

# The usefulness of surface electromyography in rehabilitation and physiotherapy: systematic review

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## ABSTRACT

**Introduction:** Technological developments in surface electromyography (sEMG) equipment are providing more and more new opportunities in the application of this technique in different fields, not just in clinical medicine but also in physiotherapy. The purpose of this study is an educational review that provides examples of the clinical use of sEMG in rehabilitation and physiotherapy.

**Materials and methods:** Studies were searched for on the PubMed and ScienceDirect databases using the following descriptors: "sEMG rehabilitation", "sEMG physiotherapy", "surface electromyography physiotherapy", "surface electromyography rehabilitation", resulting in 28,040 citations in total. After reviewing for inclusion criteria – methodological quality assessment using the Physiotherapy Evidence Database (PEDro) scale and

consistency with the theme of systematic review – 28,023 studies were removed from the analysis.

**Results:** The qualified 14 works were divided into 4 categories depending on the sEMG application area: urogenital system dysfunction (322 patients, PEDro scale average rating of 6.33), central nervous system damage (120 patients, PEDro scale average rating of 6.6), lower back pain (181 patients, PEDro scale average rating of 5.33) and musculoskeletal disorders (244 patients, PEDro scale average rating of 6.66).

**Conclusions:** The most recent examples of the use of sEMG in intervention studies in rehabilitation and physiotherapy in the last 5 years concerned neurology, urology, gynaecology, paediatrics, pulmonary medicine and orthopaedics.

**Keywords:** surface electromyography; sEMG; rehabilitation; physiotherapy.

## INTRODUCTION

Electromyography (EMG) is a neurophysiological examination technique consisting of the registration, recording and interpretation of bioelectrical signals generated by motor units within a muscle during voluntary or spontaneous activity [1, 2, 3, 4]. Depending on the type of receiving electrode used, 2 techniques can be distinguished: needle electromyography (nEMG) and surface electromyography (sEMG) [5]. Surface electromyography provides the opportunity to record total myoelectric activity from many motor units, enabling the assessment of the functional status of a muscle region, not just that of a single motor unit. The surface technique uses the phenomenon of bulk electrical conductivity, thus removing the effect of electrode distance from the source of signal on its shape and nature. This allows using skin surface electrodes, thus eliminating the discomfort and invasiveness of examination. Surface electromyography senses and records the electrical potential created when muscular cells are activated by neural or electrical stimulation, and the results provide information on muscular contraction, muscular tone and muscle fatigue, activation and coordination patterns [1, 2, 3, 4, 5].

With many years of research and continuously improved techniques of electromyographic signal recording and analysis, EMG enables more accurate analysis and interpretation of electrical phenomena that occur in the neuromuscular system [6]. At the same time, dynamic technological development is being

observed in sEMG equipment, providing more and more new opportunities in the application of this technique in different fields of medicine, such as rehabilitation. For example, the extraction of time-domain features from the sEMG signals uses Gradient Boosted Regression Tree ensembles to estimate the kinematics of the wrist and fingers, or for new techniques to identify low level hand movement by classifying a single channel sEMG [1, 6, 7, 8, 9, 10, 11].

The increased use of sEMG in rehabilitation and physiotherapy, not just in literature but also in clinical practice, implies the importance of presentations of examples of the use of this technique, especially in physiotherapy, where sEMG is more often used as a tool of assessment and treatment [11, 12, 13, 14, 15].

The purpose of this study is an educational review that provides examples of the clinical use of sEMG in rehabilitation and physiotherapy. The purpose of this paper is to review the most recent examples of the clinical use of sEMG in rehabilitation and physiotherapy in the last 5 years. This paper includes only interventional studies, and contains a brief description of the used therapeutic procedures along with the results and conclusions of the cited studies.

## MATERIALS AND METHODS

The guiding question is as follows: where are the main areas of use of sEMG in rehabilitation and physiotherapy in the last

5 years? The guiding question was defined from the theoretical and practical knowledge of this paper's authors, who postulate that sEMG is being increasingly used in rehabilitation and physiotherapy. The authors began with 4 search descriptors which, in their opinion, were the most appropriate to find relevant studies.

To find literature related to the use of sEMG in rehabilitation and physiotherapy, a systematic literature search was conducted on 10–12 October 2017 on the PubMed and ScienceDirect databases using the following descriptors: "sEMG rehabilitation", "sEMG physiotherapy", "surface electromyography physiotherapy", and "surface electromyography rehabilitation". Using these descriptors, 28,040 papers were found that were subsequently vetted according to the following inclusion and exclusion criteria. Inclusion criteria: articles published in journals with editorial committee in the last 5 years, articles only available in English, only experimental studies, original research and intervention research, studies using sEMG as an assessment or therapeutic tool in rehabilitation and physiotherapy, studies which confirmed the assessment of methodological quality using the Physiotherapy Evidence Database (PEDro) scale.

Exclusion criteria: manuscript was a case report, meta-analysis or systematic review, studies with access only to the abstract without access to the full text of the manuscript, studies in which healthy volunteers participated, or athletes or during sporting activity, studies describing the technical characteristics of sEMG devices or rehabilitation equipment with sEMG (myoelectric prostheses, robots, exoskeletons), research without physiotherapeutic or rehabilitation effects (other medical effects), studies using other types of neurophysiological examinations, such as: electrocardiography, nEMG, and electroneurography.

The search and selection strategy is presented in Figure 1, together with the inclusion and exclusion criteria and number

of studies. The titles and abstracts of articles, according to the first 3 inclusion criteria (experimental studies published in journals with editorial committee, in the last 5 years, available in English) were identified by electronic search. Next, the authors reviewed 391 titles and excluded duplicates. Finally, 232 abstracts were analysed to determine whether they were consistent with the guiding question, and the other inclusion and exclusion criteria. If the abstract did not provide sufficient information to determine eligibility, the whole paper was analysed to determine whether it met the criteria. In order to be included in this systematic literature review, studies had to include information on participants who were subjected to physiotherapy or rehabilitative intervention with sEMG as an assessment or therapeutic tool. In addition, to verify the methodological quality of studies, they had to be confirmed by assessment on the PEDro scale. The numbers of papers included or excluded are detailed in Figure 1.

After identifying potential papers, the titles and abstracts were reviewed by the authors independently to select relevant articles for full-text screening. These papers were divided into categories based on the type of patient dysfunction. The authors discussed discrepancies until a consensus was reached. A number of systematic review guides were referenced to establish data extraction elements [16, 17, 18].

Studies that met the inclusion criteria had assessed the methodological quality using the PEDro scale [19, 20]. According to the PEDro score, each paper was rated as excellent (9–10), good (7–8), fair (5–6), or poor ( $\leq 4$ ). Finally, we decided to select 14 studies for detailed analysis which had rated 5–11 or more on the PEDro scale. The reading and data extraction produced an analytical matrix consisting of the following: authors and year of publication, sample, therapeutic procedures, purpose of sEMG use in the study, and conclusions (Tab. 1).

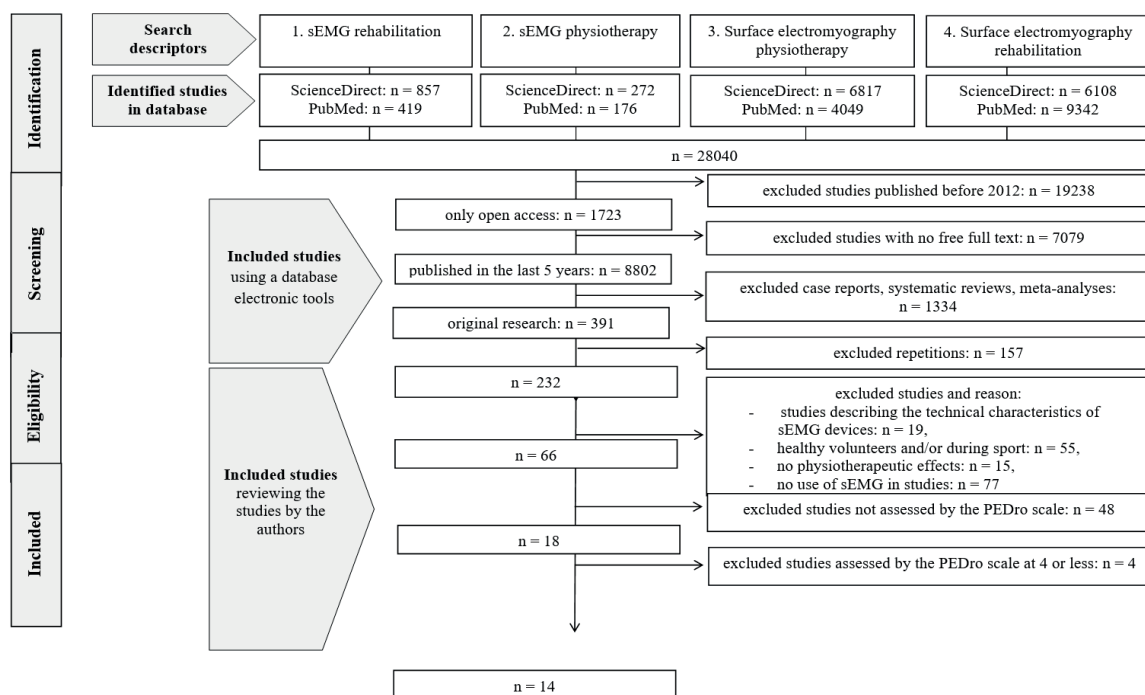


FIGURE 1. Scheme for searching and selecting studies according to inclusion and exclusion criteria

TABLE 1. The usefulness of surface electromyography in rehabilitation and physiotherapy

Author (PEDro scale)	Sample	Therapeutic procedures	sEMG purpose	Results and conclusions
<b>Urogenital system dysfunction</b>				
Hou et al. [21] (5/10)	n = 61 ♂ after TUR-P gr. T: n = 32 (m.g. 69.67 yr.); gr. C: n = 29 (m.g. 71.41 yr.)	5 min PFM exercise 3 times a day by 12 weeks	a sEMG was applied to confirm the correct PFM exercise of the patients	compared with the gr. C, the gr. T showed improvement in their maximal urinary flow rate and lower urinary tract symptoms, and had a better quality of life; PFM exercise is suggested for patients who undergo TUR-P
Dieperink et al. [22] (8/10)	n = 161 ♂ PCa patients treated with radiotherapy and androgen deprivation therapy gr. T: n = 79 (m.g. 68.2 yr.); gr. C: n = 82 (m.g. 69.0 yr.)	the self-training home programme: PFM exercises integrated in daily activities; 3 sessions of 10–12 repetitions for each muscle group; general physical activities for at least 30 min per day	evaluation of effectiveness of multidisciplinary rehabilitation using PFM sEMG after completed radiotherapy in patients with PCa	PFM activity measured during rest and activity by sEMG ↓ in both groups (p = 0.0001), no significant differences between gr. T and gr. C; self-training home program and nursing care not increase strength PFM
Terlikowski et al. [23] (6/10)	n = 93 ♀ with SUI gr. T: n = 64 (m.g. 46.9 yr.); gr. P: n = 29 (m.g. 45.6 yr.)	TVES with sEMG for 8 weeks, 2 a day. TVES parameters: f = 10–40 Hz, Pd = 200–250 μs, 20 min	sEMG used as assisted biofeedback in treatment SUI by TVES	TVES with sEMG is a trustworthy method for treating premenopausal women with SUI; therapy ↑ muscle strength most during the 1st 2 months of treatment and was well preserved at 4 months
<b>Central nervous system damage</b>				
Patten et al. [24] (7/10)	n = 19 PSP gr. A: n = 9 (6 ♂, 3 ♀, m.g. 64.7 yr.); gr. B: n = 10 (9 ♂, 1 ♀, m.g. 72.9 yr.)	intervention: FTP and FTP + power training – HYBRID. Treatment was delivered in 2 4-week blocks of 12 sessions each, interspersed with a 4-week washout period: gr. A: FTP → washout period → HYBRID; gr. B: HYBRID → washout period → FTP	assessment whether inclusion of HYBRID in upper-extremity rehabilitation would produce greater effects on clinical and neuromechanical indicators of functional motor recovery	↑ MVIC, agonist EMG and peak power were significantly ↑ following HYBRID vs. FTP (p < 0.05) and effects were retained 6-months post-intervention (p < 0.05). Reduced: EMG position threshold and burst duration at fast speeds (≥120°/s) (p < 0.05), passive torque post-washout (p < 0.05) following HYBRID. sEMG confirmed functional and neuromechanical ↑ greater following HYBRID than FPT; after HYBRID program, no deleterious consequences found (e.g. increase of spasticity or musculoskeletal complaints)
Ramos-Murguialday et al. [25] (8/10)	n = 32 PSP gr. T: n = 16 (9 ♂, 7 ♀, m.g. 49.3 yr.); gr. C: n = 16 (9 ♂, 5 ♀, m.g. 50.3 yr.) 50.3 ± 12.2	15 days over 4 weeks: gr. T: BMI + 1 h physiotherapy; gr. C: shame-BMI + 1 h physiotherapy	evaluation of efficacy of daily BMI training to increase beneficial effects of physiotherapy	gr. T: ↑ in paretic side activity during upper arm and elbow extension at location deltoid from (p = 0.040), sEMG waveform length ↑ after treatment (p = 0.109); gr. C: not significant change (p = 0.106); overall sEMG results suggest an improvement in the ability to voluntarily engage muscle activity in the paretic hand after brain-machine-interface training
Xu et al. [26] (5/10)	n = 68 (25 ♂, 43 ♀) children with HCP (2–14 yr.) CIMT: n = 22, CIMT + ES: n = 23, TOT: n = 23	2 week hospital intervention (3 h, 5 days); 2 weeks and a 6-month home exercise program (2 h); ES 20 min, 5 a week, for 2 weeks, f = 50 Hz, Pd = 300 μs	comparison change in electrical activity after CIMT, CIMT + ES and traditional occupational therapy in children with HCP	↑ RMS was elevated in all 3 groups CIMT + ES: - a greater rate of ↑ in iEMG of the involved wrist extensors and cocontraction ratio compared to the other 2 groups at 3 and 6 months, - in RMS of the involved wrist extensors than TOT (p < 0.05). Positive correlations found between UEFT and iEMG of the involved wrist as well as grip strength and iEMG of the involved wrist extensors (p < 0.05). The sEMG results suggested that electrical stimulation should be probably an effective potential method to raise the shrunken type II fibers of children with HCP

Author (PEDro scale)	Sample	Therapeutic procedures	sEMG purpose	Results and conclusions
<b>Low back pain</b>				
Lomond et al. [27] (5/10)	n = 38 with LBP gr. STB: n = 18 (9 ♂, 9 ♀); gr. STC: n = 20 (9 ♂, 11 ♀)	10-week special physical therapy programs: - stabilization, - strength + conditioning	to determine whether impaired automatic postural responses could be improved using either STC or STB exercises	improvements and muscle activation patterns were similar for both groups ( $p < 0.05$ ); analysis of sEMG signal shown that the STB does not preferentially improve treatment outcomes or inter-muscle postural coordination patterns for persons with LBP
Jacobs et al. [28] (6/10)	gr. C: n = 27 (9 ♂, 18 ♀) without LBP (28–36 yr.); gr. T: n = 68 with LBP (38–44 yr.); gr. STB: n = 27 (15 ♂, 12 ♀); gr. MSI: n = 41 (26 ♂, 15 ♀)	STB or MSI: 6 weeks, in 1 h sessions, home exercises	to determine whether STB and MSI directed exercises are effective at ameliorating impairments in postural responses to perturbations of standing balance	before treatment, the subjects with LBP exhibited smaller muscle activation amplitudes than the subjects without LBP ( $p < 0.0001$ ); no significant effects of treatment on sEMG responses were evident ( $p > 0.05$ ); STB and MSI-directed treatments do not affect trunk sEMG responses to perturbations of standing balance in people with LBP
Lomond et al. [29] (5/10)	gr. C: n = 15 without LBP; gr. T: n = 33 with LBP; gr. STB: n = 12 (1 ♂, 11 ♀); gr. MSI: n = 21 (3 ♂, 18 ♀)	STB or MSI: 6 weeks, by 1 h sessions + home exercises	evaluation the impact of current motor retraining treatments on LBP-associated changes in movement coordination during tasks that do and do not require APA	during the pre-movement phase, subjects with LBP demonstrated ↓ EMG amplitude than subjects without LBP ( $p < 0.001$ ); during the movement-related phase, subjects with LBP demonstrated ↑ muscles activation than subjects without LBP ( $p < 0.001$ ); movement impairments in persons with LBP are not limited to tasks requiring an APA; stabilization and movement system impairment-based treatments for LBP do not ameliorate and may exacerbate APA impairments
<b>Musculoskeletal disorders</b>				
Park et al. [30] (6/10)	n = 53 ♂ functional scoliosis H-bp: n = 23 (m.g. 20 yr.); C-bp: n = 28 (m.g. 20.6 yr.)	the 50-min exercise programme was identical in both groups: 18 exercises, 3 times/week for 10 weeks	evaluation of static and dynamic back muscles activity through sEMG after therapy	muscle strength (dynamic sEMG) was significantly ↑ compared with baseline ( $p = 0.029$ ): H-bp ( $\mu\text{V}$ ): T0 = 153.6, T1 = 157.3; C-bp ( $\mu\text{V}$ ): T0 = 144.2, T1 = 160.9; no significant effect on static sEMG (back muscle symmetry); no significant differences between groups; a 10-week core strengthening exercise programme improves back muscle strength in patients with functional scoliosis ( $p = 0.029$ )
Halvorsen et al. [31] (5/10)	n = 50 patients with cervical radiculopathy neck-specific gr.: n = 27 (12 ♂, 15 ♀, m.g. 47 yr.); physical activity gr.: n = 23 (11 ♂, 12 ♀ m.g. 49 yr.)	underwent neck-specific training or prescribed physical activity by 14 weeks	evaluation the effects of specific vs. general exercise on neck muscle function including myoelectric manifestations of fatigue, co-activation	no significant change in the median frequency was noted ( $p > 0.05$ ); for the neck-specific training group, splenius capitis was less active during neck flexion at both follow-ups ( $p < 0.01$ ), indicating reduced muscle co-activation; in both groups significant ↑ in neck flexor endurance time compared with baseline ( $p < 0.05$ ); both specific and general exercise increased neck flexor endurance, but neck-specific training only reduced co-activation of antagonist muscles during sustained neck flexion
Sundstrup et al. [32] (8/10)	n = 66 slaughterhouse workers with chronic upper limb pain gr. ST: n = 33 (25 ♂, 8 ♀, m.g. 48 yr.); gr. ET: n = 33 (26 ♂, 7 ♀, m.g. 43 yr.) Ergonomic training	ST: 3 a week, for 10 min by week 10; ET included ergonomic guidance and the training program took place during the 10 weeks	to investigate the effect of specific ST and usual care ET on skeletal muscle fatigue in slaughterhouse workers with upper limb chronic pain and work disability	gr. ST: ↑ MVC strength by 11% ( $p < 0.01$ ), extensor muscle peak EMG and mean EMG ↑ by 24% and 18%, respectively; gr. ET: ↓ MVC muscle strength by 16% ( $p < 0.01$ ); specific strength training improves muscular fatigue resistance and strength

Author (PEDro scale)	Sample	Therapeutic procedures	sEMG purpose	Results and conclusions
de Oliveira Melo et al. [33] (7/10)	n = 45 ♀ (60–75 yr.) with knee osteoarthritis  gr. LLLT: n = 15; gr. NMES: n = 15; gr. LLLT + NMES: n = 15	intervention 2 a week, for 8 weeks: - NMES (18–32 min, f = 80 Hz, Pd = 400 µs, A = 40% of MIVC), - LLLT (D = 4–6 J per point, 6 points)	to determine the effects of NMES and LLLT on muscle electrical activity in elderly subjects with knee osteoarthritis	all gr. showed ↑ sEMG activity after intervention (p = 0.01). ΣRMS (mV): LLLT: T0 = 0.36, T1 = 0.42; NMES: T0 = 0.35, T1 = 0.43; LLLT + NEMS: T0 = 0.40, T1 = 0.50; no between-group differences were observed for the ΣRMS percentage values after intervention (p = 0.14); NMES results in positive effects ↑ quadriceps strength and muscle mass; the combination of NMES and LLLT does not have any additional effects on functioning or neuromuscular parameters
Wada et al. [34] (7/10)	n = 30 patients with COPD  gr. T: n = 15 (8 ♂, 6 ♀, 61 ± 5.4 yr.); gr. C: n = 15 (7 ♂, 7 ♀, 64 ± 5.6 yr.)	gr. T: respiratory muscle stretching; gr. C: upper and lower limb muscle stretching; 24 sessions of aerobic training (2 a week, for 12 weeks)	to evaluate the respiratory muscular activity and ABD mobility during exercise in patients with COPD	total respiratory muscle activity divided by the CW volume (EMG/CW) during exercise, mean: gr. C = 80 10–3 mV/L, gr. T = 45* 10–3 mV/L (p < 0.05); *lower EMG/L reflects less respirator muscle activity per liter of breathed air; respiratory muscle stretching associated with aerobic training ↓ respiratory muscle activity during exercise and improves lung volumes and capacities by increasing the ABD contribution

♀ – female; ♂ – male; ↑ – increase; ↓ – decrease; f – frequency; m.g. – mean age; Pd – pulse duration; T0 – baseline; T1 – immediate; T2 – 48 h after therapy; gr. T – therapy group; gr. P – placebo group; gr. C – control group; H-bp – home-based programme; C-bp – community-based programme; A – amplitude; ABD – abdominal; APA – anticipatory postural adjustment; BMI – brain-machine interface; CIMT – constraint-induced-movement therapy; COPD – chronic obstructive pulmonary disease; ES – electrical stimulation; ET – ergonomic training; FTP – functional task practice; HCP – hemiplegic cerebral palsy; iEMG – integrate electromyography; LBP – low back pain; LLLT – low-level laser therapy; MIVC – maximal isometric voluntary contraction; MSI – movement system impairment; NEMS – neuromuscular electrical stimulation; PCa – prostate cancer; PFM – pelvic floor muscle; PSP – post-stroke patient; RMS – root mean square; sEMG – surface electromyography; ST – strength training; STB – trunk stabilization exercise; STC – strength/conditioning treatment; SUI – stress urinary incontinence; TOT – traditional occupational therapy; TUR-P – transurethral resection of the prostate; TVES – transvaginal electrical stimulation; UEFT – upper extremity functional test

Interpretation, discussion of results and conclusion were performed in a descriptive and integrative manner.

## RESULTS

The database search resulted in 28,040 citations in total, but finally 14 studies were included in the analysis presented in the tables and discussion. Figure 1 details the flow of the review process of the studies.

As a result of selection for this review and comparison, only methodologically valuable papers describing the implementation of sEMG in clinical trials were included. Fourteen studies were divided into 4 categories of the sEMG use in rehabilitation: urogenital system dysfunction, central nervous system damage, low back pain (LBP) and musculoskeletal disorders. A general description of these 14 studies is presented in Table 1, including information about the study design, participant demographics, intervention, dosing parameters, methodological quality, results and conclusion about the usefulness of sEMG.

The urogenital system dysfunction category comprised 3 studies on 322 subjects in total that investigated the effectiveness of different types of rehabilitation for pelvic floor muscle (PFM) strength and lower urinary tract symptoms. Scores on the PEDro scale for the papers in this category ranged 5–8, with an overall average rating of 6.33. Two of the studies were rated good and 1

was rated fair [21, 22, 23] – Table 1. The central nervous system damage category comprised 3 studies on 120 subjects in total that evaluated the effectiveness of various types of rehabilitation in patients with nervous system damage. Scores on the PEDro scale for the papers in this category ranged 5–8, with an overall average rating of 6.6. Two of the studies were rated good and 1 was rated fair [24, 25, 26] – Table 1. The LBP category comprised 3 studies on 181 subjects in total that investigated the impact of different types of rehabilitation on LBP. Scores in the PEDro scale for the papers in this category ranged 5–6, with an overall average rating of 5.33. Each study included in this category was rated fair [27, 28, 29] – Table 1. The musculoskeletal disorders category comprised 5 studies on 244 subjects in total that investigated the impact of different types of rehabilitation on muscle activity in patients with musculoskeletal dysfunction. Scores on the PEDro scale for the papers in this category ranged 5–8, with an overall average rating of 6.66. Three studies included in this category were rated good and 2 were rated fair [30, 31, 32, 33, 34] – Table 1. Comparison between these studies was difficult as they included patients with various musculoskeletal disorders and different types of therapy. Nevertheless, their common feature is the use of sEMG to evaluate the effects of the applied therapy.

More details about the analysed studies, reference to treatment groups, therapeutic procedures and findings, are presented in Table 1.

## DISCUSSION

As regards the main objectives of the papers in question, there was a high number of studies that used sEMG in different types of rehabilitation and physiotherapeutic procedures. An analysis of all identified sources in this systematic review was not possible, which is a limitation of this paper. For this reason our literature review did not include all possible sEMG applications in such a vast field like rehabilitation, rather focusing on the papers showing the physiotherapeutic effects in different disorders of the musculoskeletal system. This literature review does not include studies on robotic exoskeletons or prostheses for rehabilitation with EMG-based control [9, 35, 36], or the assessment of muscle activity in healthy volunteers or athletes [37, 38].

In this review we applied specific refined criteria which aimed at separating out methodologically valuable and thematically consistent papers, while trying at the same time to answer as widely as possible the research question raised by us. Comparisons between the selected studies are difficult due to differences in the muscle groups investigated, the tasks performed, the sample size and characteristics, the different therapies and different outcome variables being used.

One area showing the versatility of sEMG in rehabilitation and physiotherapy is urogenital system dysfunction associated with urinary incontinence, which affects both women and men [10, 21, 22, 23, 24, 25, 39]. Surface EMG can evaluate stress urinary incontinence treatment outcomes by recording the change in voltage over the muscle fibre membrane that initiates the contraction. The studies analysed in our review shows that it is a reliable technique supporting the treatment of patients with urogenital system disorders. As a biofeedback tool, sEMG makes it easier for a physiotherapist to train isolated PFM contraction, facilitate goal setting, and help keep the patient highly motivated. With the aid of sEMG, a physiotherapist is able to confirm that patients are performing the PFM exercises correctly [22, 23]. An equally important application of sEMG is to verify the effectiveness of rehabilitation [21, 22]. The sEMG technique can validate exercise programmes and provide feedback for their correction. A lack of control over the exercise cannot then be a reason why an at-home self-training programme does not bring the expected results [20].

Another very important area in the use of sEMG in rehabilitation is central nervous system damage. It is worth noting that this technique can be used without restriction in older patients (for example after a stroke) and in very young children (for example with cerebral palsy), which is demonstrated in the studies reviewed (Tab. 1).

The most effective therapies are still being sought for those patients with central nervous system damage [24, 25, 26, 40], with the following listed among the most effective: classic exercise physiotherapy, power training, assistive robotic devices, electrical stimulation (ES) and functional electrical stimulation, robotic exoskeleton or prosthesis with EMG-based control for rehabilitation, non-invasive electroencephalography-based

brain-computer interfaces, and functional near-infrared spectroscopy or orthosis-brain-machine interface training [21, 25, 26, 35, 36, 40, 41, 42]. All the above listed physical disabilities affect motor function performance. Surface EMG is considered a reliable technique in the evaluation of motor unit activity [25, 26, 40, 42]. An abnormal pattern of sEMG signals is a quantitative evaluation of motor function [3, 4]. According to literature, sEMG metrics are both objective and convenient, and can provide more neuromuscular control information about motor dysfunction. For this reason, which was confirmed in this literature review, sEMG is a useful technique to evaluate therapies in post-stroke patients and in hemiplegic cerebral palsy children [24, 25, 26, 39, 41].

Low back pain persists as a significant socioeconomic and public health problem, and the leading disabling musculoskeletal disorder globally. At the same time it is 1 of the main reasons for patients reporting to a physiotherapist [28, 43, 44]. People with chronic LBP exhibit many impairments, for example, of postural control across several contexts of motor behaviour [28], altered neural control of movement, aberrant movements, or aberrant anticipatory postural adjustment [29]. Each such dysfunction can be objectively measured using sEMG. The ability of electromyography-based techniques, such as sEMG, in studying altered trunk neuromuscular behaviour in LBP patients is well documented [43, 45]. The studies in EMG have led, among other things, to a new theory of secondary pain-related trunk neuromuscular adaptation, over the original belief of primary neuromuscular impairment in LBP patients [45]. In addition, unhindered access to and the non-invasive nature of sEMG analysis contribute to the fact that sEMG begins to be increasingly used in the clinical scope to assess patients with LBP. Median frequency (MDF) and root mean square (RMS) are the main parameters used to describe muscle fatigue process and amplitude of muscular activity [46, 47].

According to the current recommendation, clinicians should refer their patients to rehabilitation as early physical therapy is inversely associated with a subsequent decreased use of medical services [44, 48]. In the studies analysed in this review, various forms of exercise therapy were applied, and sEMG was used to document and evaluate the effects of the exercises in patients with LBP [27, 28, 29].

Surface EMG is also useful in the verification of therapeutic effects in relation to musculoskeletal disorders associated with such diseases as: functional scoliosis, cervical radiculopathy, chronic upper limb pain, knee osteoarthritis (OA), and even chronic obstructive pulmonary disease (COPD) [30, 31, 32, 33, 34] – Table 1.

In addition, sEMG can be used to facilitate exercise control and strengthen motivation to exercise [30]. Surface EMG can also be useful in evaluation of the activity of respiratory muscles, for example, in patients with COPD. To assess the load on the respiratory muscles, the EMG/L ratio (expressed in mV/L) is applied. A reduction in inspiratory muscle sEMG amplitude per L of air breathed demonstrates the increased efficiency of respiratory muscles [35].

The assessment of myoelectric fatigue during an endurance test can provide valuable information about the effectiveness of the applied therapy, for example, in patients with cervical radiculopathy [31, 49]. The sEMG parameters most frequently observed during fatigue assessment are: spectral variables such as mean frequency or MDF, and amplitude variables such as average rectified value or RMS [3, 4, 31, 49]. During sustained contractions, a typical pattern of sEMG signal characteristics is present, i.e. a decrease in spectral variables over time and an initial increase in signal amplitude prior to the onset of muscle fatigue [3, 4, 49].

The results of our literature review show that the effectiveness of physical stimuli can be assessed by EMG [13, 33], for example low-level laser therapy and neuromuscular ES on muscle activation with knee OA [33], showing increased muscular activation and increased sEMG signal amplitude (maximum voluntary contraction) after low level laser therapy (LLLT) and neuromuscular electrical stimulation (NEMS). The positive results of LLLT are mostly due to the analgesic, anti-inflammatory and regenerative effects [33], while NMES induces structural and functional changes in the neuromuscular system [33, 50].

## CONCLUSIONS

The most recent examples of the use of sEMG in intervention studies of rehabilitation and physiotherapy in the last 5 years have concerned: neurology, urology, gynaecology, paediatrics, pulmonary medicine and orthopaedics. In physiotherapy and rehabilitation, sEMG can be an important complement to clinical examination, raising the objectivity. The main applications of EMG include objective assessment of the effects of both physical stimuli and therapeutic exercises used. In addition, it is also used to verify the correctness of exercises and can be an important biofeedback tool that raises the attractiveness of applied procedures and strengthens the motivation of patients. Surface EMG has turned out to be an extremely useful tool for assessing the activity of the neuromuscular system after physiotherapeutic and rehabilitation exposure in all these areas, as demonstrated by this literature review across 867 patients.

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