Using surface electrical stimulation in the management of upper limb spasticity

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Objectives

At the end of this session participants will be able to:

- Explain the rationale for using electrical stimulation to address spasticity.
- Apply 1-channel, surface electrical stimulation to the upper limb with the goal of reducing spasticity.

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Outline

1. Overview of electrical stimulation
   - What, Why & Who
   - Use of e-stim in rehabilitation
2. Overview of spasticity
   - Terminology
   - Pathophysiology
3. Research evidence
   - Guidelines
   - Upper limb examples
   - Meta-analysis
4. Application of ES for spasticity
   - Temporary & longer-term effects
   - Parameter settings

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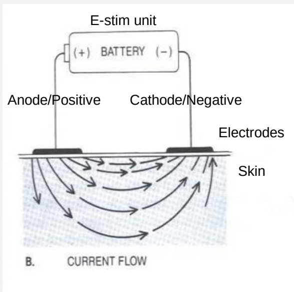
Electrical Stimulation

Application of current to the skin & underlying tissues



NeuroMuscular Electrical Stimulation (NMES)

- Non-specific term
- Applies to any ES intervention using muscle contraction, regardless of treatment goal
- To enhance muscle strength & endurance

Functional Electrical Stimulation (FES)

Use of electrical stimulation of the peripheral nervous system to contract muscles during functional activities such as standing, walking, reaching, grasping, etc.

Why use NMES/FES?

- 2 broad goals: **orthotic** versus **therapeutic**

Orthotic (FES)

- Neuroprosthesis
- ES as orthotic substitute for a particular muscle function
- Client regains independence only with FES

Orthotic Effect - Example

- Alon & McBride 2003 – SCI
- Bioness H200
- Practice of grasp, hold, release
- Studied success rate of 2 ADLs

Results of 1 ADL task:

Baseline	1 wk with H200	3 wk with H200	3 wk no H200
21%	93%	100%	21%

Therapeutic

- Re-establish voluntary control of body position & movement after disruption of motor control mechanisms
- Muscle re-education
- Needs to be applied in context of motor learning
  - Functionally relevant activities
  - Intermittent feedback
  - Client must be an active participant

Therapeutic Effect - Example

Popovic et al. 2002

What causes a therapeutic effect?

- ↑ muscle strength (Glanz et al. 1996)
- ↑ motor unit recruitment (Newsam & Baker 2004)
- Strengthened corticospinal connections (Everaert et al. 2010)
- ↑ cortical activation (Page et al. 2010)

Why E-stim?

- Electrical currents depolarize nerves, causing sensory & motor responses that are used to increase muscle strength & control
- Increase the intensity of rehabilitation
  - Train at higher contraction intensities (Vanderthommen et al. 2003)
- Simultaneously addresses several impairments: weakness, reduced selective motor control, spasticity, sensation/awareness
- Another tool in your tool bag

Why E-stim?

- Strong evidence to support its use
  - Evidence-based Review of Stroke Rehabilitation (ebrsr.com)
  - Spinal Cord Injury Research Evidence (scireproject.com)
- Emerging evidence to support its use
  - Clinical Practice Guideline for the Rehabilitation of Adults with Moderate to Severe TBI (braininjuryguidelines.org)
  - Cerebral Palsy (Novak et al. 2013)

Potential Applications

Potential goals:

- Maintain or ↑ ROM
- ↓ edema
- Muscle strengthening
- Prevent muscle atrophy, shoulder subluxation
- Assist with standing, sitting, transfers
- Improve gait function
- Improve UE function
- **Reduce spasticity**
- Assist with breathing…

Who is *most* appropriate?

- Stroke
- Brain injury
- Spinal cord injury (lesions above T12)
- Cerebral palsy
- Multiple sclerosis
- Parkinson's Disease
- Familial/hereditary spastic paraparesis

- Polio
- Motor neuron disease
- Guillain-Barre syndrome
- Complete peripheral nerve damage

Need intact peripheral nerve

Spinal cord lesions above T6 - autonomic dysreflexia

Contraindications & Precautions

- Implanted electronic devices
- Active DVT
- Pregnancy
- Recently radiated tissue (past 6 months)

- Skin irritation/damage
- ↓ sensation
- ↓ cognition
- Osteoporosis
- Uncontrolled epilepsy
- Conditions that may be exacerbated by ↑ circulation (e.g. infection, neoplasm)

(Houghton et al. *Physiotherapy Canada* 2010)

1 – E-stim

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Have you used e-stim in your practice or research? If yes, for what purpose?

Have you used e-stim in your practice or research to address spasticity?

1 – E-stim

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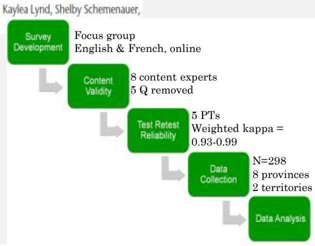
FES Use

Physical Therapists' Use of Functional Electrical Stimulation for Clients With Stroke: Frequency, Barriers, and Facilitators

Nolan Auchstaetter, Juliana Luc, Stacey Lukye, Kaylea Lynd, Shelby Schemenauer, Maura Whittaker, Kristin E. Musselman

(Physical Therapy 2016)



1 – E-stim

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Results: FES Use

Table 1.
Use of Functional Electrical Stimulation by Physical Therapists to Address Specific Therapeutic Goals[a]

Goal	Never	Rarely	Occasionally	Sometimes	Frequently	Most of the Time
Prevent/↓ shoulder subluxation	48.47%	20.68%	10.51%	9.15%	5.76%	5.42%
↑ arm function	48.81%	16.72%	9.90%	9.56%	8.87%	6.14%
↑ walking function	38.85%	18.24%	16.89%	10.47%	8.11%	7.43%
↑ muscle strength, endurance	39.66%	20.34%	14.58%	12.54%	9.15%	3.73%
↓ hypertonia/spasticity	59.93%	17.47%	8.56%	7.19%	4.79%	2.05%
↑ sensation	70.21%	16.10%	7.19%	3.08%	3.08%	0.34%

[a] Never=0% of the time, rarely=1%–20% of the time, occasionally=21%–40% of the time, sometimes=41%–59% of the time, frequently=60%–79% of the time, most of the time=≥80% of the time.

Auchstaetter et al. 2016

Barriers

- 4 main themes identified:

1. Lack of resources
2. Therapist lacking knowledge or training in FES
3. Perception that FES is inappropriate for some stroke patients
4. Therapist preference

53% of respondents would like to increase their use of FES

Barriers

Perception that FES is inappropriate for some stroke patients:

- Children
- Dementia
- **Spasticity**
- Poor skin quality
- Fraility
- Poor sensation
- Acute injury

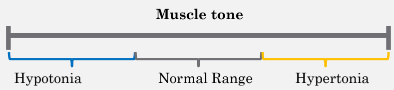
"Lack of success in some clients with lots of spasticity."

- "On the one hand studies employing FES aim for a reduction of spasticity, on the other hand, spasticity might complicate successful electrical stimulation…"
  - Quandt & Hummel 2014

Terminology

- Tone = "resistance to passive stretch while the patient is attempting to maintain a relaxed state of muscle activity"
- Hypertonia = "abnormally increased resistance to externally imposed movement about a joint"
  - May be caused by spasticity, dystonia, rigidity or a combination

Sanger et al. 2003



Terminology

Spasticity

- "Hypertonia in which 1 or both of the following signs are present:
  1. Resistance to externally imposed movement increases with increasing speed of stretch & varies with direction of joint movement
  2. Resistance to externally imposed movement rises rapidly above a threshold speed or joint angle."

Sanger et al. 2003

"Spasticity is something you feel, dystonia is something you see."

- Amy Bastian PT PhD

Pathophysiology of Spasticity

- Spasticity caused by adaptive changes in spinal networks
  - Does not appear immediately post-lesion

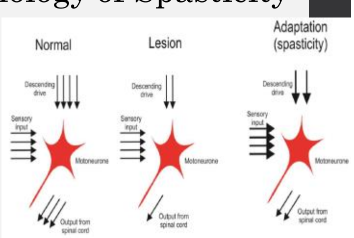
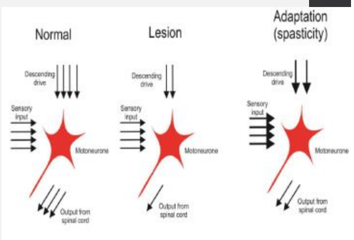


Fig. 2. Theoretical changes in sensory and descending input to spinal motoneurones in the acute and chronic phase following central motor lesion.

Figure from Nielsen et al.
http://elsassfonden.dk/files/2015/05/Chapter2jl.pdf

Pathophysiology of Spasticity

- Underlying mechanisms of adaptive change are not known
- Imbalance in inhibitory & excitatory input to alpha motor neurons



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Research Evidence

Evidence-based Review of Stroke Rehabilitation 16th ed (ebrsr.com)

There is *strong* (level 1a) evidence that ES decreases spasticity in chronic stroke.

(Teasell et al. 2014)

Evidence-based Review of Stroke Rehabilitation 17th ed (ebrsr.com)

- Level 1a evidence that NMES/FES may not ↓ elbow or wrist spasticity
- Level 2 evidence that NMES/FES ↓ spasticity in the hemiplegic shoulder
- Level 1b evidence that NMES/FES with botulinum toxin injection ↓ muscle tone

(Teasell et al. 2016)

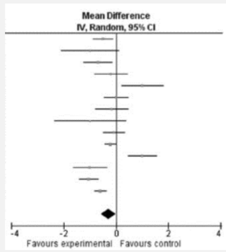
Examples from the Literature

Sahin et al. 2012

- Chronic stroke (n=42) with forearm flexor spasticity (Modified Ashworth Score (MAS) score 2 or 3)
- RCT with 2 arms
  - Arm 1: stretching with PNF after hot treatment followed by 15 min of NMES to wrist extensors
  - Arm 2: stretching with PNF after hot treatment
- 5 days/week for 20 sessions total
- Outcomes assessed pre- & post-intervention: MAS, wrist extension ROM, total FIM, Brunnstrom motor staging
- Both groups showed significant improvements on all outcomes; Arm 1 showed significantly greater improvement than Arm 2

Stein et al. 2015

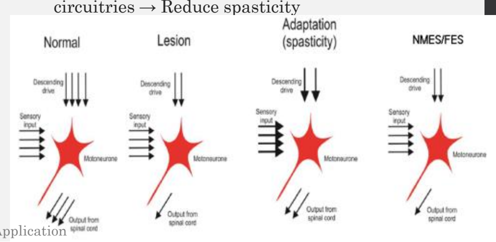
- Meta-analysis of effect of NMES (w/wout other therapy) vs. placebo or other intervention
- Primary outcome: MAS
- 14 RCTs included
- NMES ↓ spasticity: -0.30, 95% CI -0.58 - -0.03), $I^2 = 81\%$ (high heterogeneity)



*Need for biomechanical & electrophysiological assessment of spasticity (Nielsen & colleagues)

Management of Spasticity with ES

- Temporary ↓ in spasticity
  - Motor-level stim
  - Sensory-level stim
- Longer-term ↓ in spasticity
  - NMES/FES may induce plasticity in spinal cord circuitries → Reduce spasticity



Management of Spasticity with ES

- Temporary ↓ in spasticity reported when <u>motor-level</u> ES applied to:
  1. Antagonist (Alfieri 1982, Bakhtiary & Fatemy 2008)
     - May be due to reciprocal inhibition of spastic muscle
  2. Spastic muscle (Robinson et al. 1988)
     - Causes neuromuscular fatigue at higher frequencies
     - Antidromic propagation of APs to, & post-tetanic potentiation of, Renshaw cells in spinal cord inhibit alpha motor neurons of spastic muscle
  - #1 preferred because also involves training of weak, non-spastic muscle

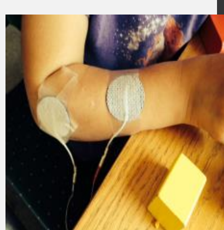
Management of Spasticity with ES

- Temporary ↓ in spasticity reported with <u>sensory-level</u> ES applied to:
  1. Dermatomes of nerves supplying spastic muscles (Bajd et al. 1985)
  2. Skin over peripheral nerve trunk, branches of which innervate spastic muscles & their antagonists (Levin et al. 1992, Goulet et al. 1996, Chung & Cheng 2010)
- Sensory-level ES of UE reported to reduce LE spasticity (Walker 1982)
  - Depression of spinal reflex excitability

Management of Spasticity with ES

Longer-term effects: pediatric case

- 2.5 year old girl with hemiplegic CP
- ↑ tone preventing elbow, wrist & finger extension
- Limited use of UE in daily activities
- 8 week trial of FES to UE
  - 2-channel (triceps & wrist/finger extensors)
  - two 30-minute sessions/day
  - 5 days per week
  - 8 wk program



Musselman et al. 2018

Management of Spasticity with ES

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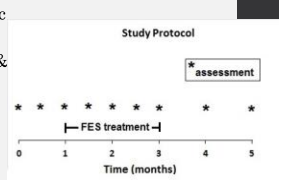
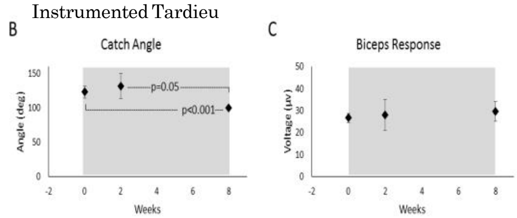


Musselman et al. 2018

Management of Spasticity with ES

Instrumented Tardieu



*Is benefit retained long-term?

Management of Spasticity with ES

<u>Evidence-based Review of Stroke Rehabilitation 17th ed</u>

Level 1b evidence that NMES/FES with botulinum toxin injection ↓ muscle tone

How ES might ↑ anti-spasticity effect of botox:

1. Paralytic effect of botox starts earlier when toxin uptake ↑ by ES
2. Moving muscles through flexion-extension cycles may mechanically spread toxin
3. Direct effects of ES on hypertonicity

(Wilkenfeld 2013)

Case Study

- **History:** Tom is a 28 year-old teacher who suffered a traumatic brain injury from a motor vehicle crash 3 months ago (he was in a coma for 2 weeks). He was recently admitted to a rehabilitation facility.
- **Evaluation:**
- ROM
  - PROM L elbow extension: -30
  - PROM L wrist extension: -20 from neutral
  - Unable to extend fingers to neutral position
- Spasticity
  - Modified Ashworth Grade 3 in L biceps & wrist extensors
- Functional Assessment
  - Requires minimal assistance to maintain sitting dynamic balance
  - Unable to bear weight in L UE to assist with maintaining balance
- Unable to use L upper extremity for ADLs

Case Study

- **Goal:**
- **NMES/FES treatment plan:**
- **Physiologic rationale:**

E-stim Parameters

Don't be a "**Knobologist**"!

"Knobology is a 'tongue-in-cheek' term for the study of application without theory…the term for students and clinicians who want to know only which knobs on a therapeutic modality to turn and are uninterested in why they are doing so…patients would suffer from inadequate treatment."

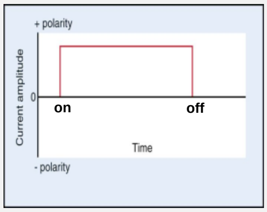
(Knight & Draper, Therapeutic Modalities: The Art and Science)

E-stim Parameters

1. Currents
2. Waveform, polarity
3. Electrode placement
4. Amplitude
5. Pulse duration
6. Frequency
7. Ramp up/down
8. On/off time

Currents

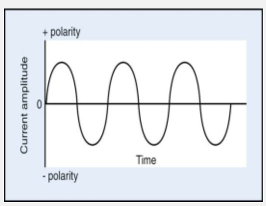
1) Direct Current (DC)
   - Uninterrupted flow of charged particles in 1 direction
   - Iontophoresis, wound healing, stimulating denervated muscle
2) Alternating Current (AC)
3) Pulsatile Current



4 – Application

Currents

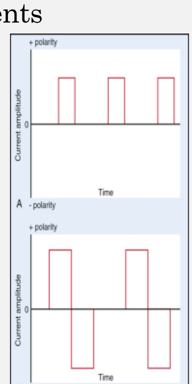
1) Direct Current (DC)
2) Alternating Current (AC)
   - Continuous flow of charged particles in alternating directions
   - Symmetrical or asymmetrical
3) Pulsatile Current



4 – Application

Currents

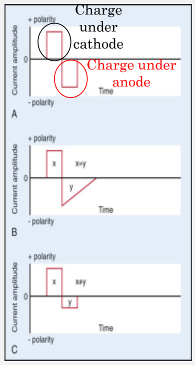
1) Direct Current (DC)
2) Alternating Current (AC)
3) Pulsatile Current (PC)
   - Interruptions in current flow
   - Most common current used in electrotherapeutic devices



4 – Application

Waveform

- Shape or visual representation of current over time
- Biphasic can be symmetrical (fig A) or asymmetrical
- Asymmetrical can be balanced (fig B) or unbalanced (fig C)



Polarity

- Cathode/anode
- Issue only when current is monophasic or asymmetrical, unbalanced, biphasic PC
- In these cases, cathode (negative) will elicit greater response for same charge than anode

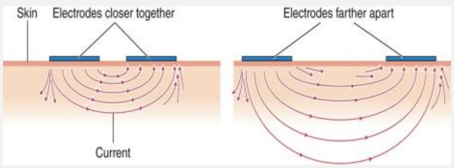
Waveform/Polarity

- Important for discrete and comfortable stim
- Symmetric biphasic most comfortable for larger muscles
- Asymmetric, unbalanced required for small muscles to ensure specificity (Baker et al. 1988)
  - Cathode on motor point
  - http://www.axelgaard.com/Education/Motor-Point-Location-for-Electrode-Placement

Electrode Size & Placement

Electrode size:
- ↓ size will ↑ current/charge density (amount of current delivered per unit area of electrode)

Electrode placement:
- Distance between electrodes affects depth of current



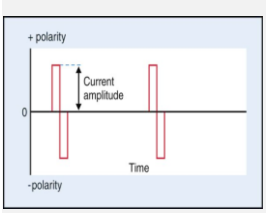
Case Study

- **Electrode position:**

http://www.axelgaard.com/Education/Elbow-Extension
http://www.axelgaard.com/Education/Wrist-and-Finger-Extension

- **Waveform/polarity:**

Amplitude

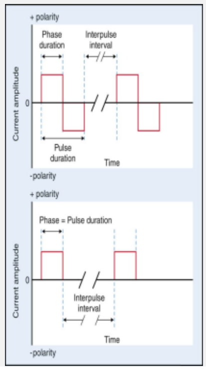


- AKA intensity or strength of current, measured in Amperes
- Magnitude of current or voltage
- Affects total current delivered

Increase in amplitude → increase in current delivered → increase in number of motor units recruited → increase muscle force generated

Pulse Duration

- AKA pulse width (cycle duration for AC)
- Length of time 1 pulse lasts
- Units: μs (10^{-6}) or ms (10^{-3})
- Affects total current delivered
- ↑ pulse duration to ↑ charge
- Motor response >100 μs



4 – Application

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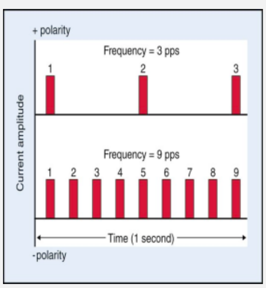
Frequency



- Number of pulses (PC) or cycles (AC) delivered per unit of time
- Expressed in pulses per second (pps) for PC or Hz for AC
- Affects the pattern or quality of response
  - Tetany at ~30-35 pps or Hz
- ↑ fatigue with ↑ frequency

4 – Application

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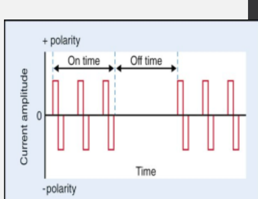
On/Off Time

- On time = time during which pulses occur
- Off time = time when no current flows
  - Used to delay fatigue
- Duty cycle = ratio of on time to total cycle time (on time + off time)



4 – Application

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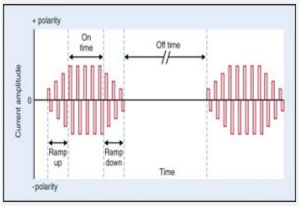
Ramp Up/Ramp Down

Time it takes for current to increase from zero to maximum amplitude and vice versa



- Ramp-up
  - comfort
  - mimic ↑ in muscle force of voluntary contraction
  - Prevent ↑ spasticity in antagonist
- Ramp-down
  - mimic relaxation of voluntary contraction

Spasticity (Motor-level)

Parameters	Settings
Pulse/cycle duration	150-200μs small muscles, 200-350μs large muscles
Current amplitude	To visible contraction
Ramp-up/Ramp-down	At least 1s (longer when stimulating antagonist to spastic muscle)
Frequency	35-50 pps
On time	2-5s
Off time	2-5s; equal on:off times
Treatment time	10-30min, every 2-3hrs until spasm relieved
Electrode configuration	Over spastic muscles or antagonists

From: Cameron, Michelle H. *Physical Agents in Rehabilitation: From Research to Practice*. 4th ed. 2013.

Case Study

- **Pulse duration:**
- **Frequency:**
- **Amplitude:**

Case Study

- **Ramps:**
- **On/off time:**
- **Intervention duration:**

Summary & Questions