are not aware of a dedicated definition of B.SES, however, B-SES focuses on the stimulation of gluteals and lower extremities using belt-electrodes

## C. Outcomes

### i. Physical Function and Fitness Domain

More than 90% of the studies/projects included in the evidence map address physical function and fitness parameters however only a minority of the studies/projects defined physical function or fitness parameters as the core study outcome [12,28,29,31,35,43,48,51,52,65,68,75,84,87,95]. Of note, some of these studies listed scores (i.e. Sarcopenia Z-Score) or test batteries (e.g. Senior Fitness Test battery) that included several fitness parameters as the primary or core study outcome. (Fig 2)

#### 4. Maximum Strength

Maximum strength changes of the lower extremities [12,15,21,22,28,31,36,39,40,44,45,50,52,56,60,61,66,70,74,81,82,84,85], trunk [12, 36, 40, 50, 54, 70, 92] and upper extremities/hand were determined by many studies [12,15,21,24,26,40,44,48,56,60-62,68,70,75,84]. About two thirds of the studies/projects applied isometric tests; functional tests were performed by seven studies and eight studies used isokinetic devices for strength assessments [15,21,44,45,56,66,74,82]. Maximum strength change was defined as primary outcome in the trials of Suzuki et al., Tanaka et al and Teschler et al. [12,81,84].

#### 4.1 Power

The eligible studies determined changes in maximum power of the lower extremity by the 10s/3reps/5reps chair rise test [12,21,29,44,50,62,68,84,85], jump tests [44,50], leg press/leg extension devices [39,56] or functional tests [60,64].

#### 4.2 Strength Endurance

Changes in strength endurance of the lower extremities were determined by a 30 s sit to stand test [21,24,26,61,65,75,87], 2

min step test or by an isokinetic leg extensor test [60,82]. Strength endurance of the trunk was determined by isometric or functional tests (e.g. front plank test) upper extremity muscle endurance was determined by 30 s arm curl test [15,26,87].

#### 4.3 Endurance

In summary, longitudinal intervention data on endurance parameters were reported by 18 trials/projects [12,15,24,26-29,39,60,61,65,68,75,84-88,90]. Changes in endurance were defined as primary outcome by the trials of Homma et al [29]. and Teschler et al. [12]. Most studies applied the 6 min (or 1 mile [60]) walking test [12,24,26,28,29,61,65, Park, 2023 #170,75,84, 85,87]. Spiroergometry data was reported by [15,27,39,88,90].

#### 4.4 Flexibility

Only a few studies/projects focus on flexibility changes as an outcome [24,26,31,35,65,80,86]. All authors focus on lower extremity flexibility, four of them used the sit and reach test to determine flexibility of the hamstrings and lower back [24,65,80,86]. Kataoka et al considered ROM for hip flexion/abduction, knee flexion and extension as the primary study outcome in his cohort of bedridden elderly patients and Imaoka et al focus on ankle dorsiflexion range in diabetes patients undergoing minor amputations [31,35]. Three authors determined flexibility of trunk/ upper extremity muscles by applying the back scratch test [26,65,86].

#### 4.5 Balance

In summary, twelve authors reported results of tests related to balance [21,24,29,50,61,62,65,74,81,84,85,87]. Six projects applied the balance tests included in the short physical performance battery (SPPB) four trials used the timed up and go tests (TUG)



one study focused on the berg balance score [21,24,29,61,62,68, 81,84,85,87]. Tests on balance platforms were conducted by two trials [50,80]. None of the studies considered balance as the primary study outcome. Changes in SPPB (...and 6MWT) was the primary study outcome of one trial [29].

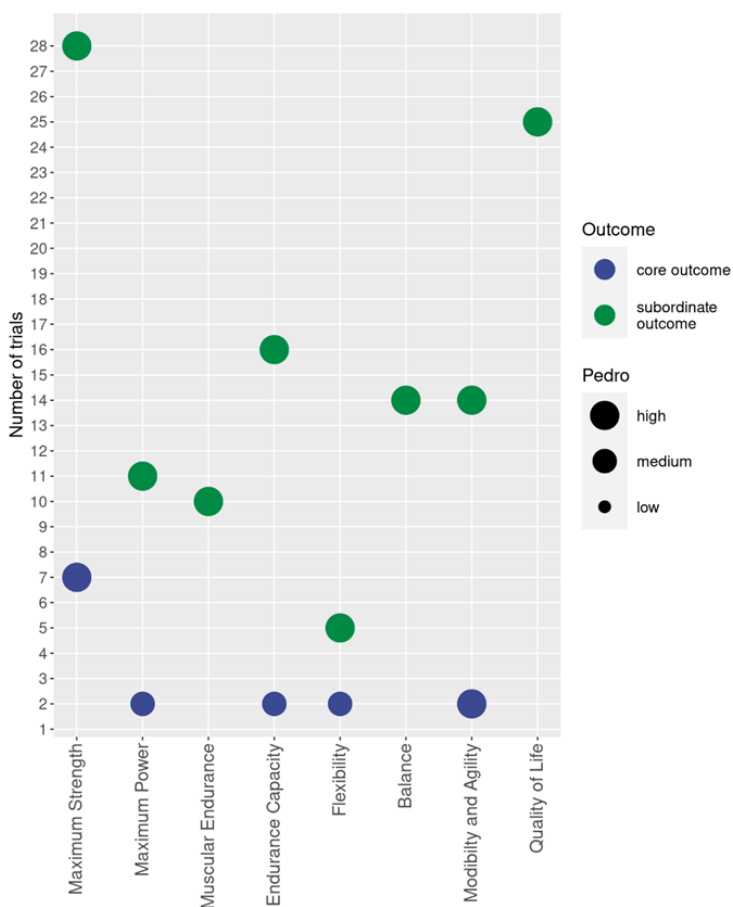
### 5. Mobility, Agility

Apart from studies that applied the 4m (habitual) walking speed test included in the Short Physical Performance Battery (SPPB) [21,29,62,68,84,85] or the TUG-Test [21,24,81,87], only a few other studies listed parameters related to mobility and/or agility [21, 24,43,48,51,57,65,75]. Habitual gait velocity was determined by [43,48,51,61,65,75]. Schink et al [75]. Also focus on advanced gait parameters (e.g. stride time, swing time, variability. Blöckl et al [21]. Used the choice stepping reaction test (CSRT) to assess agility and reaction time in his older cohort. Di Cagno et al [24]. applied a soda pop test in his cohort of Parkinson's patients. None of the studies considered mobility, agility or coordination as the primary outcome.

### a. Quality Of Life Domain

In summary, 25 projects and 27 publications listed patient-reported changes in outcomes related to the quality of life (QoL) domain [12,21,24,27,29,31,33,38,45,50,51,54,57,58,62,63,66,68,70,76, 80,81,83,89,92]. This included outcomes related to "Disability" [12,29,31,45,50,51,57,58,62,63,75,80] or frailty status [68].

Changes in overall pain [38,70,76], knee pain [66] and in particular low back pain as determined by dedicated questionnaires/ protocols were reported by the participants of nine studies [27, 50,54,80,92]. Five of the studies considered knee or lower back pain reduction as the primary study outcome [50,54,66,80,92]. Further, two of the studies reported changes in disability related to back pain [50,80]. Fatigue related to Parkinson's disease [24] or advanced cancer were reported by two research projects [73,76]. In parallel, only two projects (FitAging, [33]; advanced cancer, addressed insomnia/sleep quality as a secondary outcome [73,76]. Of importance, none of the studies considered QoL parameters as the primary study outcome.



**Figure 2:** Physical fitness/function-related outcome addressed by WB-EMS. The y-axis presents the number of studies that focus on the corresponding cohort (x-axis). Different colors indicate whether the domain was considered a core (primary) or subordinate outcome. The size of the bubble indicates the methodological quality according to PEDro. The largest size indicates at least one study of high methodological quality in the domain. The smallest size of the bubble chart represents at least one study of low methodological quality in the domain.

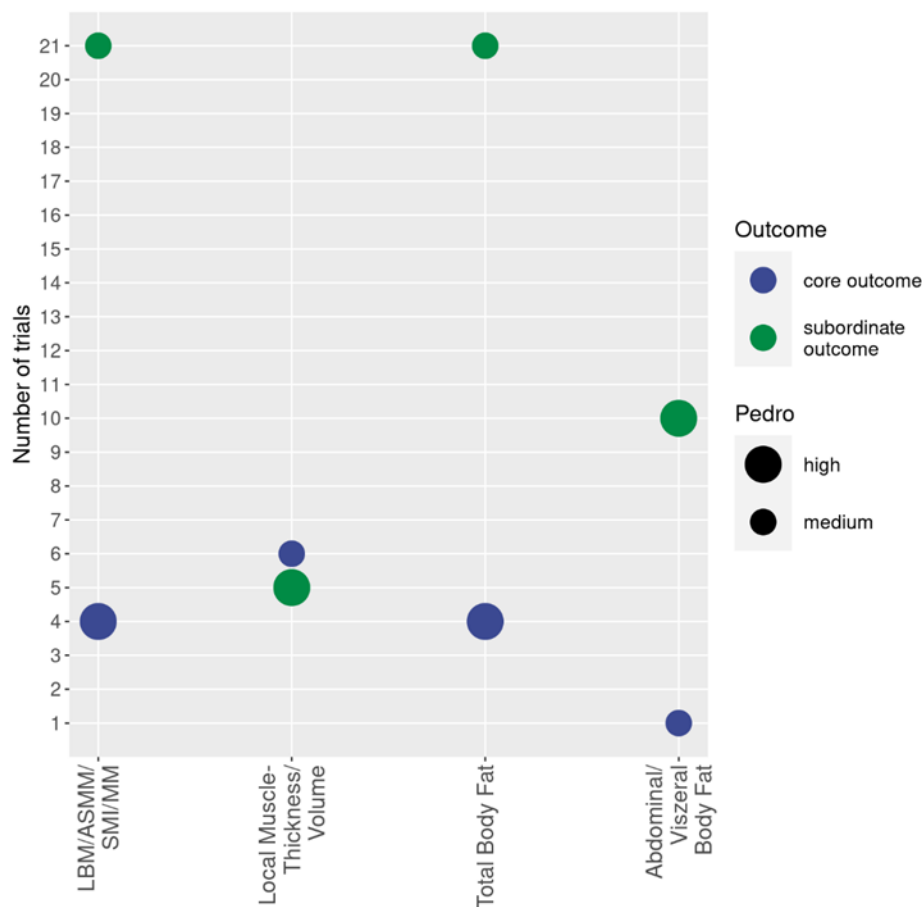
## b. Body Composition and Anthropometry

More than two thirds of the studies/projects reported changes body composition parameters as primary, secondary or tertiary outcome. Although difficult to conclude (e.g. Kim et al [49]. listed “body composition” as the main outcome and Kemmler et al [43, 48]. applied Sarcopenic Obesity as the primary study outcome), about 14 studies considered changes in body composition and anthropometry at least as a core outcome (Fig 3) [20,22,26,38,43, 48,49,52,53,57,58,62,67,76].

Lean body mass/fat free mass (LBM/FFM: [12,18,20,22,26,27, 30,36,37,40,56,64,74] or/and muscle mass: [49,53,66-68,70,76, 82] or/and appendicular skeletal muscle mass/skeletal muscle mass index (ASSM/SMI: [29,38,40,43,48,53,85]) were reported by 25 projects.

Total body fat changes [12,18,20,22,26,27,30,36,38,40,43,48,49, 53,56,64, 66-68,70,73,74,76,82,90] were reported by 25 projects. Most studies/projects applied BIA [12,20,22,26,27,29,48,49, 53,64, 66-68,70,73,75-77,82,85,90] for the assessment of body composition. The minority of studies used DXA-technique, [18, 30, 38, 43, 56, 74, 91], one study [36] relied on the caliper method and a further study determined changes in thigh and calf circumference [52].

Apart from total body fat, several studies determined trunk, abdominal, or visceral fat mass/rate by BIA [45,64], DXA [18,30, 38,40] or CT [67] or, less sophisticated, by waist circumference [18,20,38,64,70,74,93].



**Figure 3:** Body Composition Related outcome Addressed by WB-EMS and Classified According to the Aspect whether the Domain was Considered a Core (primary, blue color) or a Subordinate outcome (green color).

Eleven studies focus on local muscle parameters (muscle thickness, cross-sectional area, cross-sectional volume) predominately at the mid-thigh/quadriceps site [22,26,28,45,53,57,58,62,67,82,85], calf [22] or upper arm [26] applying either ultrasound (US) [22,26, 28,62,85], computed tomography (CT) [57,58,67] or magnetic resonance imaging (MRI)[45,82] techniques. Of relevance, five of the studies consider thigh muscle layer thickness (by US) as a primary outcome [22,53,57,58,62].

Resting metabolic rate. Two studies determine the basic or resting metabolic rate (RMR) by gas exchange parameters as the gold standard procedure [19,36]. One of them considered EMR as the primary study outcome [36].

## c. Health Related Outcomes

Apart from physical function and body composition parameters important for health, about 80% of the studies/projects addressed

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outcomes listed in the ICD 10. Of importance, some outcomes (e.g. TNF $\alpha$ ; S-Klotho, creatine-kinase) refer to more than one ICD-10 classification, correspondingly the parameter might be listed several times (Fig 4)

## 6. Neoplasm

Outcomes related to cancer and malignancies were addressed by 3 projects with 7 studies [49,66,73,76-79]. Kim et al reported change in carcinoembryonic antigen (CEA), and together with Park et al [49]. Determined inflammatory biomarkers including TNF $\alpha$  in general [66]. The advanced cancer project reported outcomes on dedicated cancer parameters e.g. malignant cell growth, proliferation and apoptosis or fatigue in a cohort of patients with advanced cancer [73,76-79].

### 6.1 Endocrine Regulation

Thirteen studies of eight projects reported outcomes related to endocrineregulation. ThreestudiesoftheFitAgingprojectdetermined WB-EMS effects on 1.25OH<sub>2</sub>D (Calcitriol) [23], testosterone, free Testosterone, Cortisol, Dehydroepiandrosteronesulfate (DHEA-S) [25] or S-Klotho [16], the latter as the primary project outcome. Di Cagno et al. addressed neurotropic/growth factors (brain derived neurotropic factor (BDNF), Fibroblast growth factor-21 (FGF-21), Nerve Growth Factor, (proNGF)) and  $\alpha$ -synuclein, which are particularly relevant outcomes in Parkinson patients [24]. Apart from inflammatory markers also considered as hormones (e.g. Interferon  $\gamma$  (IFN $\gamma$ ), Interleukin 1 (IL1), Interleukin 6 (IL6), Tumor Nekrosis Factor (TNF $\alpha$ )), Reljic et al. and Kim et al listed WB-EMS effects on Adiponectin [69] and Resistin in their obese cohorts [49]. In parallel, Homma et al addressed insulin-like growth factor 1 (IGF-1) and Irisin as a secondary study outcome in older hemodialysis patients [29]. Schwappacher et al reported changes in testosterone levels and neurotropic/growth factors (e.g. BDNF, IGFBP-3) in advanced cancer patients [79]. Suzuki et al. determined IGF-I, DHEA-S, adiponectin, and particularly relevant for his cohort of dialysis patients, atrial (ANP) and brain natriuretic peptide (BNP) [81]. Finally, Insulin was addressed by six studies/projects that focus on obesity, the Metabolic Syndrome (MetS) or non-insulin-dependent (type II) diabetes mellitus (NIDDM) [17, 20,68,69,81,82].

### 6.2 Diabetes Mellitus and the Metabolic Syndrome

Apart from the studies that determined Insulin [17,20,68,69,81,82] or Resistin levels [49,66] several other studies addressed glucose metabolism, the MetS or NIDDM with more dedicated outcomes or scores [17,20,30,39,46,68,71,81,82,85,88,93]. HbA1c results were reported by six studies [20,30,68,71,81,82,88]. HOMA and/

or Quicki-Indices were reported by Amaro-Gahete et al. [17]; Bellia et al [20]; Park et al [68], Reljic et al. [71], and Suzuki et al. [82]. Three other studies calculated a metabolic risk [17]/ Metabolic Syndrome Z-Score [71,93]. Parameters related to the MetS [20, 71], or insulin resistance were considered as primary or main outcome in six studies [30,82,85,88].

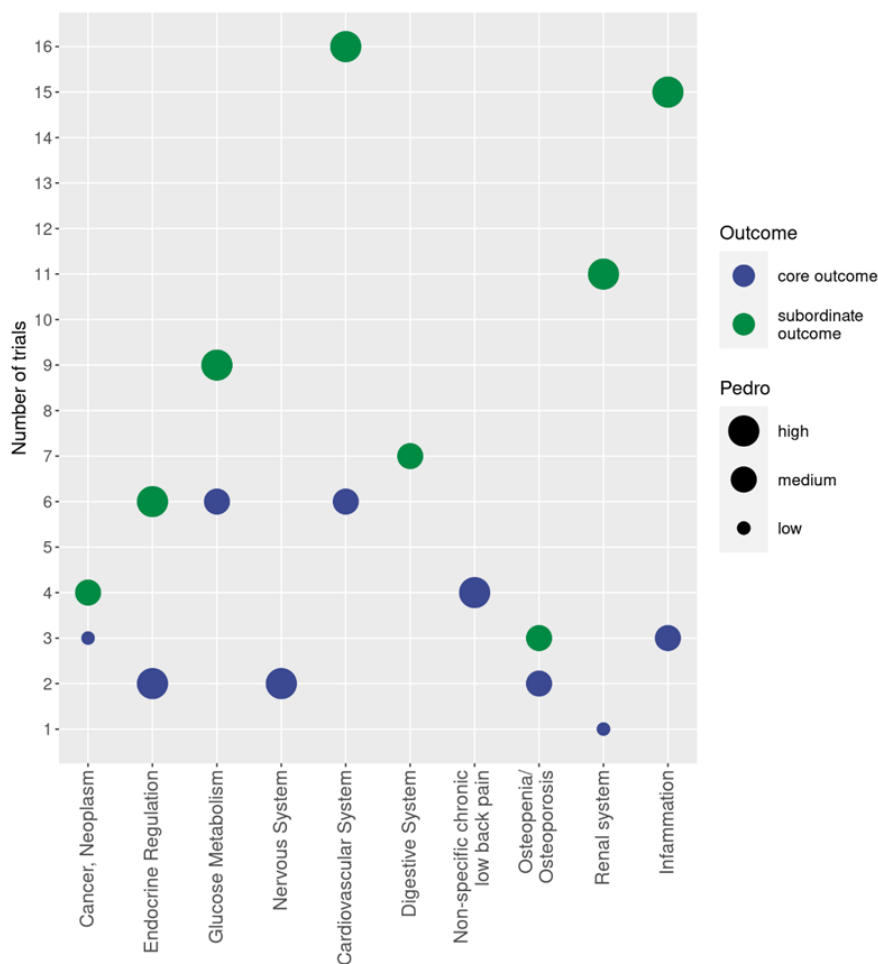
### 6.3 Diseases of the Nervous System

Only two studies addressed outcomes related to diseases of the nervous system [24,51]. In a cohort of Parkinson patients, Di Cagno et al. determined Parkinson Fatigue Score and neurotropic factors, growth factors (see above) and  $\alpha$ -synuclein, biomarkers closely related to Parkinson's disease [24]. Lukashevich et al applied the Modified Rankin-Scale, the Rivermead Mobility Index, Scandinavian Stroke Scale, functional tests and lower extremity kinematics in the early recovery phase after a cerebral infarction [51].

### 6.4 Cardiovascular Diseases

A large number of studies/projects determined changes in outcomes related to cardiovascular diseases or conditions. Changes in blood pressure were reported by 12 studies [17,20,27,29,39,55,63,68,71, 85,90,93]; apart from heart rate changes one author focused on heart rate variability (HRV) [59]. Biomarkers of lipid metabolism including oxylipins and endocannabinoids [34] were addressed by 16 trials [12,17,20,22,30,34,39,46,49,68,71,72,81,82,85,93]. A further five authors stated changes in hematologic and/ or coagulation parameters [22,29,76,81,84] two further studies assessed changes in brain-natriuretic peptide levels as a safety outcome [81,84]. Changes in cardiorespiratory parameters as determined by spirometry were reported by five studies [17, 27,60,88,90]. Although not explicitly stated, oxygen uptake can be considered the primary outcome of van Buuren et al. [90].

Mori et al. and Park et al [55]. [68] addressed vascular endothelial function of the lower extremities in dialysis patients [55] or pre-frail older women via ultrasound imaging [68]. Park et al. and Ochai et al [68]. assessed WB-EMS/B-SES effects on arterial stiffness via ankle-brachial index (ABI) in prefrail older people or patients with peripheral arterial disease (PAD) and severe ischemia of the lower extremities [63, 68]. Finally, four studies focus on changes in left ventricular ejection fraction (LVEF) [84, 88, 90] and/or NT-pro-BNP [47,90] in older patients with acute or chronic heart failure [84,90], diabetes mellitus [88] or sarcopenic obesity [47]. In the latter cohort, Kemmler et al. additionally addressed changes of CKMB and highly sensitive Troponin, pivotal biomarkers for the detection of cardiac injuries [47].



**Figure 4:** Health-related outcome addressed by WB-EMS and Classified According to the aspect whether the Somain was Considered a Core (primary) or a Subordinate outcome.

## 7. Diseases of the Respiratory System

Two studies determined “days under mechanical ventilation” as secondary outcome in their cohorts of critically ill patients [57, 58].

### 7.1 Diseases of the Digestive System

The few studies that addressed this category [12,17,58,72,77] focus predominately on liver function determined by dedicated biomarkers [12,17,72] in healthy aged adults, or sarcopenic rehabilitation patients [12]. Nakamura et al. [58] focus on changes in diarrhea and vomiting events and gastric residual volume in his critically ill cohort (secondary outcome); appetite loss, constipation and diarrhea events as determined by questionnaire were secondary study outcomes in the advanced cancer project [73,76].

### 7.2 Diseases of the Musculoskeletal System

One WB-EMS study focused on osteoarthritis in older women with early knee Osteoarthritis applying the Knee Injury and Osteoarthritis Outcome Score (KOOS) [66]. Non-specific chronic low back pain (NCLBP) was addressed by four trials [50,54,80,

92] applying the visual analogue scale (VAS) [80] or the numeric rating scale (NRS10/11) [50,54,92] as a patient-reported outcome. Konrad et al and Silvestri et al [50]. Also applied the Oswestry Disability Index that focuses on low back pain and degenerative disc disease [80]. Of importance, all of the studies clearly stated NCLBP as the primary study outcome.

Sarcopenia, recently included in the ICD-10 (M62.5), was addressed as a primary outcome by two studies [43,48]. At least three other studies addressed morphometric (i.e. ASMM, SMI) and functional parameters (strength, power, muscle function) involved in the complex Sarcopenia diagnosis. Outcomes related to exertional rhabdomyolysis were determined by several studies [39,40,85]. Changes in creatine-kinase, myoglobin and other markers of muscle damage were also monitored by several other studies predominately for safety aspects [12,21,22,27-29,47,49, 70,72,77]. In particular Blöckl et al. [21] and Schink et al [77] applied an advance protocol with multiple assessments during the WB-EMS intervention and [21] CK-levels drawn 48 and 72h post-exercise (CK and Myoglobin peaks occurred 48 to 72 h post-WB-EMS ([96]). Outcomes related to rhabdomyolyses were main

outcomes in one study/project [21].

Bone mineral density (BMD) or bone mineral content (BMC), i.e. outcomes specifically dedicated to Osteoporosis, were determined by five studies [18,56,74,86,91]. All studies applied dual energy x-ray absorptiometry (DXA) considered as the gold standard of bone densitometry and focus on middle aged to older women. Four studies determined whole body BMD, while von Stengel et al. assessed BMD at the lumbar spine and femoral neck/total hip region of interest [91]. Two studies considered BMD changes as the primary study outcome [91]. No study has so far focused on changes in markers of bone metabolism.

### 7.3 Diseases of the Genitourinary System

Outcomes related with conditions or diseases related to the genitourinary system were addressed by several studies. Apart from outcomes on biomarkers of muscle status [12,21,22,29,47,52,70,72,77] also relevant for renal health, some studies additionally focus on outcomes related to renal function or failure [12,21,29,58,61,84]. Two studies that applied a combination of moderate (1.5 g/kg/d) [47] or high (1.8 g/kg/d) protein intake and WB-EMS/B-SES in people with sarcopenic obesity or critically ill patient do not report relevant changes in blood urea nitrogen, creatinine, GFR, cystatin or other urea markers of protein metabolism and renal health [58]. This result was confirmed by Tanaka et al. that (comparable to the aforementioned studies that focus on the present outcome) observed no worsening of renal function or acute kidney injury in his cohort of frail patients with acute heart failure [84]. Of importance, so far no eligible study on conventional WB-EMS or B-SES has focused on urinary incontinence as a study outcome.

### 7.4 Inflammation

Apart from creatine kinase (CK) as a marker of inflammation-induced muscle impairment, a large number of studies addressed outcomes related to inflammation predominately in older cohorts [97]. C - reactive protein (CRP) was determined by 12 studies/projects [22,28,29,31,49,52,58,61,66,69,77,81], highly sensitive CRP was assessed by three studies/projects [47,68,69]. IL-1  $\alpha$  was measured by Reljic et al [69], a further five studies reported data on IL-6 [29,47,49,66,69]. TNF $\alpha$  results were listed by two studies [49, 66]. Boutry-Regard et al [22] also addressed Transthyretin, Fibrinogen, Orosomucoid as inflammatory outcomes; in parallel Reljic et al reported data on Interferon  $\gamma$  (IFN  $\gamma$ ) and Lipopolysaccharide-Binding Protein (LBP) [69]. Hematologic outcomes on inflammation were provided by two authors [31,58].

### 7.5 Adverse Effects

While five studies failed to report adverse effects and did not respond to our queries, no project/study listed relevant side effects related to the WB-EMS or B-SES application (Table 2) [55,56,58, 61,85]. In detail, no study reported musculoskeletal adverse effects or injuries or negative effects on inflammatory, cardiovascular and cardiometabolic biomarkers or renal health, be it in cohorts with sarcopenia [12], sarcopenic obesity [47], advanced cancer [77],

frailty [21], acute heart failure [84] or critical care patients [58]. Nevertheless, several studies reported changes in creatine-kinase, myoglobin and other markers of muscle damage [12,21,22,27-29, 47,49,70,72,77], two of them listed significant post-intervention CK increases [72,76]. However, both studies reported changes far below the 5fold increase of resting CK levels considered as the threshold of rhabdomyolysis. While the clinical relevance of minor longitudinal CK changes is scarce, there is considerable evidence for severe rhabdomyolysis after too intense WB-EMS [98], particularly in novice applicants Blöckl et al [96]. 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 [21]. In contrast, Fritzsche et al. reported one case of mild rhabdomyolysis (2770 IE/l CK) after acute WB-EMS in a patient with chronic heart failure, albeit without any clinical sign of rhabdomyolyses [27].

## 8. Discussion

The present evidence map aimed to identify and summarize WB-EMS application in middle aged and older people with respect to the study outcomes addressed. In summary, our results indicate the broad application of WB-EMS in several areas. Apart from physical fitness/function (Fig 2) and body composition (Fig 3) parameters expected to be addressed by a training technology with a comprehensive resistance exercise character health-related outcomes were evaluated by the majority of studies/projects [1, 2]. We doubt that this finding might only be due to the advanced age of the cohort included in this review, since a twin study of this publication that focused on non-athletic adult cohorts addressed by WB-EMS confirmed the high relevance of health-related topics in WB-EMS research [5]. Reviewing this domain, a large variety of diseases and conditions have so far been addressed by longitudinal WB-EMS-trials (Fig 4); nevertheless, many health-related issues still have to be addressed. Considering the nature of WB-EMS i.e. the unique ability to stimulate large muscle areas simultaneously, not all health-related issues were similarly relevant for WB-EMS application and corresponding research, however. This particularly relates to local limitations (e.g. arthropathies, spondylopathies) and health issues in which the less elaborate local EMS might be the better option.

Summarizing general evidence for the different outcomes addressed by WB-EMS is a daunting task. This is particularly the case when it comes to the classification of outcomes in the present evidence map. We intended to strictly classify the outcomes of a trial into primary, secondary or subordinate study outcomes in order to categorize the relevance of the given outcome. However, many studies (a) do not specify a hierarchy of study outcomes, (b) listed a category of outcomes (i.e. "body composition") as the primary study endpoint, (c) defined multiple parameters as primary endpoints or (d) focus on scores (e.g., MetS, Sarcopenic Z-score, SPPB) that combined multiple outcomes. Although we carefully checked articles, registers and online databases, we are aware that our categorization of core/primary vs. secondary/

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subordinate outcomes might be considered as not reliable in some cases. Another problem, albeit of lesser relevance for the present work, is the lack of a core outcome set (COS) that enables a pooled analysis of harmonized outcomes [99]. As an example, considering body composition, diverging outcomes largely based on the similar assessment (e.g. total or subtotal lean body mass (LBM), fat free mass (FFM), soft LBM or FFM, muscle mass, appendicular skeletal muscle mass, skeletal muscle mass index etc.) aggravate a joint analysis. Accordingly, for better comparability of study outcomes and data pooling, a COS with the minimum of the most important study endpoints under consideration of health conditions and population should be defined at least for domains (i.e. physical fitness/function, body composition, safety aspects) frequently addressed in WB-EMS trials [99]. A further problem important for the interpretation of the present evidence map is the aspect that outcome and cohorts do not match in all studies. This concerns, for example, the relevance on blood pressure outcomes in normotensive cohorts.

But taking these limitations into account, we feel that several outcome domains were addressed with sufficient evidence. These are in particular the domains of physical fitness and function entailing the categories “maximum muscle strength”, “power”, “strength endurance”, “aerobic endurance”, “balance”, “mobility/agility”, and (with some restriction) “flexibility” - although more data on specific cohorts (e.g. stroke patients) is welcome. Correspondingly, sufficient evidence of WB-EMS application on outcomes related to body composition is provided so far. In detail however, muscle quality and local or overall fat distribution, for example, should be addressed with more emphasis by applying advanced technology [45,67].

Quality of life (QoL), also included in figure 2, covers a large variety of outcomes differently addressed by the included trials. While sufficient evidence exists for self-reported pain episodes and disability outcomes, at least a few trials addressed other physiological aspects (e.g. [76]). Nevertheless, the mental health aspects of QoL in particular were rarely evaluated. However, due to the very individualized setting of WB-EMS it will be difficult to properly refer corresponding effects to WB-EMS effects per se and not to the close interaction between trainer and trainee.

As stated, health related outcomes were frequently addressed by WB-EMS trials in middle aged to older adults. In summary, we feel that sufficient evidence for the application of WB-EMS was provided for non-insulin dependent diabetes mellitus and the MetS, obesity, cardiovascular disease, renal health, sarcopenia, and in particular unspecific chronic low back pain. Five studies focus on BMD as determined by DXA, thus sufficient evidence for the application of WB-EMS in the area of osteopenia/osteoporosis is evident. In detail however, only one study applied a sufficiently long intervention (>6 months [100]) and focused on a region of interest (e.g. lumbar spine, femoral neck [101]) specified for osteopenia/osteoporosis research [91].

Outcomes closely related to neoplasm/tumor/malignancies were predominately provided by the ongoing “advanced cancer project” in Erlangen, Germany [73,75-79]. Due to the palliative setting most of these studies however focus on physical function, QoL and body composition rather than dedicated biomarkers as primary outcomes. In parallel, endocrine regulation is also a complex cluster of diverging outcomes. So far, WB-EMS-induced changes of anabolic steroids (e.g. 1.25 OHD, Testosterone, DHEAS), growth factors (e.g. IGF-I), adipose tissue peptide hormones (e.g. Adiponectin, Resistin), myokines (e.g. BDNF, Irisin, IL-6) and their corresponding binding proteins (e.g. SHBG, IGFBP-3) have been evaluated by WB-EMS trials. However, none of the studies specifically focus on hormone deficiency conditions (e.g. hypogonadisms, post-menopause); thus the relevance of the results on the endocrine outcomes addressed remains limited. Considering that many studies focus on older patients, we suggest that changes in dedicated hormone profiles at least as explanatory outcomes for muscle and bone health should be addressed with more emphasis. Given the relevance of an exercise training technology able to trigger involuntary muscle contraction of large skeletal areas with dedicated stimulus intensity, the domain of diseases of the nervous system including paresis, paralysis, and spastic is particularly insufficiently addressed by WB-EMS. Although some evidence provided by local neuromuscular electromyostimulation (review in [102]) might be transferable to WB-EMS, more studies should focus on outcomes related to the nervous system.

A highly relevant finding of the present work is the lack of relevant adverse effects, limited albeit by a few articles that failed to report such effects [55,56,58,61,85]. Of note, four of these five studies applied B-SES in vulnerable cohorts (e.g. critical care patients, end stage kidney disease) which might have aggravated the proper assignment of the undesired side effect to the EMS intervention. While still many promising outcomes remain unaddressed by WB-EMS technology, some diseases or conditions considered as absolute WB-EMS contraindications for WB-EMS were frequently addressed by the closely medically supervised trials [103]. This particularly refers to non-insulin-dependent (type II) diabetes mellitus, tumor and cancer, outcome addressed by several studies predominantly in affected cohorts (e.g. [30,31,76, 88]). Considering further the mandatory regulations on WB-EMS operation and trainer education provided by federal authorities in 2019 [104,105], it might be justified to revise the present absolute contraindications in the nearest future and so open WB-EMS application for cohorts in need of appropriate training methods [103]. Of relevance however, WB-EMS for vulnerable cohorts still has to be applied in a closely supervised medically setting (i.e. medical WB-EMS [106]).

Some features of this evidence map might be confusing or hard to grasp for the reader. (1) First, in contrast to other types of literature reviews, evidence maps do not consider the intervention effect on the given outcome. This feature may be uncommon for the reader that potentially expect evidence for the effectiveness of WB-EMS on dedicated outcomes. However, considering

the multitude of different outcomes along with the aspect that a systematic review that aimed to provide interpretable intervention effects have to adequately describe the cohort addressed and the intervention provided, indicate the sheer illegibility of such an approach. Applying a reasonable categorization and simple counting of eligible studies along with basic methodologic quality criteria in contrast enable a quick and comprehensive overview of outcomes addressed by WB-EMS and particularly current research gaps. Nevertheless, insight on the effectiveness of WB-EMS on various outcomes is crucial, however corresponding research should focus on single outcome domains (i.e. body composition) or single outcome categories (i.e. NCLBP). (2) Due to the large number of potentially eligible studies combined with (a) poor or confusing information provided, (b) difficulties in proper translation, (c) missing author response to our queries and (d) the approach of publishing several articles that reported overlapping outcomes of a project, we cannot be sure that we have identified all the eligible articles and properly classified their outcomes. (3) In order to provide a comprehensive overview on outcomes addressed by WB-EMS and related technologies, we included all types of interventional cohort studies, independent of randomization or the presence of a control group. (4) While WB-EMS and B-SES shared many features, some differences should be considered. First, B-SES focuses on hip and lower limb muscles, while WB-EMS addresses all main muscle groups including upper back, chest and upper extremities. Further, the included B-SES studies consistently focus on EMS application in a lying position and passive mode, while WB-EMS studies usually applied EMS in an upright position with adjuvant movements during the impulse phase. Finally, WB-EMS uses bipolar stimulation while B-SES relies on mono-polar impulses. (5) Another limitation already discussed refer to trials that failed to define a reliable hierarchy of outcomes. In summary, this reduces the plausibility of the analysis and contributes to publication bias. However, this limitation might be much more relevant when study effects were addressed. (6) Methodological quality was rated by the PEDro scale specifically dedicated to clinical physiotherapy and exercise studies. However, PEDro might not be perfectly applicable for non-randomized controlled trials, particularly those without control groups.

Nevertheless, it is important to classify the contribution of the single studies for evidence and relevance of the domain. Rating of methodological quality is definitely a component of this process. (7) Finally, we based our criteria of “safety” on adverse effects reported by the studies. Apart from acute increases in CK post-exercise [27] that were comparably noted after heavy resistance exercise [107] and few drop-outs due to “discomfort with WB-EMS” (e.g. [48]) none of the included studies reported clinically relevant adverse effects. This does not necessarily indicate that WB-EMS is a “harmless” exercise technology for all cohorts. Undoubtedly, too intense stimulation intensity has resulted in severe rhabdomyolysis particularly in novice users [96,98]. Thus, it is important to respect guidelines and the rather restrictive contraindications on WB-EMS to ensure safe and effective application [103,108].

## 9. Conclusion

The present work provided evidence for the application of WB-EMS and the closely related B-SES technology to address a wide range of outcomes. While a large variety of musculoskeletal and cardiometabolic outcomes were sufficiently addressed by WB-EMS/B-SES research, particularly outcomes related to the domain of diseases of the nervous system have rarely been evaluated so far. Considering the character of WB-EMS as a highly supervised NMES technique that enables the simultaneous stimulation of large muscle groups with dedicated intensity, WB-EMS might be a promising option for favorably addressing outcomes related to neuronal diseases. The fact that none of the trials reported clinically relevant adverse effects should not obscure the fact that inappropriate (e.g. too intense or/and frequent) WB-EMS application will lead to severe adverse effects. Strict adherence to the guidelines for safe and effective WB-EMS application and corresponding contraindications should therefore be mandatory.

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**Table S1: Search strategies and their results**

Database	Search date	Search terms	Number of hits
Medline (PubMed)	6 <sup>th</sup> March 2023	(WB-EMS[TIAB] OR "whole-body electromyostimulation"[TIAB] OR "whole body electromyostimulation"[TIAB] OR "whole-body electrostimulation"[TIAB] OR "whole body electrostimulation"[TIAB] OR electromyostimulation[TIAB] OR "EMS training"[TIAB] OR "EMS intervention"[TIAB] OR "EMS suit*" [TIAB] OR "EMS belt*" [TIAB] OR "B-SES"[TIAB] OR "belt electrode"[TIAB])	421
CENTRAL	6 <sup>th</sup> March 2023	(WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body electrostimulation" OR electromyostimulation OR "EMS training" OR "EMS intervention" OR "EMS suit*" OR "EMS belt*" OR "B-SES" OR "belt electrode"):ti,ab,kw	248
CINAHL	6 <sup>th</sup> March 2023	1. TI (WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body) electrostimulation" OR electromyostimulation OR "EMS training" OR "EMS intervention" OR "EMS suit*" OR "EMS belt*" OR "B-SES" OR "belt electrode" 2. AB (WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body) electrostimulation" OR electromyostimulation OR "EMS training" OR "EMS intervention" OR "EMS suit*" OR "EMS belt*" OR "B-SES" OR "belt electrode" 3. S1 OR S2	104
SPORTDiscus	6 <sup>th</sup> March 2023	1. TI (WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body) electrostimulation" OR electromyostimulation OR "EMS training" OR "EMS intervention" OR "EMS suit*" OR "EMS belt*" OR "B-SES" OR "belt electrode" 2. AB (WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body) electrostimulation" OR electromyostimulation OR "EMS training" OR "EMS intervention" OR "EMS suit*" OR "EMS belt*" OR "B-SES" OR "belt electrode" 3. S1 OR S2	185
PEDro	6 <sup>th</sup> March 2023	Abstract & Title: "whole-body electromyostimulation" Method: clinical trial	34

Clinicaltrials.gov	6 <sup>th</sup> March 2023	other terms: WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body electrostimulation" OR electromyostimulation OR "EMS suit*" OR "EMS belt*" OR "belt electrode*"	39
ICTRP	6 <sup>th</sup> March 2023	Search: WB-EMS OR "whole-body electromyostimulation" OR "whole body electromyostimulation" OR "whole-body electrostimulation" OR "whole body electrostimulation" OR electromyostimulation OR "EMS suit*" OR "EMS belt*" OR "belt electrode*"	72
Google Scholar	6 <sup>th</sup> March 2023	Advanced search: "whole body electromyostimulation" OR "WB EMS" OR "EMS suit" OR "belt electrode" with at least one of the words, anywhere in the article	1293

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