MULTIPLE SCLEROSIS JOURNAL | MSJ

Topical Review

Functional electrical stimulation for foot drop in people with multiple sclerosis: The relevance and importance of addressing quality of movement

Multiple Sclerosis Journal

1–8

DOI: 10.1177/1352458520923958

Angela Davies Smith, Terezie Prokopiusova, Rosemary Jones, Tania Burge and Kamila Rasova

Correspondence to:
K Rasova
Department of Rehabilitation, Third Faculty of Medicine, Charles University, Ruská 87, Prague 10, Czech Republic.
kamila.rasova@gmail.com

Angela Davies Smith
Rosemary Jones
Tania Burge
The Brain Centre, North Bristol NHS Trust, Southmead Hospital, Bristol, UK

Terezie Prokopiusova
Kamila Rasova
Department of Rehabilitation, Third Faculty of Medicine, Charles University, Prague, Czech Republic

Abstract: Impaired mobility is common in people with multiple sclerosis (MS). Changes in gait have different causes and require individualised gait rehabilitation. A common and often early cause of mobility impairment is footdrop, inability to lift the foot during the swing phase of gait, with increased risk of falls, effortful walking and fatigue. Using literature review, we have characterised published data on footdrop treatment in MS, specifically functional electrical stimulation (FES) to better understand the reported outcomes relevant to the user. We discuss the strengths and weaknesses of FES and how far it meets the needs of people with footdrop. Physiotherapy combined with FES may further enhance the benefits of FES. MS studies emphasise the value of maintaining activity levels in early MS but discussion on how to achieve this is lacking. We emphasise the value of qualitative measures to broaden our understanding and improve treatment and adherence and identify areas for further research. Supplementary video material illustrates key features of MS gait and its correction using FES and physiotherapy.

Keywords: Multiple sclerosis, gait, foot drop, functional electrical stimulation

Date received: 7 December 2019; revised: 1 April 2020; accepted: 10 April 2020.

Practitioner summary

A survey of literature from 1990 to 2020 shows substantial evidence for the positive value of functional electrical stimulation (FES) for treatment of footdrop in multiple sclerosis (MS) using quantitative measures but few that reported qualitative outcomes. User and observer reported improvements in quality and safety of walking, user satisfaction and reduced effort and fatigue indicate wider benefits of the management of footdrop using FES than walking speed or endurance alone. Using short video clips, we illustrate, footdrop, FES at different stages of impaired mobility and postural correction by physiotherapy, all important to optimise FES use in MS.

Introduction

MS is a progressive condition most frequently resulting in impaired mobility. Many studies describe the impact of footdrop on gait efficiency and walking safety.[1] Falls have been documented in 50% and repeat falls in 28% of single aid users.[1] Decreased walking ability is related to decreased levels of activity,[2,3] which affects activities of daily living (ADL) and employment.[4,5]

Footdrop, due to weakness of the anterior calf muscles or increased tone in the posterior calf muscles, is routinely treated with provision of orthotics such as an ankle foot orthosis (AFO). The orthotic effect of such devices is well documented, but many patients discard them due to discomfort, footwear limitations and cosmesis.[6,7]

FES is a technological approach providing functional correction of footdrop by delivering electrical impulses to the common peroneal nerve and anterior calf muscles. Stimulation mimics normal voluntary gait movement (lifting the foot during the swing phase of gait and achieving correct placement on the ground).[3] FES use in MS is usually delivered through surface adherent

Table 1. Literature search, inclusion criteria and key words.

Population: MS	MS, multiple sclerosis, pwMS, progressive neurological disorders, demyelinating disorders
Footdrop: unilateral or bilateral	drop foot, dropfoot, footdrop, dropped foot, drop-foot, drop – foot
Intervention studies using functional electrical stimulation (surface worn)	FES, peroneal nerve stimulation, dropped foot stimulator, peroneal electrical stimulation, foot drop stimulator, Functional electrotherapy, common peroneal nerve, ankle flexor and extensor muscles, reciprocal inhibition
Outcomes include user perception, user satisfaction and self-report measures	quality of life, QOL, effort of walking, activities of daily living, ADL, perception of function, walking ability, psychosocial impact of assistive devices, Multiple Sclerosis Walking Scale, MSWS 12, 36-Item Short Form Health Survey, SF36, Patient global impression of change
English language 1990–2020	
Exclusion criteria: non-MS population, FES not used as an intervention, systematic reviews and conference papers.	

electrodes although implanted systems are also available, but are used rarely in MS due to possible implantation risks.[8] FES, seen as an alternative, has a comparable or better orthotic effect[7,9,10] generating active rather than passive movement but is in limited use despite users reporting significantly reduced perception of exertion on walking and many choosing FES as a preferred option compared to AFOs.[11]

This topical review offers a summary of the most relevant recent information on FES for foot drop in MS including its limitations, to provide an overview of the research underpinning current FES treatment and to address the need to report qualitative as well as quantitative outcomes in rehabilitation trials. In addition, recent research indicating that maintenance of activity may have greater neuroprotective potential than previously recognised suggests that further research into maintaining activity in people with MS is merited.[12]

Literature search

Literature searches using databases Embase, PubMed, Google Scholar and Web of Science for publications listed between 1990 and 2020 were completed by two independent research MS specialist physiotherapists (A.D.S., T.P.) between 2018 and 2020 with following keywords: people with MS, with foot drop, intervention FES, used to identify relevant FES studies (see Table 1 for keywords and inclusion criteria). Further terms such as user satisfaction, user perception and self-report outcomes allowed further identification of publications using qualitative outcomes. Thirty-five articles meeting the search criteria were identified, 19 of these were assessed for inclusion eligibility and 9 were included in the analysis.[10,11,13–19] Eligible papers were scrutinised and participant characteristics, methods of data collection and analysis and major findings of each paper were extracted (A.D.S., T.P.). A critical interpretive synthesis of the literature and analysis of the evidence was undertaken[20] (A.D.S., T.P., R.J., T.B., K.R.).

Supplementary material

Additional supplementary video recordings showing key aspects of footdrop and FES or physiotherapy in MS were prepared from clinical archives in Bristol and Prague (A.D.S., T.P., K.R.) with informed consent. Six anonymised video clips are used to illustrate gait affected by footdrop and specific aspects of FES and physiotherapy treatment on gait. These are referred to in the text.

Why consider FES for MS footdrop?

Footdrop can be an early MS symptom and is sometimes overlooked by the clinician or unrecognised by the patient except after sustained walking when the onset of fatigue can exacerbate gait problems (Supplemental Video 1A). We suggest footdrop merits treatment at this stage of impairment for gait correction, to enable functional walking distance to be maintained[21] and to avoid trips and falls. Maintaining activity in MS is now recognised to be important for a range of reasons not the least of which is motivation of daily activity to encourage independence and maintain general fitness.

A review of 21 studies on FES for footdrop in MS[22] shows positive orthotic benefit (the immediate change in gait with FES on, compared with FES off)[13,15,17,19,21,23–33] (Supplemental Video 1B). Although few studies to date report therapeutic benefit (effect that persists after FES removed[2,5]), interest is growing in the potential for activity to be neuroprotective. Little attention has yet been paid to mechanisms of neuroprotection through

regular exercise nor its impact. It is well accepted that reduction in daily general activity levels and deconditioning are frequent findings in early stages of MS.

FES evaluation: quantitative and qualitative outcomes

Most studies evaluated the effect of FES using only quantitative outcome measures such as walking speed or walking distance (2-, 5- or 6-minute walking tests, 10-m or 25-foot timed walking tests).[21,28,34,35] Such tests can be quickly administered in clinic to record and monitor user's gait speed or distance over time. However, such quantitative measures can be confounded by a range of other factors, for example, neuromuscular fatigue. Some studies have explored a relationship between gait speed and cognitive load[36–38] which may also confound quantitative measures of FES impact when used in isolation.

Improvement in walking speed when using FES has repeatedly been shown to be significant in slow walkers,[39] but not in those with faster walking speeds. Those with self-selected walking speeds <0.8 m/s consistently showed improvement, while those whose walking speed was >0.8 m/s did not;[21] hence, slow walkers are more likely to benefit from an increased walking speed using FES. However fast and slow walkers both report qualitative improvements such as better gait and reduced risk of tripping and falling (Supplemental Video 1B).

Acknowledging that quantitative measures alone may not capture important aspects of footdrop treatment such as quality of gait, acceptability, appropriateness and possible benefits of long-term use of FES, analysis of literature including qualitative outcomes was undertaken.

Applying 'Evidence-Based Medicine', patients' perspective should be an integral part of an assessment. Several studies[9,11,13–19] have used self-report outcomes, for example, Multiple Sclerosis Walking Scale (MSWS-12), Multiple Sclerosis Impact Scale (MSIS-29) and Modified Fatigue Impact Scale (MFIS) (Table 2) that could provide further important and relevant information to the user than quantitative measures alone. In addition, improvements in posture, gait pattern[32] and reduced number of falls,[16,40] all point to safer walking. Improvements in Functional Gait Assessment[41] and evaluation of fatigue and physiological cost of gait all indicate reduced fatigue.[42,43] One long-term follow-up study[29] records reduced musculoskeletal pain with FES use, an under explored benefit of FES. Health-related quality of life is affected positively by FES.[44] Improvements in such outcomes are more likely to result in sustained FES use than a change in walking speed or distance.

FES combined with physiotherapy

Research indicates that FES effectiveness could be increased if used together with exercise stimulation or physiotherapy.[15,23] One study evaluated the effect of FES together with physiotherapy and found that the addition of physiotherapy treatment enhanced the effect of FES on balance (numbers of falls) and gait (Rivermead Observational Gait Analysis).[18] In this study, where physiotherapy focused on strengthening the deep abdominal and lower back muscles and controlling hip stability, FES had the dominant effect.[18] However, our pilot study[45] found that FES improves balance (Berg Balance Scale, The Activities-Specific Balance Confidence Scale, Timed Up and Go Test) and walking ability (2-minute walk test, timed 25-foot walk test, Multiple Sclerosis Walking Scale-12) but no more than facilitation physiotherapy (Motor Program Activating Therapy;[46] Supplemental Video 3B). FES, with physiotherapy using facilitation techniques, would seem the most effective but randomised controlled trials are needed to understand which therapeutic methods are most effective.

Using FES with physiotherapy could increase plastic and adaptive processes in the central nervous system (CNS). An effect of both FES and physiotherapy on brain plasticity has been documented, but not used together. While an effect of physiotherapy has been documented at the system level[47] by diffusion tensor imaging (brain microstructure)[48] or functional magnetic resonance imaging (fMRI brain and spine pathways),[47,48,49,50] an effect of FES using motor-evoked potentials by transcranial magnetic stimulation over the motor cortex[51] was found. This promising finding needs to be verified.

Long-term use of FES

To fully understand the value of FES use or possible therapeutic benefit over long-term other outcome measures should be considered. Although most published studies of FES in MS[13,15,17,19,21,23–33] have limited follow-up, one long-term follow-up[29] emphasises reduction of musculoskeletal pain and fatigue, important and often neglected benefits of FES. Only one study offers evidence for benefit in more severely affected MS users. FES has been shown to sustain walking despite increasing disability.[13] Supplemental Video 2A documents an

Table 2. Studies of functional electrical stimulation in MS that use self-report outcomes (in bold).

Reference	Study type Condition (*N*)	Age (years)	Intervention	Outcome measures	Assessment	Disability (EDSS)	Results ↑ Improvement
Barrett and Taylor[13]	Clinical audit MS (20) Stroke (21)	41–70	18-week use of FES	**PIADS** 10MWT	18 weeks baseline + 18 weeks	NR*	MS only results reported ↑ **Perceived QOL** ↑ Walk speed, significant at 18 weeks
Bulley et al.[14]	Qualitative MS (10)	36–59	Focus group AFO (4) Focus group FES (8)	**Interpretative phenomenological analysis**		NR*	↑ **Fatigue,** ↑ **gait, fewer trips and falls (FES and AFO)** ↑ **Walking distance,** ↑ **physical activity and** ↑ **fitness (FES),** ↑ **balance and stability (AFO)**
Downing et al.[15]	Case series MS (19)	51.77 ± 10.16	2-week use of FES	**MSIS-29 MSWS-12** T25FW	Baseline and 2 weeks	NR*	↑ **QOL MSIS-29 ($p < 0.0001$)** ↑ **Perception of walking MSWS-12 ($p < 0.0001$)** ↑ Walk speed T25FW ($p < 0.0001$)
Esnouf et al.[16]	RCT MS (53)	55	FES group or physiotherapy exercise group for 18 weeks	**COPM Falls diary**	18 weeks	4.0–6.5	↑ **Performance and satisfaction PIADS ($p < 0.05$) and less falls reported ($p = 0.036$) in FES group compared to exercise group**
Mayer et al.[17]	Case series MS (20) on dalfampridine	36–68	Daily use of FES	T25FW, 6MW, GaitRite FAP, **MSWS-12, SF-36**	Screening, baseline, 1 and 3 months	NR*	Screening to baseline: ↑ **MSWS-12 ($p = 0.024$),** ↑ **SF-36 Physical Function domain** ($p = 0.028$) Screening to 3 months: ↑ T25FW, ↑ **MSWS-12 ($p = 0.003$) and SF-36** Physical Function ($p = 0.032$) and Role Limitation ($p = 0.012$)
Taylor et al.[18]	RCT MS (28)	56 ± 8.6	6 weeks FES, add gluteal stimulation week 12 add core stability exercise week 18 or core stability exercise add FES week 12, add gluteal stimulation week 18	**MSIS-29 Falls diary** ROGA 10MTW	0, 6, 12, 18, 24 weeks	⩽6.5	FES ↑ walking speed and ROGA score Adding gluteal stimulation further ↑ ROGA score, adding physiotherapy did not **Both interventions reduced falls, adding FES to physiotherapy reduced falls further. FES had greater impact on MSIS-29**
Van der Linden et al.[19]	Pilot, case series MS (9)	35–64	12 weeks FES use	**MSWS-12, MSIS-29 FSS, Borg RPE**, 3D gait analysis, 10MTW, 2MW step count	−4, baseline, 6 and 12 weeks	NR*	FES ↑peak dorsiflexion inswing ($p = 0.006$), 10MWT ($p = 0.006$) and 2 MWT ($p = 0.002$) compared to no FES **MSWS-12 improved at 6 weeks ($p = 0.034$)** **MSWS-12, MSIS-29, FSS**, step count: **no effect of FES at 12 weeks**
Khurana et al.[11]	Randomised crossover trial MS (20)	32–74	2 walks (1 × AFO, 1 × FES) 1-hour apart for 3–10 minutes	**Borg RPE**, HR, O_2 consumption, speed, distance	2 visits 1–4 weeks apart	4.0–6.0	**Significant decreased perceived exertion levels for FES compared to AFO ($p = 0.01$)** No significant difference between devices for energy and efficiency
Miller Renfrew et al.[10]	Multicentre, powered, non-blinded, randomised trial MS(85)	AFO group: 50.4 ± 10.4 FES group: 51.4 ± 11.2	Receive a custom-made, AFO ($n = 43$) or FES device ($n = 42$)	5MW self-selected walk test (primary), T25FW, oxygen cost of walking, **MSIS-29 MSWS-12 MFIS Euroqol 5-D, ABC Scale, PIADS,** equipment and National Health Service staff time costs of interventions	0, 3, 6 and 12 months	AFO group: 5.3 ± 1.3 FES group: 4.9 ± 1.4	In all, 38% dropped out by 12 months (AFO, $n = 21$; FES, $n = 11$) Both groups walked faster at 12 months with device ($p < 0.001$; AFO, 0.73 (0.24); FES, 0.79 (0.24) m/s) but no difference between groups. Significantly higher **PIADS** found for FES for competence ($p = 0.016$; AFO, 0.85 (1.05); FES, 1.53 (1.05)), adaptability ($p = 0.001$; AFO, 0.38(0.97); FES 1.53 (0.98)) and self-esteem ($p = 0.006$; AFO, 0.45 (0.67); FES 1 (0.68)). Effects were comparable for other measures. FES may offer value for money alternative to usual care AFOs and FES have comparable effects on walking performance and patient-reported outcomes; however, high drop-outs introduces uncertainty

MS: multiple sclerosis; FES: functional electrical stimulation; QOL: quality of life; AFO: ankle foot orthosis; NR*: not reported; PIADS: Psychosocial Impact of Assistive Devices Scale; MSWS-12: Multiple Sclerosis Walking Scale; MSIS-29: Multiple Sclerosis Impact Scale; COPM: Canadian Occupational Performance Measure; SF-36: 36-Item Short Form Health Survey; RCT: randomised controlled trial; 3D: three-dimensional EuroQol 5-D Euroqol five-dimensional five-level questionnaire; FSS: Fatigue Severity Scale; MFIS: Modified Fatigue Impact Scale; Borg RPE: Borg Scale Rating of Perceived Exertion; ABC Scale: Activities-Specific Balance and Confidence Scale; T25FW: Timed 25 foot walk test; 10MWT: timed 10-minute walk test; 6MW: 6-minute walk test; 5MW: 5-minute walk test; 2MW: 2-minute walk test; GaitRite FAP: GaitRite Functional Ambulation Profile; ROGA: Rivermead Observational Gait Analysis.

important role of FES for people with severe disability and very limited walking. It illustrates a long-term FES user able to walk with FES but no longer able to walk without FES (Supplemental Video 2B). This illustration of FES use is not widely addressed and most published studies[9,13,16,18,32] evaluated FES use over a limited period (up to 52 weeks). Clinical follow-up of FES users may span several years.

Patient assessment for FES

Although an effect of FES using both quantitative and qualitative methods has been demonstrated, FES is not suitable for everyone. Selection and optimum device programming is very important. For example, spasticity is a sign that could influence whether a person can use FES. Although an improvement in spasticity and physiological cost of gait is primarily expected,[43] FES may also cause visible negative effect[26,30] (Supplemental Video 3). Expertise in assessment for patient selection and accurate device programming are vital elements in the successful delivery of FES services. Use of FES is limited due to factors such as cost but also the lack of widespread expertise in assessment and device programming, requirements to maximise benefit.

FES as an enabler for exercise

In MS as with other long-term conditions, there is lower adherence to regular exercise,[52] due in part to patients' psychological barriers and physical limitations.[52] Regular exercise is now known to be neuroprotective and to promote cardiovascular health in this patient group.[53] Regular use of FES has the potential to enable people with footdrop to better access and maintain regular activity, probably due to the positive role of FES on reduction of exertion.[11,14,16] We advocate further FES research to investigate the physiological impact of FES and overall role as a motivator and activator.

Conclusion

We offer arguments for why documented FES benefits should routinely include user opinions and observed changes in quality of walking and reduction of fatigue as well as walking speed, safety and endurance. Walking speed, while useful, may be only a secondary consideration for patients as studies repeatedly show little effect on this measure in those with faster walking speeds. Including considerations that are important to the user are needed to gain a fuller understanding. Assessment and appropriate patient selection by experienced FES clinicians is important to optimise FES use in MS and discussion opportunities to address this should be sought. Due to the progressive nature of MS, ongoing monitoring with the potential need to adjust FES devices to accommodate gait changes over time needs to be considered. Video recordings may benefit clinicians and user feedback and research to develop appropriate quantitative evaluation is indicated.[54]

Further investigation into the use of FES in more disabled people with MS is strongly indicated. Further research integrating FES with physiotherapy is needed to provide data to guide clinicians in optimising outcome for this patient group.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by MH CZ-DRO ('Kralovske Vinohrady University Hospital–FNKV, 00064173'), Research Projects of 112616/GAUK/2016, 260533/SVV/2020, Q35 and Q37 and MS Research Training and Education (MSRTE) Charity No 1043280.

ORCID iDs

Terezie Prokopiusova https://orcid.org/0000-0001-5580-1858
Kamila Rasova https://orcid.org/0000-0002-3201-1770

Supplemental material

Supplemental material for this article is available online.

References

1. Coote S, Hogan N and Franklin S. Falls in people with multiple sclerosis who use a walking aid: Prevalence, factors, and effect of strength and balance interventions. *Arch Phys Med Rehabil* 2013; 94(4): 616–621.
2. Pau MPM, Pilloni G, Coghe G, et al. What gait features influence the amount and intensity of physical activity in people with multiple sclerosis? *BMC Neurology*. Epub ahead of print 28 January 2020. DOI: 10.21203/rs.2.22011/v1.

3. Larocca NG. Impact of walking impairment in multiple sclerosis. *Patient* 2011; 4(3): 189–201.
4. Gulick EE and Goodman S. Physical activity among people with multiple sclerosis. *Int J MS Care* 2006; 8: 121–129.
5. Peterson EC, Cho C and Finlayson ML. Fear of falling and associated activity curtailment among middle aged and older adults with multiple sclerosis. *Mult Scler* 2007; 13: 1168–1175.
6. Bregman DJ, Harlaar J, Meskers CG, et al. Spring-like Ankle Foot Orthoses reduce the energy cost of walking by taking over ankle work. *Gait Posture* 2012; 35(1): 148–153.
7. Sheffler LR, Bailey SN and Chae J. Spatiotemporal and kinematic effect of peroneal nerve stimulation versus an ankle-foot orthosis in patients with multiple sclerosis: A case series. *PM R* 2009; 1(7): 604–611.
8. Taylor PN, Wilkinson Hart IA, Khan MS, et al. Correction of Footdrop Due to Multiple Sclerosis Using the STIMuSTEP Implanted Dropped Foot Stimulator. *Int J MS Care* 2016; 18(5): 239–247.
9. Renfrew LM, Paul L, McFadyen A, et al. The clinical- and cost-effectiveness of functional electrical stimulation and ankle-foot orthoses for foot drop in Multiple Sclerosis: A multicentre randomized trial. *Clin Rehabil* 2019; 33(7): 1150–1162.
10. Miller Renfrew L, Lord AC, McFadyen AK, et al. A comparison of the initial orthotic effects of functional electrical stimulation and ankle-foot orthoses on the speed and oxygen cost of gait in multiple sclerosis. *J Rehabil Assist Technol Eng* 2018; 5: 2055668318755071.
11. Khurana SR, Beranger AG and Felix ER. Perceived Exertion Is Lower When Using a Functional Electrical Stimulation Neuroprosthesis Compared With an Ankle-Foot Orthosis in Persons With Multiple Sclerosis: A Preliminary Study. *Am J Phys Med Rehabil* 2017; 96(3): 133–139.
12. Motl RW and Sandroff BM. Exercise as a Countermeasure to Declining Central Nervous System Function in Multiple Sclerosis. *Clin Ther* 2018; 40(1): 16–25.
13. Barrett C and Taylor P. The effects of the odstock drop foot stimulator on perceived quality of life for people with stroke and multiple sclerosis. *Neuromodulation* 2010; 13(1): 58–64.
14. Bulley C, Mercer TH, Hooper JE, et al. Experiences of functional electrical stimulation (FES) and ankle foot orthoses (AFOs) for foot-drop in people with multiple sclerosis. *Disabil Rehabil Assist Technol* 2015; 10(6): 458–467.
15. Downing A, Van Ryn D, Fecko A, et al. Effect of a 2-week trial of functional electrical stimulation on gait function and quality of life in people with multiple sclerosis. *Int J MS Care* 2014; 16(3): 146–152.
16. Esnouf JE, Taylor PN, Mann GE, et al. Impact on activities of daily living using a functional electrical stimulation device to improve dropped foot in people with multiple sclerosis, measured by the Canadian Occupational Performance Measure. *Mult Scler* 2010; 16(9): 1141–1147.
17. Mayer L, Warring T, Agrella S, et al. Effects of functional electrical stimulation on gait function and quality of life for people with multiple sclerosis taking dalfampridine. *Int J MS Care* 2015; 17(1): 35–41.
18. Taylor P, Barrett C, Mann G, et al. A feasibility study to investigate the effect of functional electrical stimulation and physiotherapy exercise on the quality of gait of people with multiple sclerosis. *Neuromodulation* 2014; 17(1): 75–84; discussion 84.
19. van der Linden ML, Hooper JE, Cowan P, et al. Habitual functional electrical stimulation therapy improves gait kinematics and walking performance, but not patient-reported functional outcomes, of people with multiple sclerosis who present with foot-drop. *PLoS ONE* 2014; 9(8): e103368.
20. Dixon-Woods M, Cavers D, Agarwal S, et al. Conducting a critical interpretive synthesis of the literature on access to healthcare by vulnerable groups. *BMC Medical Research Methodology* 2006; 6: 35.
21. Miller L, Rafferty D, Paul L, et al. The impact of walking speed on the effects of functional electrical stimulation for foot drop in people with multiple sclerosis. *Disabil Rehabil Assist Technol* 2016; 11(6): 478–483.
22. Dapul G and Bethoux F. Functional electrical stimulation for foot drop in multiple sclerosis. *US Neurology* 2015; 11(1): 10–18.
23. Barrett CL, Mann GE, Taylor PN, et al. A randomized trial to investigate the effects of functional electrical stimulation and therapeutic exercise on walking performance for people with multiple sclerosis. *Mult Scler* 2009; 15(4): 493–504.
24. Burridge J, Taylor P, Hagan S, et al. Experience of clinical use of the Odstock dropped foot stimulator. *Artif Organs* 1997; 21(3): 254–260.
25. Burridge JH, Elessi K, Pickering RM, et al. Walking on an uneven surface: The effect of common peroneal stimulation on gait parameters and relationship between perceived and measured benefits in a sample of participants with a drop-foot. *Neuromodulation* 2007; 10(1): 59–67.
26. Sheffler LR, Hennessey MT, Knutson JS, et al. Neuroprosthetic effect of peroneal nerve stimulation

in multiple sclerosis: A preliminary study. *Arch Phys Med Rehabil* 2009; 90(2): 362–365.

27. Stein RB, Everaert DG, Thompson AK, et al. Long-term therapeutic and orthotic effects of a foot drop stimulator on walking performance in progressive and nonprogressive neurological disorders. *Neurorehabil Neural Repair* 2010; 24(2): 152–167.
28. Street T, Taylor P and Swain I. Effectiveness of functional electrical stimulation on walking speed, functional walking category, and clinically meaningful changes for people with multiple sclerosis. *Arch Phys Med Rehabil* 2015; 96(4): 667–672.
29. Street T and Singleton C. Five-year follow-up of a longitudinal cohort study of the effectiveness of functional electrical stimulation for people with multiple sclerosis. *Int J MS Care* 2018; 20(5): 224–230.
30. Taylor P, Burridge J, Dunkerley A, et al. Clinical audit of 5 years provision of the Odstock dropped foot stimulator. *Artif Organs* 1999; 23(5): 440–442.
31. Hausmann J, Sweeney-Reed CM, Sobieray U, et al. Functional electrical stimulation through direct 4-channel nerve stimulation to improve gait in multiple sclerosis: A feasibility study. *J Neuroeng Rehabil* 2015; 12: 100.
32. van der Linden ML, Scott SM, Hooper JE, et al. Gait kinematics of people with multiple sclerosis and the acute application of functional electrical stimulation. *Gait Posture* 2014; 39(4): 1092–1096.
33. Springer S and Khamis S. Effects of functional electrical stimulation on gait in people with multiple sclerosis: A systematic review. *Mult Scler Relat Disord* 2017; 13: 4–12.
34. Miller L, Rafferty D, Paul L, et al. A comparison of the orthotic effect of the Odstock Dropped Foot Stimulator and the Walkaide functional electrical stimulation systems on energy cost and speed of walking in Multiple Sclerosis. *Disabil Rehabil Assist Technol* 2015; 10(6): 482–485.
35. Miller L, McFadyen A, Lord AC, et al. Functional electrical stimulation for foot drop in multiple sclerosis: A systematic review and meta-analysis of the effect on gait speed. *Arch Phys Med Rehabil* 2017; 98(7): 1435–1452.
36. D'Orio VL, Foley FW, Armentano F, et al. Cognitive and motor functioning in patients with multiple sclerosis: Neuropsychological predictors of walking speed and falls. *J Neurol Sci* 2012; 316(1-2): 42–46.
37. Allali G, Laidet M, Assal F, et al. Walking while talking in patients with multiple sclerosis: The impact of specific cognitive loads. *Neurophysiol Clin* 2014; 44(1): 87–93.
38. Leone C, Patti F and Feys P. Measuring the cost of cognitive-motor dual tasking during walking in multiple sclerosis. *Mult Scler* 2015; 21(2): 123–131.
39. Kempen JC, de Groot V, Knol DL, et al. Community walking can be assessed using a 10-metre timed walk test. *Mult Scler* 2011; 17(8): 980–990.
40. Gervasoni E, Parelli R, Uszynski M, et al. Effects of functional electrical stimulation on reducing falls and improving gait parameters in multiple sclerosis and stroke. *PM R* 2017; 9(4): 339–347.
41. Forsberg AAM and Nilsagård Y. The functional gait assessment in people with multiple sclerosis. *Int J MS Care* 2017; 19(2): 66–72.
42. Chang YJ, Hsu MJ, Chen SM, et al. Decreased central fatigue in multiple sclerosis patients after 8 weeks of surface functional electrical stimulation. *J Rehabil Res Dev* 2011; 48(5): 555–564.
43. Paul L, Rafferty D, Young S, et al. The effect of functional electrical stimulation on the physiological cost of gait in people with multiple sclerosis. *Mult Scler* 2008; 14(7): 954–961.
44. Miller Renfrew L, Lord AC, Warren J, et al. Evaluating the effect of functional electrical stimulation used for foot drop on aspects of health-related quality of life in people with multiple sclerosis. *Int J MS Care* 2019; 21(4): 173–182.
45. Prokopiusová T, Pavlikova M, Markova M, et al. Randomized comparison of functional electric stimulation in posturally corrected position and motor program activating therapy: Treating foot drop in people with multiple sclerosis. *Eur J Phys Rehabil Med*. Epub ahead of print 8 May 2020. DOI: 10.23736/S1973-9087.20.06104-3.
46. Rasova K, Prochazkova M, Tintera J, et al. Motor programme activating therapy influences adaptive brain functions in multiple sclerosis: Clinical and MRI study. *Int J Rehabil Res* 2015; 38(1): 49–54.
47. Ibrahim I, Tintera J, Skoch A, et al. Fractional anisotropy and mean diffusivity in the corpus callosum of patients with multiple sclerosis: The effect of physiotherapy. *Neuroradiology* 2011; 53(11): 917–926.
48. Rasova K, Krasensky J, Havrdova E, et al. Is it possible to actively and purposely make use of plasticity and adaptability in the neurorehabilitation treatment of multiple sclerosis patients? A pilot project. *Clin Rehabil* 2005; 19(2): 170–181.
49. Matthews PM, Johansen-Berg H and Reddy H. Non-invasive mapping of brain functions and brain recovery: Applying lessons from cognitive

neuroscience to neurorehabilitation. *Restor Neurol Neurosci* 2004; 22(3–5): 245–260.

50. Morgen K, Kadom N, Sawaki L, et al. Training-dependent plasticity in patients with multiple sclerosis. *Brain* 2004; 127(Pt. 11): 2506–2517.
51. Everaert DG, Thompson AK, Chong SL, et al. Does functional electrical stimulation for foot drop strengthen corticospinal connections. *Neurorehabil Neural Repair* 2010; 24(2): 168–177.
52. Heesen C, Bruce J, Gearing R, et al. Adherence to behavioural interventions in multiple sclerosis: Follow-up meeting report (AD@MS-2). *Mult Scler J Exp Transl Clin* 2015; 1: 2055217315585333.
53. Latimer-Cheung AE, Pilutti LA, Hicks AL, et al. Effects of exercise training on fitness, mobility, fatigue, and health-related quality of life among adults with multiple sclerosis: A systematic review to inform guideline development. *Arch Phys Med Rehabil* 2013; 94(9): 1800–1828.
54. Jewitt C. An introduction to using video for research. *National Centre For Research Method Working Paper*, 2012, http://eprints.ncrm.ac.uk/2259/4/NCRM_workingpaper_0312.pdf