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Functional Electrical Stimulation in Neurorehabilitation

Jill Seale, PT, PhD, NCS

Learning Outcomes

After this course, participants will be able to:

- Define functional electrical stimulation (FES).
- Identify at least two mechanisms for therapeutic benefit from functional electrical stimulation (FES).
- Identify at least three common uses for functional electrical stimulation (FES) in neurological rehabilitation.
- Identify the current best evidence for the use of functional electrical stimulation (FES) in persons with a neurological diagnosis.
- Design a treatment plan of care for the use of functional electrical stimulation (FES) in the neurological population.

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Functional Electrical Stimulation (FES)

- Using neuromuscular electrical stimulation to enhance control of movement
- Replacing or assisting a persons voluntary movement when motor function is impaired
- Goal is to improve performance of activity
- Common diagnoses: stroke, spinal cord injury, traumatic brain injury, MS, other neurological diagnoses

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NMES v FES

NMES	FES
▪ Substitute for or augment voluntary contractions ▪ Used for strengthening or hypertrophy ▪ Part of a training program with goal of increasing strength	▪ Substitute for or augment voluntary contractions ▪ Used for strengthening or hypertrophy ▪ Use of NMES to promote **functional** activities

continued

Benefits of NMES

- No clear evidence to support OR refute that NMES results in increased voluntary muscle strength in: Spina bifida, peripheral nerve injury, MS, SCI, or CP
- May increase strength after stroke (modest support)
  - Better than no intervention
  - Not clear if better than progressive resistive training
  - Not clear if NMES added to training = additional benefit
    - Glinsky J, Harvey, L, Van Es P, *Physiother Res Int*, 2007

continued

FES

CONTINUED

Possible Peripheral Mechanisms

- Improve fitness and strength of remaining motor units
- Improved flexibility and ROM, thereby making voluntary efforts more effective
- Reduce spasticity, and subsequently improve function

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Possible Central Mechanisms

- Cortical reorganization
  - Central effects of FES
    - Activates motor and sensory fibers
  - Segmental reorganization – changes in reflex function occur at segmental level post injury; alterations in connectivity of anterior horn cell
    - Antidromic firing –capable of repeated activation of horn cell
    - Hebb synapses- modifiable synapses strengthened if pre-synaptic firing coincided with or was shortly following by postsynaptic discharge

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What does all that mean for us?

- FES may provide artificial way to sync presynaptic and postsynaptic activity
- ONLY WORKS IF… electrical stimulation applied in combination with voluntary effort

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Other (less scientific) Benefits

- Facilitate practice that could otherwise not occur
- Engage attention
- Provide repetition
- Provide challenge
- Provide sensory and visual feedback

CONTINUED

Where do we start?

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Contraindications

- Demand type pacemakers or implantable cardioverter defibrillators
  - Don't place electrodes on trunk or heart region
  - Consult with cardiologist
- Pregnancy
  - Don't use over abdominal, pelvic, lumbar or hip region
- Over carotid bodies

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

CONTINUED

Contraindications

- Other implanted electrical devices such as phrenic nerve or urinary bladder stimulators
- Areas of know peripheral vascular disease, areas of DVT or thrombophlebitis
- Over phrenic nerve, gonads, or eyes
- Areas of active osteomyelitis
- Areas of hemorrhage

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

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Exam	Question	Reason
Muscle innervation	Capable of stimulation?	Typically require innervation
Strength	Current accurate MMT	Determine effectiveness
ROM	Limitations?	May affect function; may be rationale for ES
Sensation	Normal, impaired, absent	Caution and monitoring with sensory impairment
Pain	Present? When? Severity?	Determine effectiveness
Spasticity	Present? Severity?	Impact on parameters; may have + or – impact on spasticity
Cognition	Able to provide feedback?	Safety issue

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

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FES not appropriate with:

- Complete peripheral nerve damage
- Polio
- Motor neuron disease
- Guillain-Barre syndrome
- SCI T6 or above (use with caution due to autonomic disreflexia

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FES Paradigm

- Independent Application
  - Use for prescribed period of time to encourage motor relearning
  - Progress to not using FES
- Dependent Application
  - Enables user to perform functional tasks with wouldn't otherwise be possible (use of device as neuroprosthesis)

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General Parameters for FES

- Waveform
  - Biphasic PC or burst modulated AC
- Pulse Frequency
  - 20-60 pps or burst per second
- Pulse Duration
  - 200-600 μsec
- Amplitude
  - To level appropriate for functional activity
- Duration
  - Task Specific

CONTINUED

How critical are parameters?

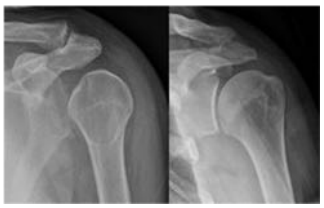
- "triggered or volitionally activated ES is more likely to yield improvements in motor control than non-triggered"
- Found not relationship between specific parameters and clinical outcome
  - de Kroon JR et al, *J Rehabil Med*, 2005

Common uses of FES in Neurological Diagnoses

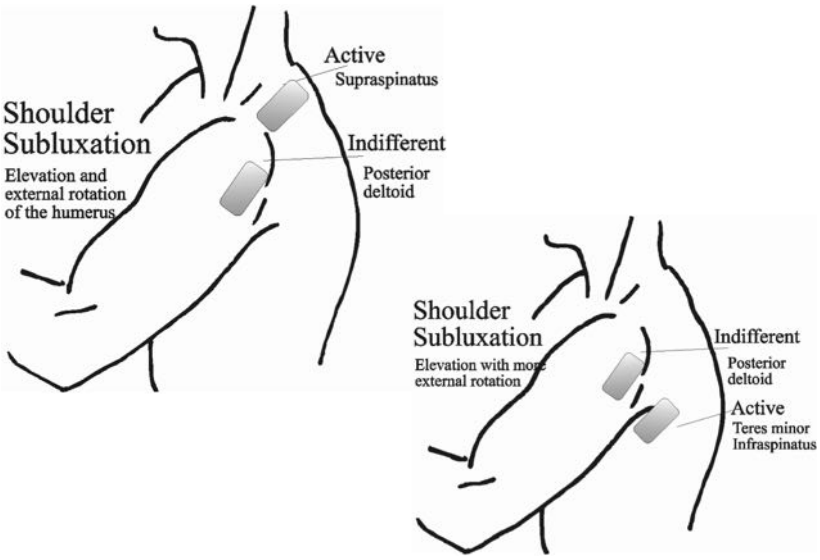
- Limited only by creativity
- Most common uses will be covered today:
  - Shoulder subluxations
  - Upper extremity function
  - Ambulation
  - Exercise

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

FES for Shoulder Subluxation



Hellerhoff [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)] Anterior (L) Posterior (R)



Parameters for Subluxation

- Waveform: Symmetrical or asymmetrical biphasic
- Pulse Frequency: 20-40 pps
- Pulse Duration: 200-350 μsec
- Amplitude: To achieve only desired effect
- Ramp up/down: 3 sec : 3 Sec
- Duty Cycle: 1:5 to 15:1 (goal to increase on time, decrease off time)
- Time and Duration: 30 minutes to 6 hrs (start low and increase); 5-7 days per week x 4-6 weeks

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

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Evidence

- FES in addition to conventional superior to conventional alone
  - Prevention or treatment
  - Acute to subacute stroke (less than 6 months
- Review is strongly supportive of short-term effects, but inconclusive for long term effects

-Vafadar AK, Cote JN, Archambault PS

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FES for Upper Extremity Function

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FES for UE Function

- Most common in stroke and TBI
  - Also CP and SCI
- Trigger devices
  - More for training
- Forearm and hand-molded orthoses
  - Devices that stimulate wrist and finger flexors AND extensors

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Parameters for Hand Function

- Waveform: Symmetrical or asymmetrical biphasic
- Pulse Frequency: 12-40 pps
- Pulse Duration: 200-350 μsec
- Amplitude: To achieve only desired effect (keep as low as feasible)
- Ramp up/down: shortest to achieve function
- Duty Cycle: N/A (timed with demand)
- Time and Duration: 30 -40 minutes, once or twice daily, 3-6 times per week, 6-16 weeks

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

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Evidence

- FES does not have significant effect on upper arm motor function early after stroke (impairments improved, not necessarily function)
- In chronic stroke, 2/3 studies found effect (EMG activity and abduction force, but no functional improvement)
  - Vafadar AK, Cote JN, Archambault PS, *BioMed Research International*, 2015
- Lateralization of activity dependent on severity of impairment… patients with some finger extension shift towards focused activity in ipsilesional site; those without finger extension showed enhanced involvement of contralateral site
  - Quandt F, Hummel FC, *Experimental & Translational Stroke Medicine*, 2014

CONTINUED

FES for Ambulation

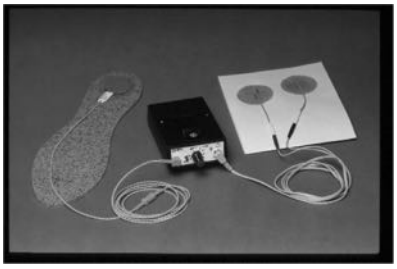
- Stance – No stimulation
- Foot switch detects heel rise
- Causes stimulation of the electrodes
- Produces dorsiflexion and eversion through swing
- Foot switch detects heel strike
- Stimulation ends after lower foot to ground

Primary use is for providing dorsiflexion assist for patients who present with decreased foot clearance (AKA drop foot) during swing phase of gait

Trigger Mechanisms

- Heel switch or foot switch
- Tilt sensor that detects leg's position
  - WalkAide
- Sensor on shoe and computer based algorithms to control timing of stimulation
  - NESS L300

FES for Ambulation



Traditional foot switch

WalkAide

Ness L300

CONTINUED

Parameters for Dorsiflexion Assist

- Waveform: Symmetrical or asymmetrical biphasic
- Pulse duration: 200-350μsec
- Frequency: 30-40 pps
- Amplitude: to achieve 3+/5 contraction
- Ramp up/down: 0-1 sec/ 0-1 sec
- Duty cycle: N/A
- Time and duration: determined by muscle fatigue

Adapted from *Modalities for Therapeutic Intervention*, 5th Ed, 2012

CONTINUED

FES for Ambulation post Stroke

- Faster walking speeds than walking training alone or no intervention
  - Robbins et al, *Arch Phys Med Rehabil*, 2006
- Evidence inconclusive
  - Roche et al, *Physical Therapy Reviews*, 2009
- Further walking distance compared with walking training alone or no intervention
  - Pereira et al, *Topics in Stroke Rehabilitation*, 2012
- FES appears to moderately improve activity compared with no intervention and training alone
  - Howlett et al, *Arch Phys Med Rehabil*, 2015

CONTINUED

Meta-Analysis of Orthotic Effect

- "AFOs have equally positive combined-orthotic effects as FES on key walking measures for drop foot caused by stroke"
  - Prenton S, Hollands KL, Kenney LPJ, *J Rehabil Med*, 2016

CONTINUED

FES for Ambulation in Persons with MS

- Significant increase in walking speed, initially and at 20 week f/u
- No significant training effect
- Functional walking category maintained or improved in 95% of responders
  - Street T, Taylor P, Swain I, *Arch Phys Med Rehabil*, 2015
- Systematic review and meta-analysis found that FES used for foot drop had positive initial and ongoing effect on gait speed in short walking tests.
  - Miller L et al, *Arch Phys Med Rehabil*, 2017

CONTINUED

Reduction of falls and Improvement in gait

- Subjects with stroke and MS
- Performed daily walking training using FES x 8 weeks
- FES reduced falls and improved walking, specifically there was increased foot clearance during swing
  - Gervasoni E et al, *PM&R*, 2017

CONTINUED

One more interesting finding

- Investigation of impact of FES on corticomotor plasticity
- Persons with chronic stroke completed treadmill walking session with or without FES to ankle DF and PFs
- Results: increased PF corticomotor symmetry related to observed increase in ankle moment symmetry (with FES)
  - Palmer JA, Hsiao HY, Write T, Binder-Macleod SA, *Phys Ther*, 2017

CONTINUED

FES for Ambulation after SCI

- Parastep®
- Stim to dorsiflexors
- Stim to glutes and quads
- Operated by controls on walker

CONTINUED

Neurorehabil Neural Repair. 2006 Sep;20(3):355-60.

Peroneal nerve stimulation versus an ankle foot orthosis for correction of footdrop in stroke: impact on functional ambulation.

Sheffler LR[1], Hennessey MT, Naples GG, Chae J.

Author information

Abstract

OBJECTIVE: To compare the efficacy of the Odstock Dropped-Foot Stimulator (ODFS), a transcutaneous peroneal nerve stimulation device, versus an ankle foot orthosis (AFO) in improving functional ambulation of chronic stroke survivors.

INTERVENTION: Fourteen chronic stroke survivors with foot-drop participated in the study. Participants received ambulation training under 3 test conditions: 1) ODFS, 2) customized AFO, and 3) no device. Each participant was evaluated using the modified Emory Functional Ambulation Profile under the 3 test conditions. All participants were evaluated with a post-evaluation survey to solicit device feedback and preferences.

RESULTS: Functional ambulation with the AFO was significantly improved, relative to no device, on the floor (P = 0.000), carpet (P = 0.013), and "up and go" test (P = 0.042). There was a trend toward significance on the obstacle (P = 0.092) and stair (P = 0.067) trials. Functional ambulation with the ODFS was significantly improved, relative to no device, on the carpet(P = 0.004). A trend toward significance on floor (P = 0.081), obstacle (P = 0.092), and stair (P = 0.079) trials was observed. The difference in functional ambulation between the AFO and ODFS showed a trend toward statistical significance on floor (P = 0.065) and up and go (P = 0.082) trials only. Given a choice between the ODFS and AFO for long-term correction of footdrop, participants indicated a preference for the ODFS.

CONCLUSION: The AFO and the ODFS may be comparable in their effect on improving functional ambulation as compared to no device. Specific characteristics of the ODFS may make it a preferred intervention by stroke survivors. More rigorously controlled trials are needed to confirm these findings.

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More Recently

- Long term f/u comparing FES to AFO in persons with chronic stroke
- AFO provided "to adequately alleviate foot drop" only
- Results : FES proved "noninferior" to AFOs for all primary measures
  - Bethoux et al, *Neurorehabilitation and Neuro Repair*, 2015

CONTINUED

The problem is this…

- Gait is swing AND stance
- FES only affects swing
- In stance, the primary deficit is lack of force production in the plantarflexors to control the limb through forward progression
- FES, thus far, does not impact that

And the problem is this…

User experiences, preferences and choices

- Qualitative study in persons with stroke
- Preference for FES for "primary tool for managing foot drop"
- But…"different experiences of both tools led to frequent choices to supplement FES with different types of AFOs"
  - Bulley C, Shiels J, Wilkie K, Salisbury L, *Physiotherapy*, 2011

CONTINUED

FES for Exercise

CONTINUED

FES Cycling

- Mainly used with persons with SCI
- Bicycle with stim to quadriceps, gluteal, hamstring, anterior tibialis, gastroc-soleus
- Can be used at home
- 60 minutes daily, 5 times per week
- Can add volitional UE exercise

CONTINUED

FES UE Cycling

- Used in persons with tetraplegia
- Unilateral or bilateral UE FES
- Gains in oxygen uptake and power output for single case with C6 tetraplegia, increased power output for additional case with C6 tetraplegia

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Utilization of FES Cycling

- Usage frequency of home –based FES cycling below recommended levels
- Most users classified in low-frequency category
- Below standards for overall health maintenance
  - Kressler J, Ghersin H, Nash MS, *Top Spinal Cord Inj Rehabil*, 2014

CONTINUED

More Resources

- Cleveland FES Center http://fescenter.org/?option=com_content&view=section&id=5&Itemid=5
- Christopher and Dana Reeve Foundation https://www.christopherreeve.org/living-with-paralysis/rehabilitation/functional-electrical-stimulation
- National MS Society https://www.nationalmssociety.org/Treating-MS/Rehabilitation/Functional-Electrical-Stimulation-(FES)

CONTINUED

Some unique uses of FES

- In ICU rehab in critical illness
  - Maintaining muscle health, maximizing strengthening
  - Koester K et al, *Nutr Clin Pract*, 2018; Parry SM, Capple LS, Mourtzakis M, *Nutr Clin Pract*, 2018.
- To prevent disuse-induced functional decline in elderly
  - Valenzuela PL et al, *Ageing Res Rev*, 2018
- Efficient improvement of functional and molecular muscle physiology, and could lead to better gait and balance among less active elderly
  - Langeard A et al, *Exp Gerontol*, 2017

CONTINUED

Questions thus far?

CONTINUED

Patient Cases and Treatment Plan Development

CONTINUED

Patient Mary

- 70 y/o female with R CVA 2 wks ago leaving her w/ fairly dence L hemiplegia.
- She is getting significant return in her LLE, but remains fairly flaccid in her LUE
- Complaints of pain in L UE
- Does not appear to have any activation around the shoulder girdle
- When arm unsupported (sitting or standing), she has a 2 finger subluxation
- X-ray shows 7mm inferior subluxation of humerus
- Ambulating with Min Assist with SPC

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Decision Making Process

- Can condition be treated with FES?
- Is patient appropriate?
- What do we need to know to determine appropriateness?
- Parameters for stimulation?
- How do we progress?

CONTINUED

Patient Bob

- SCI T12 incomplete AIS D, 1 year post
- Significant weakness in R LE:
  - 1/5 PF
  - 2/5 DF
- Stronger in L LE:
  - 4/5 PF
  - 2/5 DF
- Lacking ROM at L ankle: -5 degrees DF

CONTINUED

Let's Go Back

Assessment

- Evidence of stance phase instability?
  - YES
  - Deviations?
  - Likely impairments?
- Evidence of swing phase dysfunction?
  - YES
  - Deviations?
  - Likely impairments?
- FES or AFO?

What about this one?

CONTINUED

Assessment

- Evidence of stance phase instability?
  - YES
  - Deviations?
  - Likely impairments?
- Evidence of swing phase dysfunction?
  - YES
  - Deviations?
  - Likely impairments?
- FES or AFO?

CONTINUED

Thanks!
Feel free to contact me
jseale27@sbcglobal.net

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