Changing Muscle Evoked Responses to Improve Locomotion after Spinal Cord Injury

Aiko K. Thompson

Department of Health Sciences and Research
College of Health Professions
Medical University of South Carolina
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  - Individual evaluation form

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Learning objectives

1. Recognize roles of spinal cord pathways and spinal cord plasticity in motor control and motor skill learning
2. Recognize changes in spinal cord pathways after spinal cord injury
3. Discuss how operant conditioning of muscle evoked responses can improve spastic gait in people after spinal cord injury.
Voluntary control of movement

Corticospinal activation of motoneurons
Does the cortex take care of multiple muscle activation individually?

Organization of motoneuron pools

From Yakovenko et al., J Neurophysiol. 87:1542-53, 2002

Modified from Makihara et al., J Neurophysiol. 112:1439-46, 2014
Spinal reflex pathways in motor control

- Ia excitation (i.e., spinal (M1) stretch reflex, H-reflex) and inhibition (i.e., reciprocal inhibition)
- Ib excitation and inhibition
- II excitation
- Presynaptic inhibition
- Recurrent inhibition
- Cutaneous reflexes

Multiple spinal reflex pathways are utilized in:
- activation of single muscle group
- coordinated activation of multiple muscles
  → enable normal locomotion
H-reflex activity is modulated between/within tasks.

(from Neuroscientist, 2014 Epub)
Reflex modulation is altered after SCI

2. Changes in spinal cord pathways after SCI

(from Neuroscientist, 2014 Epub)
Hyperactivity and malmodulation of the H-reflex pathway during walking
3. Operant conditioning of EMG evoked potentials to improve gait after SCI

Operant conditioning of the H-reflex

Modification of a behavior (i.e., reflex behavior) is brought about by the consequence of that behavior

Conditioning mode-appropriate CNS activity
Operant conditioning of the soleus H-reflex in human subjects

Setup view

Session schedule

- **Baseline**: 3 sessions/wk for 2 wks
- **Conditioning**: 3 sessions/wk for 8 wks
- **Follow-up**: 4 sessions over 4 mo

Session protocol

- **Control reflexes**
- **75 cond. reflexes (1)**
- **75 cond. reflexes (2)**
- **75 cond. reflexes (3)**
- **H_{max} M_{max}**

Visual feedback

Success rate 78%

Trial: 73
Human subjects can learn to change the reflex size through operant conditioning.
H-reflex conditioning does not disturb normal locomotion

(J Neurophysiol 112:1439-46, 2014)
Operant down-conditioning of the soleus H-reflex in people with incomplete SCI

**Subjects**: people with incomplete SCI who suffer from spastic hyperreflexia. (More affected leg is studied.)

**Visual feedback**

![Visual feedback chart]

**Study Schedule**

<table>
<thead>
<tr>
<th>Sessions</th>
<th>Baseline</th>
<th>Down-Conditioning or Control</th>
<th>Follow-Up</th>
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**Gait eval.**
H-reflex size decreases over the course of down-conditioning in people with incomplete SCI

(J Neurosci, 29: 5784–5792, 2009)
(J Neurosci, 33: 2365–2375, 2013)
Conditioning improves walking speed and step symmetry

Before conditioning, non-conditioned leg’s foot contact (FC) to conditioned leg’s FC interval is longer, due to spasticity and foot drop. Successful conditioning restores a more normal step rhythm.

(J Neurosci, 33: 2365–2375, 2013)
Successful conditioning improves locomotor EMG bilaterally

(J Neurosci, 33: 2365–2375, 2013)
Successful conditioning improves locomotor EMG

Smaller H-reflex

Decreased spastic activity during the swing phase

(J Neurosci, 33: 2365–2375, 2013)
Operant down-conditioning of the soleus H-reflex during walking in people with incomplete SCI

**Subjects:** people with incomplete SCI who suffer from *spastic hyperreflexia* who can walk on the treadmill (More affected leg is studied.)

H-reflex trials occur during the mid-late swing
Down-conditioning of the swing-phase soleus H-reflex in people with incomplete SCI
Swing-phase H-reflex down-conditioning may improve locomotion.
Down-conditioning of the soleus stretch reflex in people with incomplete SCI
Summary: Operant conditioning of spinal reflexes in people with SCI

• People after incomplete SCI can learn to decrease the reflex size through operant conditioning.

• Successful reflex conditioning can improve gait in people with spasticity due incomplete SCI.
Successful conditioning can improve mobility
(interview with a subject with SCI)
Operant conditioning of motor evoked potential (MEP) by transcranial magnetic stimulation

**Hypothesis**: operant up-conditioning of the ankle dorsiflexor MEP can strengthen corticospinal excitability and connectivity, and alleviate foot-drop in people with chronic incomplete SCI.

**Session schedule**

- Clin./Funct. assessment
- Baseline
- Conditioning or control
- Clin./Funct. assessment
- F1
- F2
- F3

**Visual feedback**

- Control trials: Trial: 16, Background EMG
- Conditioning trials: Trial: 38, Background EMG, MEP
- Success rate: 78.95%
Up-conditioning can increase TA MEP size in neurologically normal subjects.
Successful MEP up-conditioning does not disturb normal locomotion in normal subjects
Subjects with incomplete SCI can learn to increase MEP size in response to up-conditioning.
Successful MEP up-conditioning may improve locomotor EMG in subjects with SCI.
Gait kinematics may improve after successful MEP up-conditioning in subjects with SCI.
Summary to date:
MEP up-conditioning in people incomplete SCI

• TA MEP up-conditioning is possible in people with chronic incomplete SCI.

• MEP conditioning can improve walking speed (i.e., 17-50% faster), locomotor EMG and kinematics.

• Conditioning effects can last for a long time and can be maintained.
Conclusion

 Appropriately changing EMG evoked responses through operant conditioning protocols may improve gait in people with chronic incomplete SCI.
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