Objectives

1. Discuss the incidence and significance of sensory dysfunction following stroke.
2. Summarize current evidence on the psychometrics and clinical utility of various sensory examination tools.
3. Discuss the evidence regarding interventions that target the somatosensory systems following stroke.
4. Describe the key parameters of somatosensory interventions for individuals following stroke.

Introduction

Widespread incidence of post-stroke sensory dysfunction (PSSD)

Association between PSSD & poor outcomes

Motor capacity
Function
Length of inpatient stay
Quality of life

Sensory Information

EXTEROCEPTION
Information from the skin & subcutaneous tissue
Pain, temperature, touch, pressure

PROPRIOCEPTION
Receptors in muscles, tendons, ligaments, & fascia
Body position & movement
Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

Stroke Distribution
- Ischemic stroke most common (> 80%)
- Middle cerebral artery most commonly occluded

Incidence of PSSD
- Stroke incidence
- Reported incidence of PSSD 11% to 85% (Moskowitz, 1972; Kim, 1996; Connell, 2008)
- Reasons for underestimates (Yakutiello, 2000)
- Uni-modal versus multi-modal exam (Kim, 1996)
- Exam & reporting may hamper accurate estimates of PSSD.
# Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

## Incidence of PSSD

<table>
<thead>
<tr>
<th>Winward, 2007 (n=18)</th>
<th>Tyson, 2007 (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proprioception least impaired</td>
<td></td>
</tr>
<tr>
<td>Sensory impairment</td>
<td></td>
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<tr>
<td>Tactile sensation</td>
<td></td>
</tr>
<tr>
<td>Stereognosis most impaired</td>
<td></td>
</tr>
<tr>
<td>Proprioception proximal $\rightarrow$ distal</td>
<td></td>
</tr>
</tbody>
</table>

Incidence of PSSD

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<tr>
<th>Winward, 2007 (n=18)</th>
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<td>Proprioception proximal $\rightarrow$ distal</td>
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</tr>
</tbody>
</table>

### Significance of PSSD

- Relationship between PSSD & other impairments not clear
- Stroke severity & weakness are significantly correlated with PSSD (Tyson, 2007; Connell, 2008)
Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

Somatosensory Evoked Potentials (SSEP)

- Stimulate a peripheral nerve & record the response upstream
- Abnormal SSEPs correlated with PSSD (Williamson, 1970; Zeman, 1989; van Buskirk, 1995)

Abnormal SSEPs have been associated with reduced motor recovery following stroke (Kusoffsky, 1982; La Joie, 1982; Chester, 1989)

Acute SSEPs → predictive of motor recovery in the arm & to a lesser extent the leg (Kusoffsky, 1982; La Joie, 1982; Tzvetanov, 2003; Al-Rawi, 2009)

Acute SSEPs → significantly associated with functional outcomes (Zeman, 1989)

> 90% of PTs, OTs, & physicians regard sensory examination as clinically important in determining prognosis following stroke (Winward, 1999)

PSSD → Prognosis

- PSSD → prognostic for long-term function (Reding, 1988; Carey, 1995; Kwakkel, 1996; Fang, 2003; Tien, 2007; Welmer, 2007)
- PSSD compounds motor impairments resulting in lower functional outcomes (Ivers, 1977; Reding, 1988; Niam, 1999; Sanchez-Blanco, 1999; Patel, 2000; Han, 2002)

Significance of PSSD

- Slower recovery of motor function (Reding, 1988)
- Predictive of length of stay & discharge placement (Anderson, 1971; Smith, 1983; Rose, 1994; van Buskirk, 1995; Gottlieb, 1997; Sommerfeld, 2004)

Slower recovery of motor function (Reding, 1988)

Increased mortality (Sheikh, 1983; Appelros, 2003 & 2004)

Predictive of length of stay & discharge placement (Anderson, 1971; Smith, 1983; Rose, 1994; van Buskirk, 1995; Gottlieb, 1997; Sommerfeld, 2004)

Poor Balance
- Arm Injuries
- ↑ Incidence of Falls
- Burns
- Shoulder Pain, CRPS/RSD
- Shoulder Subluxation
- Hard swelling

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PSSD and Selection of Intervention

Determining the presence or severity of PSSD may help clinicians predict outcomes following intervention strategies.

- Constraint Induced Therapy
  (van der Lee, 1999)
- Sensory re-training
  (Yekutiel, 1993)

Natural Recovery of Somatosensation

- Less information on recovery of sensation than motor function
- Historical belief that sensation is less important to movement (Yekutiel, 2000; Winward, 2007)

PSSD and Selection of Intervention

Determining the presence or severity of PSSD may help clinicians predict outcomes following intervention strategies.

- Constraint Induced Therapy
  (van der Lee, 1999)
- Sensory re-training
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Natural Recovery of Somatosensation

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Serial sensory &amp; motor examination</td>
<td>18</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Serial sensory &amp; motor examination</td>
<td></td>
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<tr>
<td>Rivermead Assessment of Somatosensory Performance</td>
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<tr>
<td>Nottingham Sensory Assessment</td>
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</tr>
<tr>
<td>Findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All subjects showed some recovery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>with no specific pattern of recovery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>across subjects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General trend toward recovery in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>most sensory modalities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proprioception most improved</td>
<td></td>
<td></td>
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<tr>
<td>Initial sensory impairment related</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>to impairment at 6 months</td>
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<td></td>
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<tr>
<td>Motor performance predictive of</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>stereognosis improvement</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Motor Recovery Feydy, 2002

Bilateral → Contralateral

Bilateral

Natural Recovery of Somatosensation

- Sensory Recovery trajectories
  (Connell, 2008)

Sensory Recovery trajectories

(Connell, 2008)

Data-points represent mean and SE (error bar)

- Upperlimb tactile sensations
- Upperlimb fine touch sensations
- Tactile sensitivity
- Proprioception

Winward, 2007

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Winward, 2007

Natural Recovery of Somatosensation

Evoked magnetic fields - median nerve stim → activation in ipsilesional primary and bilateral secondary somatosensory cortices
(Wickston, 2000)

fMRI → cortical map reorganization along the infarct rim an important contributor to recovery of sensation
(Cramer, 2000)

Natural Recovery of Somatosensation
(Cavey, 2002)

Single case: individual with initial severe sensory loss who recovered

Serial, whole-brain fMRI

Recovery associated with a return of activation in ipsilesional primary and bilateral secondary somatosensory cortices


fMRI study of touch discrimination at 2 weeks, 3 months, and 6 months after stroke, showing activation during stimulation of the right affected hand (top two rows of images) and left “unaffected” hand (bottom two rows)

Natural Recovery of Somatosensation

Impact on Intervention?
Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

Prognosis for Recovery of Somatosensation
- Association between dysfunction & recovery is unclear
- Pattern of recovery NOT related to stroke severity (Carey, 1993)
- Significantly less recovery of sensation in individuals with lesions in the non-dominant hemisphere (Lundgren, 1982)
- Anatomical redundancy improves prognosis for recovery with cortical CVA (Carey, 1993)

Sensory Exam
- Standard practice for most PTs & OTs (Winward, 1999)
- Proprioception & light touch most commonly tested (Winward, 1999)

Concerns about the Sensory Exam
- Exam is often limited and largely subjective (Carey, 1995)
- Clinical utility of tools/batteries (time, equipment availability)

Concerns about the Sensory Exam
- Validity
  - Tools designed for PNS exam (Maas, 2002)
  - Cognitive, language, attentional barriers (Chen, 2005)
- Reliability
  - Lack of standardization
  - Large ceiling effects (Lin, 2004)

Scope of sensory exam
- Proprioception
  - Manual
  - Mechanical device
- Touch
  - Two-point discrimination
  - Tactile discrimination
  - Moving touch pressure & sustained touch pressure
  - Perceptual threshold of touch using electrical stimulation

Reliability
<table>
<thead>
<tr>
<th>Chronic &amp; split-half statistics</th>
<th>Test-retest or inter-rater reliability (ICC or kappa statistics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent: ≥ 0.80</td>
<td>Excellent: ≥ 0.75</td>
</tr>
<tr>
<td>Adequate: 0.70 - 0.79</td>
<td>Adequate: 0.40 - 0.74</td>
</tr>
<tr>
<td>Poor: &lt; 0.70</td>
<td>Poor: &lt; 0.40</td>
</tr>
</tbody>
</table>

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Scope of sensory exam

**Proprioception**
- Manual
- Mechanical device

**Touch**
- Tactile discrimination
- Two-point discrimination
- Moving touch pressure & sustained touch pressure
- Perceptual threshold of touch using electrical stimulation

**Experimental mechanical device**
- Experimental mechanical device
  - Participants compared pairs of movements of different amplitudes. Significant difference between stroke participants’ involved and less involved arms and between stroke participants and healthy controls. (Sartor-Glittenberg, 1993)

**Device to measure wrist position**
- Device to measure wrist position
  - Validity: excellent (Carey, 1996)

Tactile Discrimination Test (Carey, 2002)

- Test-retest reliability: excellent

Perceptual threshold of touch using electrical stimulation (PTT-ES)
- Validity: statistically significant positive correlation between the PTT-ES and Nottingham Sterognosis Assessment and between PTT-ES and Motor Activity Log-14
- Intrarater reliability: excellent for unwound and involved hands (Sullivan, 2008)

(Miller, 2009)

Carey, 1996
Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

Moving Touch Pressure (MTP) & Sustained Touch Pressure (STP)

Inter- & intrarater reliability: excellent for MTP and adequate for STP
Concurrent validity: MTP & STP correlated significantly with Semmes-Weinstein Monofilaments (Dannenbaum, 2002)

Scope of sensory exam

Stereognosis

Multi-modal Batteries

Rivermead Assessment of Somatosensory Performance

- touch discrimination, localization, extinction, temperature & pressure

Nottingham Sensory Assessment

- light touch, pressure, pinprick, temperature, localization, position

Sensory subscale of Fugl-Meyer Assessment

- light touch & position

Byl-Cheney-Bocci Sensory Discriminator Test

n = 28 with hand dysfunction
n = 38 controls
Interrater reliability: ICC = 0.957
Validity: significant positive correlation (+0.41 to +0.53) between the BCI and measures of stereognosis and graphesthesia
Homogeneity: significant correlation between gains on the test and function following an intervention (Byl, 2002)

Nottingham Sensory Assessment Stereognosis Scale

n = 20 with acute stroke
Interrater reliability (Gaubert, 2000)

Hand Active Sensation Test

n = 28 with chronic stroke
n = 28 matched controls
Significant difference between control and stroke groups
Test-retest reliability: adequate
Validity: significant positive correlation with two-point discrimination and wrist position test (Williams, 2006)

Single or Multi-modal Examination?

Single outcome measure (Bohannon, 1996)

Multi-modal testing (Kim, 1996; Carey, 1996; Connell, 2008)

Screening versus Detailed Test?

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**Sensory Dysfunction Following Stroke:**
*Incidence, Significance, Examination and Intervention*

**Bottom line EXAM recommendations**
- Screen somatosensation for everyone (tactile, stereognosis) distal proprioception
- Do we have to test multiple sites in a limb? (Connell, 2008, Busse, 2009)
- Formally test if linked to movement dysfunction & goals
- Standardize your exam
- Research or clinical setting?
- Consider time & equipment

**Historical Intervention for PSSD**
- Screen somatosensation for everyone (tactile, stereognosis) distal proprioception
- Do we have to test multiple sites in a limb? (Connell, 2008, Busse, 2009)
- Formally test if linked to movement dysfunction & goals
- Standardize your exam
- Research or clinical setting?
- Consider time & equipment

**Not just a sham intervention**


**Current View of Sensory Intervention/Outcomes**
- Is motor training enough?
- Is specific sensory intervention required?
- More rigorous studies
- Better outcome measures

**Overview of Recent Sensory Studies**

<table>
<thead>
<tr>
<th>Passive</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg</td>
<td>Arm</td>
</tr>
<tr>
<td>Whole Body</td>
<td>Multi-Modal</td>
</tr>
<tr>
<td>Single Session</td>
<td>Multi Session</td>
</tr>
<tr>
<td>Acute Sub-acute</td>
<td>Chronic</td>
</tr>
<tr>
<td>Trial</td>
<td>Case(s)</td>
</tr>
</tbody>
</table>

**Improvements Reported following Sensory Intervention**

<table>
<thead>
<tr>
<th>Sensation</th>
</tr>
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<tbody>
<tr>
<td>- Clinical sensory exams (tactile, discrimination, proprioception)</td>
</tr>
<tr>
<td>- Perceptual tests</td>
</tr>
<tr>
<td>- Electrophysiologic testing (e.g. SSEP)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motor Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Selective Control</td>
</tr>
<tr>
<td>- Force</td>
</tr>
<tr>
<td>- Spasticity</td>
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</tbody>
</table>

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# Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

## Improvements Reported following Sensory Intervention

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<th>Motor Function</th>
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<td>Spasticity</td>
</tr>
</tbody>
</table>

## Functional Improvements following Sensory Intervention

- Arm Function
- Balance
- Gait
- Assistance required
- Speed
- Length of stay
- Quality of Life

## Sensory Interventions

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Parameters</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory Training Tasks</td>
<td>Session length brief (10 – 90 min.)</td>
<td>Generally small (≤ 22)</td>
<td>Improvements on clinical sensory exams</td>
</tr>
<tr>
<td>Intermittent Compression</td>
<td>Repetitive (daily or every other day)</td>
<td>Several cases or single subjects</td>
<td>Motor capacity (less often reported), &amp; upright activities (balance/gait)</td>
</tr>
<tr>
<td>Thermotherapy</td>
<td>For several weeks (2-10)</td>
<td>Mostly subacute or chronic stroke</td>
<td></td>
</tr>
<tr>
<td>Passive Movement</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Sensory Exploration Studies

- 6 studies of “active sensory training” → protocols that focused on...“discriminating and localizing sensations, stereognosis, and proprioception”
- All addressed the hand
- Empirical evidence limited

## Electrical Stimulation Studies

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Parameters</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SES alone or combined with NMES to the UE, LE, or neck</td>
<td>Session length brief (15 – 60 min.)</td>
<td>3 cases</td>
<td>Improved:</td>
</tr>
<tr>
<td></td>
<td>Repetitive (2-5x/week)</td>
<td>6 RCTs</td>
<td>Impairment - force, selective movement, spasticity, perception</td>
</tr>
<tr>
<td></td>
<td>For several weeks (4-12)</td>
<td>Acute $\rightarrow$ chronic stroke</td>
<td>Function - UE, LE, balance &amp; gait</td>
</tr>
</tbody>
</table>

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SES to the Legs
Evidence that SES with task-specific exercise can result in
↑ muscle torque, gait speed, ↓ spasticity
Ng, 2007
↑ 6MWT & TUG scores
Hui-Chan, 2009
Evidence that SES can ↑ posture & balance
Tyson, 2003; Worms, 2006

SES to the Arms
↑ Sensation - Peurala, 2002,
Sullivan & Hedman 2004 & 2007
↑ Spasticity - Dewald, 1996
↓ Limb inattention - Valler, 1996; Prada, 1999; Mackenzie-Knapp, 1999,
Perennou, 2001; LaFosse, 2003
↑ Motor Control /Force - Sonde, 1998; Peurala, 2002; Confarto, 2002
Wu, 2006; Celnick, 2007

Meta-analysis
(Schabrun, 2009)
8 studies of “passive sensory training” → afferent stimulation protocols
which did not produce muscle contraction
7 studies addressed the hand
Significant beneficial effect on hand
dexterity & grip strength
Intervention parameters

Intermittent Compression

<table>
<thead>
<tr>
<th>Intervention Parameters</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermittent pneumatic compression to the UE</td>
<td>• Session length brief (up to 30 min.) &amp; • repetitive (daily) • for several weeks (4)</td>
<td>• 1 case acute stroke • 23 with chronic stroke</td>
</tr>
</tbody>
</table>

Vibration Studies

<table>
<thead>
<tr>
<th>Intervention Parameters</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration to: • calf • palm, or • whole body</td>
<td>• Session length brief (4-20 min.) &amp; • repetitive (daily) • for several weeks (4-6)</td>
<td>• 1 case report • 2 studies with 40-60 stroke subjects • Acute or chronic stroke</td>
</tr>
</tbody>
</table>

Thermotherapy Studies

<table>
<thead>
<tr>
<th>Intervention Parameters</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal intervention to: • UE (hot pack, ice H10°) • LE (water)</td>
<td>• Session length brief (10 – 30 min.) &amp; • repetitive (daily) • for several weeks (up to 6 weeks)</td>
<td>• 10-30 subjects • Acute &amp; chronic stroke</td>
</tr>
</tbody>
</table>
Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

**PROM Studies**

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Parameters</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE → Passive movement alone OR before task-based practice</td>
<td>• Session length brief (10-20 min.) &amp; • repetitive (3-5 d/week) &amp; • for 4 weeks</td>
<td>• 13 with acute stroke &amp; • 32 with chronic stroke</td>
<td>• fMRI but not clinical changes • Improved motor function</td>
</tr>
</tbody>
</table>

**Across Interventions**

<table>
<thead>
<tr>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief (10-30 minutes)</td>
</tr>
<tr>
<td>Repetitive (3-5 days/week)</td>
</tr>
<tr>
<td>for several weeks</td>
</tr>
</tbody>
</table>

**Graded Hierarchies**

(Dannenbaum, 1988; Carey, 1993; Yekutiel, 1993; Hillier, 2006; Lynch, 2007)

Do the improvements persist?

**Guidelines for Application (Yekutiel, 2000)**

1. Explore sensory loss
2. Practice mastered sensory tasks 1st and last
3. Choose tasks based on interest
4. Use vision and other hand
5. Frequent rests
6. Don’t use test tasks in training

**Guidelines for Application**

- Attention
- Obscure Vision
- Exploration
- Feedback
Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

Pay Attention!

Healthy subjects:
- Cortical change from sensory stimulation associated with attention (Johansen-Berg, 2000; Rosenkranz, 2006)

Stroke subjects:
- Attention during wrist PROM → enhanced motor evoked potentials (Lackner, 2003)
- Enhanced arm function associated with attention during sensory stimulation (Stinear, 2005; McDonnell, 2007)

Dose-response → time
(byl, 2008)

- 45-6-8-week learning-based sensorimotor training program either:
  - 1x/week, 1.5 hours/visit, OR
  - 3x/week, 0.75 hours/visit OR
  - 4x/week, 3 hours/visit
- gains were dose specific → greatest change in the high-intensity group

Passive or Active?

Voluntary movement → more effective than afferent input at inducing cortical reorganization in healthy participants (Trieu et al., 2005; Letae, 2003; Perez, 2004; Kaelin-Lang, 2005) and stroke survivors (Hennner, 2007)

Dose: Response → Amplitude

- amplitude of ES affects cortical activation (Fraser, 2002, Smith, 2003)
- dose-response relationship (Smith, 2003)
- 1º sensory cortex more sensitive to increasing stimulation amplitude (Jousmaki, 1999; Backes, 2000)
- differences may relate to afferents recruited

Underlying Mechanisms of Change

Poststroke stroke – alteration in the normal balance of cortical excitability (Liepert, 2000; Murase, 2004) & patterns brain activation (Carey, 2006)

- Plastic changes → basis for lasting behavioral change (Butefisch, 2006)

- Stimulation of muscle & articular and cutaneous afferents → activation of the sensory and motor cortex in healthy participants (Radovanovic, 2002)

Sensory Dysfunction Following Stroke: Incidence, Significance, Examination and Intervention

Underlying Mechanisms of Change

↑cortical excitability occurred either by ↑ cortical facilitation and/or ↓ intracortical inhibition (Rosenkranz, 2003; Ridding, 2000; Lewis, 2001; Kaellin-Lang, 2001, Fraser, 2002)

Effects peaked from 10 (Fraser, 2002) to 60 minutes (McKay, 2002) after stimulation began and lasted up to 20 minutes afterward (Kaellin-Lang, 2001)

Underlying Mechanisms of Change

Net ↑ in cortical excitability may set the stage for long-term potentiation → thought to underlie motor learning and cortical plasticity associated with recovery from stroke (Doblin, 2003, McKay, 2002; Miles, 2005)

Summary Points - EXAM

Incidence and significance of PSSD
Sensory screening should be part of Systems Review or Screening part of the Exam
If sensory screening is + → more detailed exam may be warranted
Multi-modal versus single modality exams?
Depends on time, equipment, and hypotheses
Research versus clinical settings

Summary Points - INTERVENTION

Sessions should be brief and repetitive.
Active intervention more powerful than passive (movement and exploration/problem-solving).
Attention to task and feedback about performance/results may enhance effect.
Graded hierarchy of tasks
Sensory input in critical to all motor performance