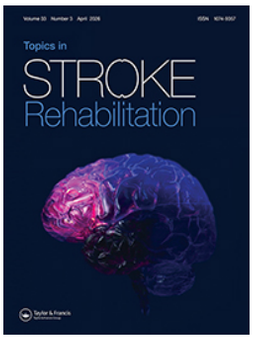

Topics in Stroke Rehabilitation

ISSN: 1074-9357 (Print) 1945-5119 (Online) Journal homepage: www.tandfonline.com/journals/ytsr20

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To cite this article: Lorie Gage Richards, Amit Sethi, Maria Paluselli & Steven C. Cramer (2026) Use of myoelectric orthosis after stroke or traumatic brain injury: a systematic review, Topics in Stroke Rehabilitation, 33:3, 324-337, DOI: 10.1080/10749357.2025.2553591

To link to this article: https://doi.org/10.1080/10749357.2025.2553591

TOPICS IN STROKE REHABILITATION
2026, VOL. 33, NO. 3, 324–337
https://doi.org/10.1080/10749357.2025.2553591

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REVIEW ARTICLE

Use of myoelectric orthosis after stroke or traumatic brain injury: a systematic review

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ABSTRACT

Background: Upper extremity (UE) paralysis and weakness due to stroke or traumatic brain injury (TBI) can limit independent functioning. Myoelectrically controlled orthoses can be used for compensatory support for activities of daily living (ADL), and for restorative rehabilitation to reduce disability.

Objective: We investigate the use of UE myoelectric orthoses (UE-MEO) for compensatory and/or restorative use after stroke or TBI.

Methods: We conducted a systematic review (PROSPERO CRD42024577225) from 15 databases including MEDLINE®, Embase®, and APA PsycInfo®. Peer-reviewed reports from 2014 onwards with patient use of UE-MEO after stroke or TBI were included.

Results: Ten studies (11 reports) met the criteria; all included individuals post-stroke and one included a post-TBI subset. The majority were Oxford level of evidence 3b and rated as low risk of bias. All compensatory use studies showed participants could complete more activities or more parts of activities while wearing the UE-MEO. Studies in which the UE-MEO was studied as a restorative therapy took place in outpatient clinics and in the home setting, with mixed results across studies.

Conclusion: The results suggest that use of a UE-MEO is a viable option as a compensatory tool to improve UE function in individuals with partial paralysis or weakness due to stroke or TBI. Additional evidence is needed to test the utility of a UE-MEO for restorative use and to identify the patient population most likely to derive benefits.

ARTICLE HISTORY
Received 5 June 2025
Accepted 23 August 2025

KEYWORDS
Myoelectric orthosis; stroke; traumatic brain injury; upper extremity; assistive device; motor rehabilitation

Introduction

Stroke and traumatic brain injuries (TBI) are the leading causes of acquired disability in adults in the United States (US).[1] Upper extremity (UE) paresis after neural injury can have a devastating impact on independent functioning in basic and instrumental activities of daily living (ADL/IADL). UE impairment is common after acquired brain injury, with stroke impacting UE function in up to 88% of individuals.[2,3]

Physical therapy (PT) and occupational therapy (OT) interventions are the primary treatments prescribed to regain UE function after neural injury, including functional task practice focused on relearning motor skills. Repetitive task-specific practice (RTP), a common UE rehabilitation component, involves practice of task-specific motor activities often in combination with or as part of other therapies, such as constraint-induced motor therapy, in which the non- paretic UE is constrained to restore paretic UE function and strength.[4] Some technology-based therapies used to improve UE function include robotic devices to deliver a high number of repetitions of in-clinic task practice, neuromuscular electrical stimulation, and virtual reality and video games that may increase participant engagement.[4]

However, even with current approaches, and despite intensive effort, many patients do not fully recover. Moreover, there is seldom sufficient training amounts to maximize recovery.[5,6] Approximately 50% of patients with stroke and 17% of patients with TBI are left with UE impairments that directly impact ADLs/IADLs.[7,8] Inability to perform ADLs/IADLs can create an

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/10749357.2025.2553591

unsafe environment, decrease quality of life, and may require home care assistance or placement in assisted living or long-term care, the costs of which can place burden on families and the healthcare system.

Post-acute rehabilitation, the dose of which has seen sharp reductions over the past 20 years,[9] risks being further restricted due to cost containment measures, despite it being a critical factor in reducing the risk of serious morbidities caused by various problems, such as immobility, and loss of functional independence.[4] Additional tools to help patients compensate for UE limitations, as well as therapeutic options that target UE function and allow for more UE practice than can be delivered through traditional rehabilitation are needed.

Responding to this unmet need, the Centers for Medicare & Medicaid Services (CMS) recently approved reimbursement for exoskeleton devices/orthoses in the brace benefit category to provide support for an impacted body part. The CMS rule defined custom fabricated powered exoskeletons/orthotic as devices that provide stabilization and support for an impacted body part to assist movement.[10] This category includes myoelectric orthoses, which are controlled by electromyographic (EMG) signals derived from residual muscle activity in paretic muscles.

The 1940's myoelectric control has been developed,[11,12] especially for veterans. This same technology has expanded to support patients with UE weakness or partial paralysis due to neural and muscular damage.

As an orthosis, myoelectrically controlled devices are used as a compensatory tool that supports a weak limb and restores aspects of its function (behavioral gains only while using the device), but they can also be used as part of a restorative therapy regimen that aims to promote motor skill relearning through motor practice (behavioral gains persist once device is removed). The orthosis uses a series of myoelectric sensors connected to controllers and motors that can help patients complete tasks by allowing anatomical joints to change positions that might not otherwise be possible. Surface EMG sensors detect residual myoelectric activity signals in the paretic arm muscle, and the signal is amplified to power a motor in the orthosis to complete the desired movement once the subject initiates a muscle contraction, rather than using electrical stimulation to activate the muscles. For example, sensors over the biceps and triceps muscles can be used to drive a motor to assist with elbow flexion and extension, respectively, proportional to muscle output; and sensors over the forearm flexor and extensor groups can be used to drive a motor that opens and closes the fingers in a three jaw-chuck grip pattern upon user initiation. The EMG threshold for triggering orthotic movement can be personalized.

To date, there has not been a systematic review of the evidence regarding the utility of a UE myoelectric orthosis (UE-MEO) as a compensatory device or as a restorative tool for motor rehabilitation for individuals with post-stroke or TBI UE impairment. The current review was performed to generate an overview of research over the past 10 years regarding UE-MEO use in patients with UE partial paralysis or weakness due to stroke or TBI. Key goals were to investigate 1) UE-MEO use as a compensatory device, i.e. the effect of UE-MEO use on the ability to complete functional tasks in individuals with UE paresis; and 2) UE-MEO use as a restorative therapy device, i.e. the effect of using a UE-MEO in a motor training program targeting UE paresis on UE motor performance.

Methodology

This systematic review was registered with the National Institute for Health and Care Research (NIHR) International prospective register of systematic reviews (PROSPERO CRD42024577225) and was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting guidelines.[13] We conducted a literature search to identify studies investigating the efficacy or effectiveness of UE-MEO use as a compensatory tool to enable ADL/IADL performance or as a restorative tool as part of a motor rehabilitation program targeting UE motor status. The search was conducted in September 2024 by a library services professional using the Dialog Platform to access 15 databases including MEDLINE®, Embase®, APA PsycInfo®, Ei Compendex®, and SciSearch®. A search query using the terms "myoelectric orthosis," "myomo," and

"myopro" was used. The query was designed to cover the broad category of "myoelectric orthosis," also including the names of the approved UE- MEO to ensure complete results. Search strategy details can be found in Appendix. We also search for additional references in reference lists from relevant search results. The search was rerun on 25 February 2025, prior to the final analysis. Any qualifying articles were included.

Two reviewers (MP and GA) independently screened titles and abstracts to identify records meeting inclusion/exclusion criteria. Full texts of potentially relevant articles were retrieved, read, and assessed against eligibility criteria. Articles were included if they 1) examined use of a UE-MEO in adults to perform activities compared to performance without a device, or UE motor status without the device before and after UE motor practice/training with a UE-MEO; 2) were published in a peer-reviewed source; 3) were published 2014 or later due to the evolution in orthosis technology; and 4) were published in English, French, or Spanish. Articles were excluded if they 1) did not include a UE-MEO; 2) examined a lower extremity myoelectric orthosis; 3) were a conference abstract/report/book chapter containing data covered by a separate journal article publication. Where more than one report from the same study existed, these reports were linked and regarded as a single study. Any disagreements between reviewers were resolved by consensus. Two reviewers (MP, LR) used the Oxford 2011 Levels of Evidence to assess each publication,[14] and articles at levels 1–3 were included.

We used critical appraisal tools from the Joanna Briggs Institute (JBI) to assess the risk of bias in randomized controlled trials and quasi-experimental studies.[15,16] Two reviewers (AS and LR) independently assessed the risk of bias, meeting to resolve any discrepancies by double-checking against the article and discussing issues to reach a consensus. Biases assessed were related to selection and allocation; intervention/exposure administration; outcomes assessment, detection, and measurement; participant retention; statistical conclusion validity; and trial design appropriateness and any deviations from the standard trial design described in the conduct and analysis of the trial for each outcome. These assessments were used in narrative synthesis relating to each research question. We calculated the proportion of criteria met on the appraisal tools, assigning one point to each criterion answered "yes." The total score was divided by the number of applicable criteria. Overall scores were rated as having a low risk of bias for scores of at least 70%, a moderate risk for scores 50 to 69%, and a high risk of bias for scores below 50%.[17]

The following data were extracted from included studies by a statistician (JB) and a reviewer (MP): study design, population type, UE-MEO use category (restorative or compensatory, done by LR), device use, sample size, age, time after nervous system injury; intervention protocols (frequency, duration, and setting) for restorative use; and all reported outcomes, mean differences, and standard deviations (SDs) at baseline as well as at intervention end. Score values were extracted directly from tables and text, and data was recorded in evidence tables in Microsoft Excel. We calculated SDs when only confidence intervals were provided.

If the studies were heterogenous in methodology and/or outcome measures, we planned a descriptive data synthesis for each question. If at least three studies used the same outcome measure, they were quantitatively assessed by calculating the standardized difference for assessments that reported change and SD from baseline until either end of in-clinic therapy, home use, or at follow-up. The standardized difference is useful for comparing changes from baseline across different outcome measures.[18] To index the mean change from baseline, it is divided by the SD of the measure; Standardized Difference = (Mean post-Mean pre)/SD, where SD is the SD of the differences from baseline. When an assessment's scoring method indicated reduction from baseline value designated improvement, absolute value of the standardized difference was used. We then calculated the median and IQR of the standardized difference assessments. We planned to conduct separate analyses on the following variables to see if there was heterogeneity within them and at least two levels of a variable were investigated in at least three studies: diagnosis (stroke or TBI), time since injury/stroke, and initial motor severity.

Results

The database searches returned 239 results, with 224 remaining after duplicates were removed. Manual titles and abstracts screening excluded 202 records not meeting criteria, leaving 22 reports for full review. Of these, 11 reports (10 studies) met the criteria for inclusion. See Figure 1 of the PRISMA diagram for a summary of study selection and reasons for exclusion.

The characteristics of the included reports are outlined in Table 1. All reports included patients after stroke (11 reports, 10 studies). One study also included a subset of patients after TBI.[25] Results are shown for the overall population and for the stroke only cohort. No distinct levels were identified for time since injury or initial motor severity, therefore separate analyses for these variables were not conducted. As the studies varied widely in methodology, intervention, and outcomes, a meta-analysis was not appropriate, and instead a descriptive synthesis was undertaken.

Five studies assessed the immediate utility of the UE-MEO as a compensatory tool to complete ADLs (76 participants); five reports from four studies assessed it as a restorative therapy (69 participants); and one study investigated the device for both compensatory and restorative use (5 participants), with UE-MEO used during in-clinic outpatient therapy sessions as well as at home.

Level of evidence ranged from 2b to 3b. Most of the studies had low risk of bias for their designs (Supplemental Table 1). The majority were non-randomized experimental studies, with one

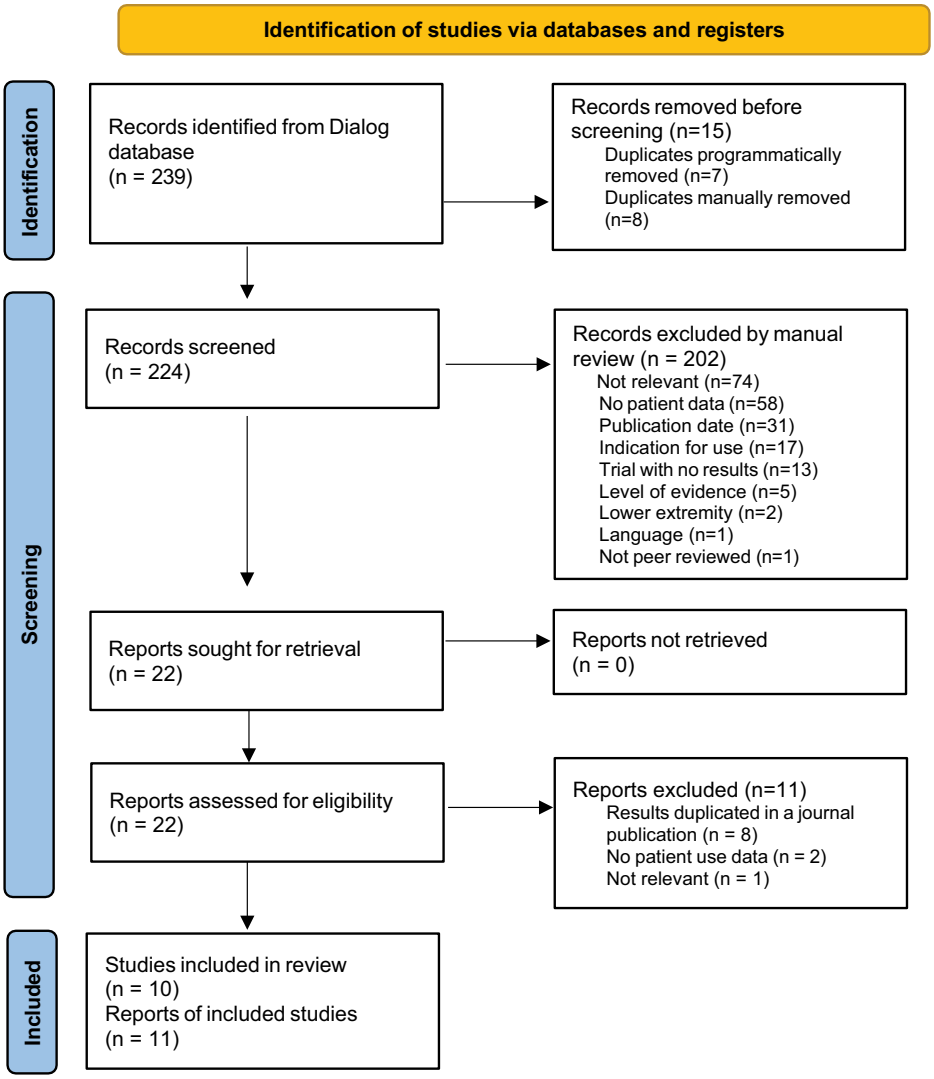

Figure 1. Article selection process: PRISMA flow diagram.

Table 1. Characteristics of included reports and patient demographics.

First Author and year	Study Design	N	Disease	Device used	Patient Age (y)	Time since injury (m)	Injury on dominant side n (%)	Setting(s)	Details of device use
Compensatory Device Use									
Chang 2024[25]	Retrospective pre/ prospective post observational	19	Stroke	MyoPro 2 and MyoPro 2+	Median 68.0, IQR [67–71]	Median 45.6, IQR [33.6-87.6]	8 (42%)	NA; data collected via videoconference	No study–specified therapy. Mean 11.7 (3.4) months between receipt of device and post assessment
Chang 2023[19]	Non- randomized experimental	18	Stroke	MyoPro 2 and MyoPro 2+	52.5 (14.7)	55.2 (30)	12 (67%)	NA; data collected via videoconference	No study–specified therapy. Tasks completed with and without UE- MEO at 2 weeks, 1 month, 2 months and 3 months
Khantan 2023[20]	Pre/post Non-randomized experimental	5	Stroke	NuroSleeve	NR	NR	NR	Outpatient OT clinic	Sessions 60 min 3x/week for 8 weeks to train and ensure fit of device, with RTP. After 8 weeks, assessments were repeated with and without the device. Device also could be used at home to assist with ADLs.
Hoppe-Ludwig 2021[24]	Non- randomized experimental	18	Stroke	MyoPro classic, Myomo motion W, Myomo motion G, adjustable MyoPro	55.5	57.6	NR	Rehabilitation clinics	Single visit, completing assessments with device and without device
Peters 2017[21]	Non- randomized experimental	18	Stroke	MyoPro Motion G	56 (11.8)	NR	NR	Outpatient clinic	Single visit, completing assessments with device and without device
Bermúdez i Badia 2014[22]	Pilot feasibility	3	Stroke	Myomo mPower 1000	56.7	NR	1 (33%)	Laboratory	Single visit, hybrid VR and UE- MEO
Restorative Device Use									
Khantan 2023[20]	Non- randomized experimental	5	Stroke	NuroSleeve	NR	NR	NR	Outpatient OT clinic	Sessions 60 min 3x/week for 8 weeks to train and ensure fit of device, with RTP. After 8 weeks, assessments were repeated with and without the device. Device also could be used at home to assist with ADLs.
Pundik 2022[23]	Prospective single-arm mixed cohort interventional pilot	13	TBI (6) Stroke (7)	MyoPro Motion G	**Overall** 50.6 (19.9) **Stroke** 65.4 (11.4) **TBI** 33.3 (11.5)	**Overall** 99.3 (116.8) **Stroke** 44.1 (37.8) **TBI** 163.7 (147.7)	**Overall** 3 (23%) **Stroke** 2 (29%) **TBI** 1 (17%)	In-clinic phase followed by Home phase	In-clinic phase: MLB 90 min using device 50% of session 2x/week for 9 weeks, with concurrent individualized home training. Home phase: 9 weeks continuing the individualized home training program. Device could also be worn to complete ADLs.
Nam 2021[26]	Non- randomized experimental	11	Stroke	Elbow- wrist-hand exoneurom usculoskeleton -WH- ENMS	57.6 (13.2)	160.8 (124.8)	NR	Rehabilitation clinic training then Home phase	Device-training tutorial, then 20 sessions. First 3 sessions at rehab lab, then at home at least 60 min/session, 3-5x/week for 7 consecutive weeks. No device use outside of prescribed sessions

(*Continued*)

Table 1. (Continued).

First Author and year	Study Design	N	Disease	Device used	Patient Age (y)	Time since injury (m)	Injury on dominant side n (%)	Setting(s)	Details of device use
Page 2020[27]	RCT	34	Stroke	Myomo e100	**UE-MEO only** 55.79 (9.25) **UE-MEO+RTP** 52.89 (11.38) **RTP only** 57.22 (7.68)	NR	**UE-MEO only** 5 (36%) **UE- MEO +RTP** 2 (25%) **RTP only** 2 (22%)	Rehabilitation clinic	Outpatient therapy: 60 min 3x/week for 8 weeks. Randomized to either (1) UE-MEO 50% of RTP session (UE-MEO+RTP) (*n*=8); (2) RTP only (*n*=9); or (3) UE-MEO 100% of RTPsession (UE-MEO only) (*n*=14)
Willigenburg 2017[28]	Substudy of Page 2020 to assess kinematics	12	Stroke	Myomo e100	53.5 (5.35)	61.7	NR	Outpatient clinic	Groups represented in substudy: (1) UE-MEO 50% of RTP session (UE-MEO+RTP) (*n*=7); (2) RTP only (*n*=5)
Kim 2015[29]	Non- randomized experimental	11	Stroke	Myomo mPower 1000	51.7 (8.5)	91.2 (116.4)	NR	In-clinic phase followed by Home phase	Outpatient therapy: 30–45 min 2-3x/week unti able to demonstrate competence with UE-MEO Home phase: 6 weeks

[#]Study investigated both compensatory use (behavioral gains only while using the device) and restorative use (behavioral gains persist once device is removed) All results are mean (SD) unless otherwise stated.
Therapy duration and frequency refers to therapy with UE-MEO unless otherwise stated.
IQR, interquartile range; m, months; min, minutes; MLB, motor-learning based therapy; NR, not reported; RTP, repetitive task practice; TBI, traumatic brain injury; UE, upper extremity; UE-MEO, upper extremity myoeletric orthosis; VR, virtual reality; y, years.

randomized controlled trial comparing the use of a UE-MEO during 100%, 50%, or 0% of in-clinic RTP therapy.

Devices used

The orthosis used in the studies varied. The majority being developed by Myomo Inc. (Cambridge, MA) and commercially available in the US (Supplemental Table S2) with two using the Myomo e1000[27,28]; two using the mPower 1000[22,29], one using the MyoPro Motion W, MyoPro Motion G, adjustable MyoPro, and Myomo Classic,[24] two studies used the MyoPro Motion G, [21,24]and two used a combination of the MyoPro 2 and MyoPro 2+[19,25] (see supplementary table 2). In addition, one study used the Neurosleeve,[24] and one study used WH-ENMS.[26]

One study included use of the mPower 1000 myoelectric orthosis (Myomo, Inc, Cambridge, MA) along with ARToolKit (ARToolworks Inc, Seattle, WA) augmented reality software toolkit that enables tracking the position (x, y, z) and orientation in space of predefined unique markers by using a webcam as an input device.[22] These devices were used with a virtual environment and training task based on the Neurorehabilitation Training Toolkit.[31] It is important to note that WH-ENMS[26] includes functional electrical stimulation (FES).

A range of outcome measures were used to assess the impact of the UE-MEO. These included measures of impairment (body/structure function limitations), measures of activity (ability to complete tasks/activities), and satisfaction ratings.

UE-MEO as compensatory tool for functional support

Six non-randomized experimental studies investigated UE-MEO as a compensatory tool to support ADL/IADL completion by comparing task performance with and without the device.[19–25] One of the studies was conducted in a laboratory setting to assess the feasibility of UE-MEO combined with virtual reality training.[22]

There was no single standardized assessment that was used in at least three studies investigating compensatory use. However, across these assessments, improvements in motor control, motor function, gross manual dexterity, flexibility, and the ability to complete tasks mimicking ADLs were noted with a UE-MEO use (Supplemental Table 3).

All compensatory studies showed a performance improvement with, compared to without, a UE-MEO. Peters et al. showed a significant increase in FMA-UE of 8.72 points with a UE-MEO ($p < .0001$),[21] which exceeded the established minimal clinically important difference (MCID) without use of a device estimated as 5.25 (lacking an MCID for the FMA-UE with a device).[33] The in-clinic ADL/IADL simulation assessments showed that UE-MEO uses improved ability to complete feeding and drinking tasks and grasping, holding, and moving objects. An overall summary of results is shown in Supplemental Table 3, and detailed results can be found in Supplemental Table 4.

UE-MEO as a restorative rehabilitation tool

Five studies (six reports) investigated a UE-MEO use in restorative rehabilitation training, with mixed results. Two studies focused on in-clinic rehabilitation,[27,28] one studied in-clinic rehabilitation followed by home use,[20] and two investigated home uses without in-clinic rehabilitation.[26,29] Amount of motor practice with the device varied across the studies from approximately 13–50 hours. All of the studies, except Page, et al.[27] had some kind of home program, with all training occurring at home in the Nam, et al.,[26] study. In two of the studies, the device used did not have a hand component.[27,29] There was a wide range of baseline severity across and within most trials, ranging from severe to moderate impairment. One device included an FES component.[26] An overall summary of the results is shown in Supplemental Table 5, and detailed results for all assessments are presented in Supplemental Table 6.

The FMA-UE and MAS were each used in at least three studies, and therefore standardized differences were calculated (Supplemental Table 7). The FMA-UE median (IQR) standardized difference was 1.8 (0.9) for the overall cohort and 1.5 (0.4) for the stroke only cohort. The median (IQR) standardized differences for the overall and stroke-only cohorts were 0.9 (0.8) for MAS.

Four studies included the FMA-UE subscale to assess motor impairment before and after UE-MEO use for motor rehabilitation. These found mixed results (Supplemental Table 8). The FMA-UE changes from baseline for the study groups using a UE-MEO ranged from 2.37 to 11.2 points. In the only study to include participants with TBI, there were slightly higher gains on the FMA-UE, 8.7 (4.0) points from baseline after the in-clinic phase and 8.3 points from baseline after the at-home phase.[23] In general, higher FMA-UE changes were associated with higher baseline scores. In all three studies including within-group statistical testing, the FMA-UE change was significant. However, in only two studies was this improvement larger than the MCID.[23,26,33] Here, we use the established MCID without the use of a device, lacking an MCID for the FMA-UE with a device. Pundik et al. included a period of home use after an in-clinic phase, and Kim et al. included a follow-up period after a home-use phase. The FMA-UE increases were maintained throughout these phases.[23,29] The Nam et al. study, primarily conducted in the home setting, showed a significant, clinically meaningful increase of 11.2 points.[26] It is important to note that the studies finding the highest FMA-UE gains were single group trials and had participants with the highest levels of baseline motor control. [26,29] Only one of the included trials was a randomized controlled trial which compared dose-matched in-clinic therapy including a UE-MEO for all, half, or none of the therapy session, and found the smallest gains, with no difference found between groups in FMA-UE ($p = 0.83$) or AMAT ($p = 0.61$).[27] There was not a clear pattern of results differentiating those studies which had or did not have a hand component or those which did or did not have a home program. Higher gains were observed in studies in which, on average, participants performed more hours of therapy,[23,26] although there was high variability in home practice across studies and sample sizes were small.[25,27] The study with the largest gains utilized the device with the FES component.[20,27,28,29]

Three studies assessed muscle tone with MAS after restorative use of a UE-MEO for motor rehabilitation. Significant improvements were shown in two studies[25,26] (Supplemental Table 9). These studies had participants with the mildest voluntary motor impairment of our studies. It was impossible to determine if differences existed in baseline spasticity severity between studies finding spasticity reductions and the one that did not, as this study failed to provide baseline MAS scores.[29] However, this study did have the fewest practice hours of the three studies and uniquely used a device without a hand component.

Discussion

The purpose of this review was to systematically review the research on the effectiveness of using a UE-MEO for improving UE function. We reviewed two usage possibilities. The first use of a UE-MEO device was as a compensatory tool for improving ADL/IADL completion without necessarily improving motor control. In this scenario, testing is done with and without the device. The second use of these devices was as a restorative tool to enable performance of UE task practice, with the aim to improve the person's own motor status. In this scenario, testing occurred before training, without the device, and then again without the device after completion of a training program.

Only 11 reports (10 studies) met our eligibility criteria, with five studies assessing a UE- MEO as a compensatory tool, four studies assessing using a UE-MEO as a restorative rehabilitation training device, and one study assessing both uses. All studies using the UE-MEO as an assistive device demonstrated that participants could complete more activities or more parts of activities while wearing the device than without the device. In contrast, there was mixed results related to whether using a UE-MEO during task practice improves motor skill gains over and above such practice by itself.

Evidence for using a UE-MEO as a compensatory tool for performing daily activities

Evidence suggests that utilizing a UE-MEO as a compensatory tool can help individuals complete functional tasks and ADLs. When neural injury after stroke or TBI is too extensive, the brain's neuroplastic ability may not be sufficient

for individuals to recover functional motor control. Therefore, disability needs to be reduced through compensatory strategy uses, such as environmental design and assistive technology. A UE-MEO can produce an approximate version of the intended action based on the person's own muscle activity. While no device yet supports the full range of independent finger movements used across daily activities, some UE-MEOs can assist with UE elevation and grasping/rough pinching that can allow activity performance that was not possible without the device. All included studies found that with a UE-MEO, participants were able to complete parts of activities or whole activities that they were unable to complete without the device. However, studies using UE-MEO for functional support were only at a moderate level of evidence, being single group trials, although the risk of bias was low for these study designs. Thus, the results of this review suggest that the use of a UE-MEO is promising as a compensatory tool to improve function outside of the clinic. Future research with stronger designs is necessary to provide greater certainty about the effectiveness of the compensatory use of a UE-MEO for increasing function, e.g. performance of ADLs in the home environment.

Evidence for using a UE-MEO as an assist for restorative motor rehabilitation to improve motor control

Five studies that used a UE-MEO as a device to assist with restorative motor rehabilitation had mixed results in individuals with stroke. While two of the single group studies found significant improvement on the FM-UE that was higher than the MCID, the other two studies either found significant improvement that was of uncertain clinical meaning (i.e. below the MCID) or failed to find any advantage of using a UE-MEO as an assist to practice over non- device task practice. Only two of the three studies measuring spasticity found that intervention reduced it. A single study with participants with TBI had only six participants but showed larger gains in this TBI group than its stroke group.[23] Unique recovery mechanisms after TBI might explain the larger gains, but they might also be related to the TBI group's milder baseline motor status [mean FMA-UE of 35(11.3) vs 24.3(5.4)].

The rationale for testing the efficacy of using a UE-MEO to assist with intense repetitive task practice is that many individuals with a prior stroke struggle to perform a variety of tasks during practice. In addition, they often fatigue easily, with more severely impaired individuals having greater limitations in the tasks and the amount they are able to practice. A UE-MEO might be able to help these individuals perform a greater variety of tasks and for more repetitions.

Unfortunately, the heterogeneity and small samples in the studies testing the use of a UE- MEO for restorative practice make it impossible to ascertain whether the use of such a device during task practice enhances the benefit of task practice. Clear result patterns based on variables that might impact intervention response did not emerge.

Multiple intervention aspects affect an intervention's effectiveness, such as therapy type, motor impairment severity, and therapy amount. The neuroplasticity underlying stroke motor recovery depends on many functional movement repetitions.[32] Repetitive task practice, in which movements are practiced with goal-directed, often real/simulated life activities, is considered the best type of practice,[4] most likely because it is more meaningful, more engaging and requires more complex real-life motor planning and execution than nonfunctional practice. Each study in this review included such practice. However, two studies used devices without hand components. In these studies, which involved severely impaired participants, the lack of a hand unit would have severely limited the types of tasks that could be practice and the type of paretic UE involvement in those tasks (e.g. as an assist, rather than an object manipulator). Such reduced hand involvement in practice may have factored in these studies' limited effects.

However, an additional study[29] with a severely impaired sample and a device with a hand component also found minimal motor skill gains, which reduces the likelihood that the practice type is the main reason for the mixed results.

Evidence suggests that the individuals for whom repetitive task practice with a UE-MEO is most

beneficial are those with moderate-level impairment. Of note, the participants in Pundik et al.[23] and Nam et al.,[26] the studies with the highest voluntary motor control gains, had the highest baseline FMA-UE scores. In the Page et al. RCT,[27] the participants had much more severe motor impairment. In fact, no group in this study (repetitive task practice + UE-MEO for all, half, or none of the sessions) made significant gains. For spasticity, it is unfortunate that the study without post-intervention spasticity reduction neglected to provide baseline spasticity scores, making it impossible to compare their results to successful studies based on spasticity severity.

The amount of practice is important yet varied across the studies. Studies that found minimal to no motor skill practice effects with MEO-UE devices[20,27,29] had fewer practice hours (range: ~ 13–24 h of practice) than the more successful trials (~30–50 h).[23,26] A null trial was the only RCT in our review. This might suggest that practice amount 24 h or less is an insufficient amount to facilitate motor skills. It is noteworthy that all included studies had significantly higher practice amounts than typically delivered during traditional rehabilitation.[5,6,34] However, studies with lower practice amounts also had more severe participants. Thus, it is not clear whether or not a larger therapy with MEO-UE device amount might increase motor gains in individuals with severe motor impairment.

There are two additional aspects of this study sample that deserve discussion. First, one study had no home program.[27] It found no motor control gains,[27] suggesting that perhaps motor practice in a person's usual environment completing their typical tasks leads to better outcomes. However, other studies with home programs also had minimal gains.[20,29] Thus, it seems unlikely that having a home program, by itself, is necessary for enhancing motor skills. Second, the study with the largest motor control gains and spasticity reduction had an FES component. This might indicate the usefulness of such a component. FES can increase the range of motion, suggesting that it can improve motor control via different mechanisms than motor practice alone.[35] Similarly, a previous systematic review[36] found moderate-level evidence for electrical neuromuscular stimulation and low-level evidence for movement therapies in reducing spasticity. Other studies have found FES to promote motor recovery.e.g.[37] Nonetheless, all studies in this review that assessed spasticity included movement practice, with spasticity reduction found only in those with at least 18 practice hours. However, the use of a device with FES[26] did not differentiate studies that found or did not find spasticity reductions.

Thus, there is some evidence that the use of a UE-MEO during repetitive task practice may facilitate improved motor skills for individuals. However, it is not yet clear if this combined type of practice would be any more effective than repetitive task practice by itself. On the other hand, Bermúdez i Badia, et al.[22] found that their participants were very satisfied with the use of their UE-MEO during a VR-based restorative motor rehabilitation program. This might imply that the use of a UE-MEO may motivate individuals to engage in more repetitions of practice than task practice alone, which might lead to greater improvements.[38] However, practicing with a VR program alone can also be very motivating.[39] Use of a UE-MEO in combination with VR to enhance motivation for practice could be promising but awaits future testing.

Other studies have found that those with more severe motor impairment are often less likely to benefit from such restorative practice.[40,41] Greater injury to key neural structures, such as the ipsilesional corticospinal tract (CST) in the context of UE motor recovery, is associated with poorer responses to restorative therapies after stroke.[42,43] Integrity of CST has also been associated with baseline levels of motor impairment.[44,45] Thus, for patients with massive injury to the CST or other motor system components, UE-MEO use might focus on it being a compensatory tool to perform daily activities.

In addition to the primary use of supporting the weak arm, the UE-MEO use might also focus on a therapy regimen that aims to promote relearning of motor skills through motor practice for patients with lesser injury. Determining which participants benefit most from the use of a UE-MEO as an assist for restorative motor rehabilitation training requires additional research that aims to directly

evaluate participants across different motor impairment levels.

Limitations

There were limitations to this systematic review. First, we limited studies to no earlier than 2014. While we did this because of the change and growth of technology around UE-MEOs since that date, it is possible that we omitted potentially relevant studies published prior to that date. Secondly, we limited studies to English, French, and Spanish. It is possible that there are relevant studies in other languages. However, one study excluded based on language was not relevant to the current search. Finally, we were unable to conduct a meta-analysis of the data due to the heterogeneity of the studies in research protocols, devices used, and in outcome assessments used.

Conclusions

The use of a UE-MEO as a compensatory tool is a viable option to assist movement and help individuals to perform more functional activities, while the evidence on the effectiveness of UE- MEO to assist repetitive task practice in restorative motor rehabilitation is mixed. The current systematic review cannot draw broad conclusions based on the strength of the evidence currently available, however current findings are concordant with the recommendations in the 2016 AHA/ASA guidelines on stroke rehabilitation and recovery for this class of devices, which considered them to be a viable option to recommend/prescribe to individuals with moderate to severe UE paresis for home use with a Class IIa Level A evidence level.[4] Indeed, confidence in the UE-MEO effectiveness, and the population that could benefit the most from their use, would be strengthened by evidence with more robust study designs. Larger, randomized, controlled studies could further bolster the evidence reviewed herein; fortunately, there is an ongoing randomized clinical trial that may address some of the concerns (ClinicalTrials.gov: NCT05296408).

Acknowledgments

The authors wish to thank Greg Ambra (GA) for literature review support and Jean Battikha, MS (JB) for data extraction and statistical support.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This paper was funded by Myomo.

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Competing interests and funding support

Support for the literature search, data analysis, and medical writing was provided by InQuiry Research and funded by Myomo, Inc.
Dr Richards (LR) is a member of the Scientific Advisory Board for Myomo, Inc. Ms Paluselli provides medical writing consulting services to Myomo, Inc.
Dr Sethi has no relevant disclosures.
Dr Cramer serves as a consultant for Astellas, Bayer, Beren Therapeutics, BlueRock Therapeutics, BrainQ, Constant Therapeutics, Medtronic, MicroTransponder, Myomo, NeuroTrauma Sciences, Simcere, and TRCare.

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Appendix Search strategy as run

Databases: APA PsycInfo®, BIOSIS Previews®, British Nursing Index, ClinicalTrials.gov, Ei Compendex®, Embase®, EMCare®, ESPICOM Pharmaceutical & Medical Device News, FDAnews, Inspec®, Lancet Titles, MEDLINE®, Northern Light Life Sciences Conference Abstracts, Publicly Available Content, SciSearch®: a Cited Reference Science Database

Set#	Searched for	Results
S1	(myomo OR myopro) and (fdb(embase, scisearch, medlineprof, publiccontentpro, emcare, clinicaltrials, biosispreviews, inspec, psycinfo, eicompendex, fdanews, espicomnews, lancet, britishnursingindex, northernlight))	176°
S2	(upper P/1 extremity P/1 myoelectric P/1 orthosis) and (fdb(embase, scisearch, medlineprof, publiccontentpro, emcare, clinicaltrials, biosispreviews, inspec, psycinfo, eicompendex, fdanews, espicomnews, lancet, britishnursingindex, northernlight))	1°
S3	(myoelectric P/1 orthosis) and (fdb(embase, scisearch, medlineprof, publiccontentpro, emcare, clinicaltrials, biosispreviews, inspec, psycinfo, eicompendex, fdanews, espicomnews, lancet, britishnursingindex, northernlight))	62°

° Duplicates across databases are removed from the search and from the result count.