Learning and Memory Processes: 
Mechanisms and Application to 
Neurorehabilitation

Contextual Interference, Practice Structure, the Action Observation System

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Motivation

• My lecture describes 3 studies motivated in part by an observation which I construed as a challenge:
  – “There have been surprisingly few studies of motor learning after stroke and almost none looking at deficits in motor memory formation despite the likely relevance of these processes to rehabilitation” (Krakauer, 2006, p. 85)
Neurorehabilitation is a complex biological, cognitive, and psychological process which aims to aid recovery from a nervous system injury, and to minimize and/or compensate for any functional alterations resulting from it.
Outline

• Mechanisms of the contextual interference effect in individuals post stroke. (*Schweighofer et al., J. Neurophys, 2011*)

• Neural substrates of motor memory consolidation depend on practice structure. (*Kantak et al., Nature Neuroscience, 2010*)

• Modulating the motor system by action observation after stroke. (*Garrison et al. 2013, Stroke*)
Mechanisms of the contextual interference practice effect in individuals post stroke

2 Groups: [Skill Level] Stroke, Young Control
2 Practice Conditions: [CI] Blocked vs Random order

Design: Computational model of motor memory: Common Fast and Distinct Slow Memory Processes

Task: One of target force profiles appears. Participant tries to exert force to match the target force profile. Target and actual force profiles shown with RMSE (Error)

Mechanisms of the CI effect post stroke

• **Rationale and Purpose:**
  
  – Contextual interference (CI) effect has been inconclusive in individuals post-stroke.
  
  – Individuals with unilateral stroke-related damage often exhibit deficits in visuo-spatial working memory (Winstein et al. 1999). Accordingly, the integrity of visuo-spatial working memory may play a role in the CI effect in individuals post-stroke.
  
  – **Purpose:** to test our previous model (Lee & Schweighofer 2009) in predicting the role of visuo-spatial working memory in modulating the CI effect, and to test the CI effect in individuals post-stroke with visuo-spatial working memory deficits, providing behavioral support for the model.

• **Hypothesis:**
  
  – Visuo-spatial working memory will be shown to modulate the CI effect behaviorally and through the computational model of motor memory.
Example Practice—Each Group
Computer Simulation CI effect—Non-disabled

Simulation with poor working memory predicts a blunted CI effect with less forgetting after blocked than in the non-disabled simulation.
Stroke Data: Wechsler figural memory test (Visuo-spatial short-term memory)

Model Simulations
The integrity of visuo-spatial working memory modulates the contextual interference practice effect

- Our research using an experimental and computational approach suggests that the CI effect is due, at least in part, to greater forgetting in visuo-spatial working memory between trials of the same task during random schedule practice than during blocked schedule practice.

- We found that the integrity of visuo-spatial working memory modulated the amount of forgetting after blocked practice in participants post-stroke: as a result, only participants with good visuo-spatial working memory exhibited the CI effect.
Outline

• Mechanisms of the contextual interference effect in individuals post stroke. (*Schweighofer et al.*, *J. Neurophys*, 2011)


• Modulating the motor system by action observation after stroke. (*Garrison et al.*, *Stroke*, 2013)
Learning-Performance distinction and memory processes: A Model

Kantak & Weinstein, Behav Brain Sci, 2012
Variable practice conditions engage a part of the brain important for memory consolidation.

- Memory consolidation takes place immediately AFTER practice.
- If we put this part of the brain to sleep temporarily after practice, what is the effect on memory?
We investigated the manner in which offline neural networks are modulated by practice structures that affect motor-skill retention.

Kantak et al., *Nature Neuroscience*, 2010
Kantak et al. *Nature Neuroscience*, 2010

DLPFC may be important for transferring short-term to long-term memory.

**Variable Practice**

- Control
- DLPFC-TMS
- MI-TMS

Non-invasive brain stimulation

Motor cortex

Retention

Next day

End of Acquisition

EoA

Error

0 5 10 15 20 25

Graph showing error comparison between Control, DLPFC-TMS, and MI-TMS groups.
Interference to dorsolateral-prefrontal cortex (DLPFC), but not to primary motor cortex (M1), after *variable* practice attenuated motor learning, whereas interference to M1, but not to DLPFC, after *constant* practice attenuated motor-skill retention.
• Mechanisms of the contextual interference effect in individuals post stroke. (*Schweighofer et al., J. Neurophys, 2011*)

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Action observation and the mirror neuron system

Figure 1. The core mirror neuron system, including the inferior parietal lobule (IPL), ventral premotor cortex (PMv), and inferior frontal gyrus (IFG).

From: Garrison, Winstein, Aziz-Zadeh, Neurorehab Neural Repair, 2010
### Study Procedure

#### MRI Session

<table>
<thead>
<tr>
<th>Practice</th>
<th>MRI Session</th>
<th>Behavioral (Outside MRI)</th>
</tr>
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<tbody>
<tr>
<td>Mock Scanner</td>
<td>MPRAGE 10 min.</td>
<td>FMRI 6 min.</td>
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</tbody>
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**Instructions:**
"Pay attention to the actions and to which hand the actor uses, as you will be asked to imitate the actions using the same hand as the actor after your MRI."

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The study includes the following steps:

- **Left Hand Action Observation**
- **Rest**
- **Right Hand Action Observation**
- **Rest**
- **Repeat Randomized**

Each action is performed 4 times, with a rest period of 12 seconds between actions.
Stroke Group Lesion Maps
Main effect of action observation
Laterality of brain activity during action observation

**A**

STROKE

<table>
<thead>
<tr>
<th>Laterality Index</th>
<th>IFGop</th>
<th>IFGt</th>
<th>preCG</th>
<th>SMG</th>
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<tr>
<td>LEFT HEMISPHERE</td>
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<td>RIGHT HEMISPHERE</td>
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**B**

NON-DISABLED

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ACTION OBSERVATION: 
- LEFT HAND (IAO)
- RIGHT HAND (RAO)
Brain activity during right hand versus left hand action observation
Relation between brain activity during action observation and motor capability to perform the same actions

A

LEFT IFGop

LEFT IFGt

B

LEFT IFGt

Contrast Value vs. Log Mean Right Hand Movement Time

Contrast Value vs. Mean Right Hand FAS Score
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Conclusion: Clinical Implications

- **CI effect in stroke:**
  - **Clinical implication:** If VSWM is < 7 on the W-VSWM test, a blocked practice schedule will be as effective for motor learning as a random one.

- **DLPFC and MI—Practice schedule effect in non-disabled:**
  - **Clinical speculation:** Lesions that affect DLPFC may be more detrimental to consolidation of complex motor sequences than those to MI

- **Action Observation after Stroke:**
  - **Clinical implication:** Using action-observation in stroke rehabilitation has shown promise in early studies, and this study is among the first to explain why it may be effective.
Thank You
Questions?

How the brain works.

USC Division of Biokinesiology and Physical Therapy