9.03
Skill Memory: Learning by Doing
Part I

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Lecture Outline

I. Overview of non-declarative memory

- Declarative VS non-declarative
- Different types of non-declarative memory
- Everyday and laboratory examples

II. Some properties of perceptual-motor learning

- Time course / stages of learning
- consolidation
- Task-specificity / transfer of learning

Textbook reference: Gluck, Mercado, Myers, Chap. 4.1

Two types of memory (Gluck, Mercado, Myers, p. 126)

1. Declarative (explicit)

- Memories for facts and events
- Recollected consciously
- Dependent on medial temporal lobe (e.g., hippocampus) and midline nuclei of thalamus
- Flexible; applied readily to novel situations
- Impaired in amnesic patients (e.g., H. M.)

2. Non-declarative (implicit) (Gluck, Mercado, Myers, p. 136)

- Expressed through performance without any necessary requirement of conscious memory content
- Independent of medial temporal lobe and midline nuclei
- Many different types: skills and habits etc.
- Dependent on diverse neural structures
- Tends to be inflexible / specific to learning condition
- Spared in amnesic patients

Different types of non-declarative memory

1. Reflexes
2. Habituation / sensitization
3. Classical conditioning
4. Priming
5. Perceptual skills
6. Motor skills (with subtypes)
7. Discovery of rules or categories
8. High level cognitive skills

   :

   :

and any combinations of the above

Types of non-declarative memory

1. Reflexes

- Stereotypic motor output in response to a specific sensory stimulus
- **In-born**; automatic; direct neural pathway

Example: Spinal stretch reflex

Image removed due to copyright restrictions.
Illustration of neural pathway of spinal stretch reflex.

Kandel, Schwartz, Jessell (2000), p. 716

- Subserve function possibly critical for survival of organism

- Memory acquired in evolutionary time through natural selection (subject to developmental / other constraints) (Shadmehr and Wise, 2005)

Types of non-declarative memory

2. Non-associative implicit memories

- Habituation: decrease in response to a stimulus after repeated presentation of the stimulus

Example: decrease in startling response after repeated presentations of loud sound

- Sensitization: increased response to a stimulus after noxious or painful stimuli

Example: animal responds more vigorously to mild tactile stimulus after a painful pinch

Types of non-declarative memory

3. Classical conditioning

Types of non-declarative memory

3. Classical conditioning (delay conditioning type)

- Simplest form of <u>associative</u> implicit memory
- Pavlov's dog
- <u>Conditioned stimulus</u> (CS): Usually produces no overt response (e.g., tone, touch, light)
- <u>Unconditioned stimulus</u> (US): Normally produces strong responses (e.g., food, shock, air-puff)
- Learning: response to US elicited by CS alone

Example: Eye-blink conditioning

US: an air-puff to the eye

CS: tone

Response: eye blink

Image removed due to copyright restrictions.
Diagram of US/CS conditioning delay.

Squire and Kandel (2000), p. 187

Types of non-declarative memory

4. Repetition priming

- Enhanced ability to identify or produce a stimulus after recent presentation of the same stimulus
- Perceptual repetition priming: Improvement in the ability to detect or identify words / objects after recent experience with them (usu. single exposure)
- Independent of conscious recognition

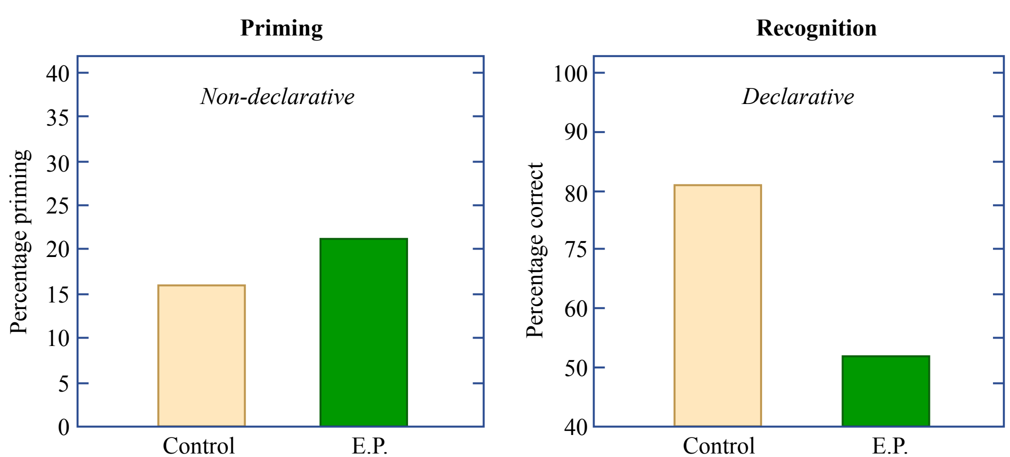
Example:

1. Study: Common English words presented

2. Priming test: flash studied and unstudied words (25 ms); test reading accuracy

3. Recognition test: Ask subject whether a word has been in the study list (Yes/No)

% correct for studied list minus % correct for unstudied list



Priming and recognition in amnesic patient E.P. Left: Patient E.P. performed a little better than the average normal subject on 12 tests of priming. Seven normal subjects were tested. The priming score is the percentage of recently studied words that could be correctly read minus the percentage of nonstudied words that could be read. Right: When asked to identify the study words themselves in six separate tests of recognition memory, E.P. scored no better than he would have by guessing (50 percent correct).

Figure by MIT OpenCourseWare.

Squire and Kandel (2000), p. 161

Types of non-declarative memory

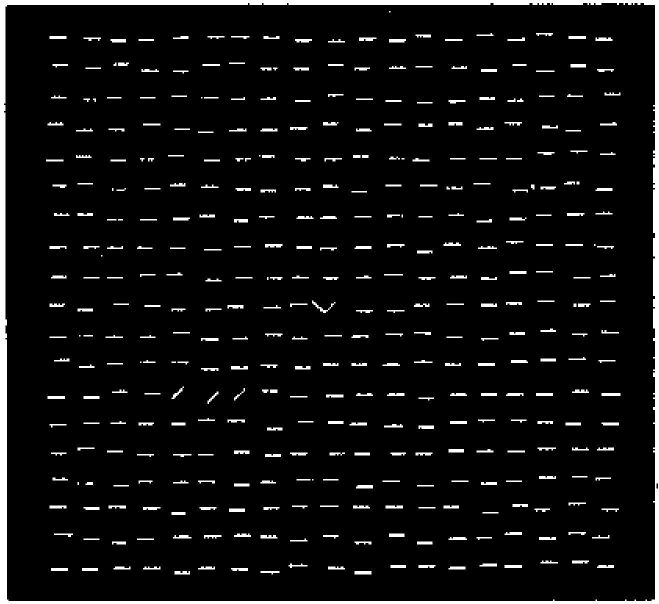
5. Perceptual learning

- Improvement in the ability to discriminate or detect simple perceptual attributes (e.g., tone, line orientations, tactile stimulus frequency)

- Different from priming: <u>gradual</u> improvement

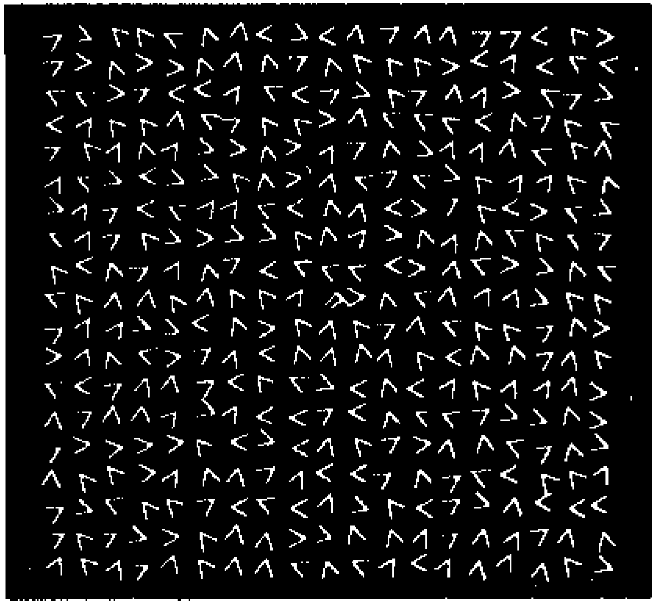
- Reward or feedback on errors not absolutely necessary (i.e., learning can be <u>unsupervised</u>) (see Gluck, Mercado, Myers, p. 133)

Example 1 (no feedback): Human visual system



Test Stimulus (10ms)

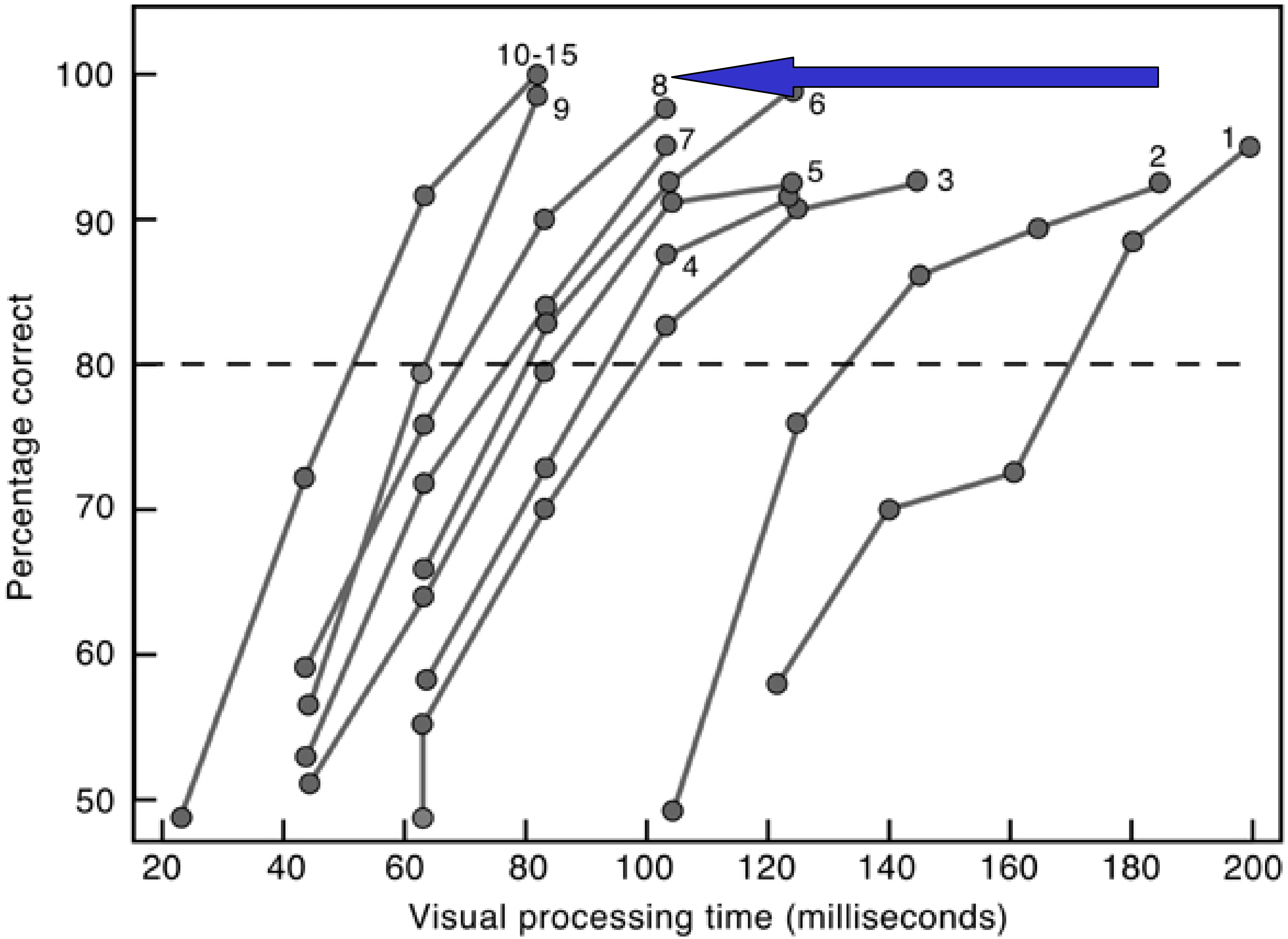
Blank screen
(variable, for manipulating visual processing time)



Mask (100ms)
(stop processing)

Task:
Subject reported "texture" of foreground (i.e., horizontal or vertical) after mask

Perceptual learning without feedback: Results of Karni *et al.*



Perceptual learning: Example 2 (with feedback)
Monkey somatosensory system

Experiments of Recanzone, Jenkins, Merzenich *et al.* (1992)

- Sinusoidal tactile stimulation applied to a restricted spot on monkey's hand
- First pulse (S1): 20 Hz
- Second pulse (S2): > or = 20 Hz
- Task: break hand position if S2 > S1
- Rewarded if response correct

- Monitor: threshold difference of frequency for correct response

Image removed due to copyright restrictions.

Day

Types of non-declarative memory

6. Motor learning

Skill Acquisition:

- learning how to perform new movement sequences; extending movement repertoire
- playing tennis (neuroscientists' favorite example)

Image removed due to copyright restrictions.

Photo of a tennis player.

Motor Adaptation:

- Changes in motor performance allowing the motor system to regain former capabilities in altered circumstances
- E.g.: compensating for perturbations / muscle paralysis / stroke

Motor learning example (motor adaptation):
Manipulandum studies from Bizzi *et al.* (2000)

Image removed due to copyright restrictions.

Please see: Fig. 7 in Mussa-Ivaldi, F. A., and E. Bizzi. "Motor Learning through the Combination Combination of Primitives." *Philosophical Transactions of the Royal Society of London* B 355 (2000): 1755-1769.

No perturbation

Perturbed by velocity-dependent force field

Time course of motor adaptation in the presence of perturbation:

Another evidence of learning: <u>after-effect</u> seen upon removal of perturbation after adaptation

Please see: Fig. 8 and 9 in Mussa-Ivaldi, F. A., and E. Bizzi. "Motor Learning through the Combination Combination of Primitives." *Philosophical Transactions of the Royal Society of London* B 355 (2000): 1755-1769.

The concept of motor program

The presence of <u>after-effect</u> supports the notion that a <u>motor program</u> (incorporating knowledge of the dynamics of the environment) is formed to compensate for perturbation (instead of passive compensation by relying on sensory feedback).

- Motor program: a sequence of motor commands, either learned or in-born, that can be executed with <u>minimal attention</u> (Gluck, Mercado, Myers, p. 141)

- The program can incorporate an internal model of the dynamical environment in which the movement is executed.

- Different from reflexes:
  - motor program can be learned
  - a motor program needs not to be triggered by a specific sensory stimulus

Types of non-declarative memory

7. Implicit learning of rules or categories

Example 1: Serial reaction time task (Gluck, Mercado, Myers, p. 136)

Image removed due to copyright restrictions.
Photograph of experiment participant at a computer, pressing keys on the keyboard.

SRT Task (adapted from Nissen & Bullemer, 1987)

Random Blocks (R)

The location of the targets is random, with the constraint that consecutive targets never appear in the same location

Sequence Blocks (S)

The targets appear in a 12-location sequence, with two constraints:

Each of the four locations appears three times

Each of the 12 first-order transitions between locations occurs only once (e.g., 1 to 2, 1 to 3, 1 to 4, 2 to 1, 2 to 3, 2 to 4, etc.)

Participants are not told that a sequence is repeated

Example 2: Learning artificial grammar

Image removed due to copyright restrictions.

Squire and Knowlton (2000), fig. 53.7

- Grammatical strings defined by arbitrary system
- Task: view a set of grammatical strings
- After training, decide whether a given new string is grammatical

- Amnesic and control subjects performed comparably well

- Could accomplish a change of sensory modality from training to testing (i.e., not just perceptual learning)

Types of non-declarative memory

8. Higher level cognitive skills

- Associated with the ability to reason or solve problems
- Can be learned without any conscious awareness of learning

Textbook example in humans: solving the Tower of Hanoi puzzle

Image removed due to copyright restrictions.
Illustration of the Tower of Hanoi puzzle.

Gluck, Mercado, Myers, p. 128

"The application of the recursive strategy enables one to solve the Tower puzzle in the minimum number of moves without having to remember each previous move declaratively. It does not logically follow, however, that learning of the recursive strategy could also be achieved without a declarative memory system."

Xu and Corkin *Neuropsychology* 15(1):69-79, 2001.

Example in chimpanzees

Images removed due to copyright restrictions.
Photographs of a chimpanzee interacting with the “artificial fruit” box.

Whiten (2002), p. 387

- Juvenile chimpanzees can learn how to open an “artificial fruit”, requiring removal of several bolts that jam the opening

- Other examples:
tool use in monkeys / dolphins

- acquiring these skills might depend on declarative knowledge?

Take-home message:
Diversity of non-declarative (implicit) memories

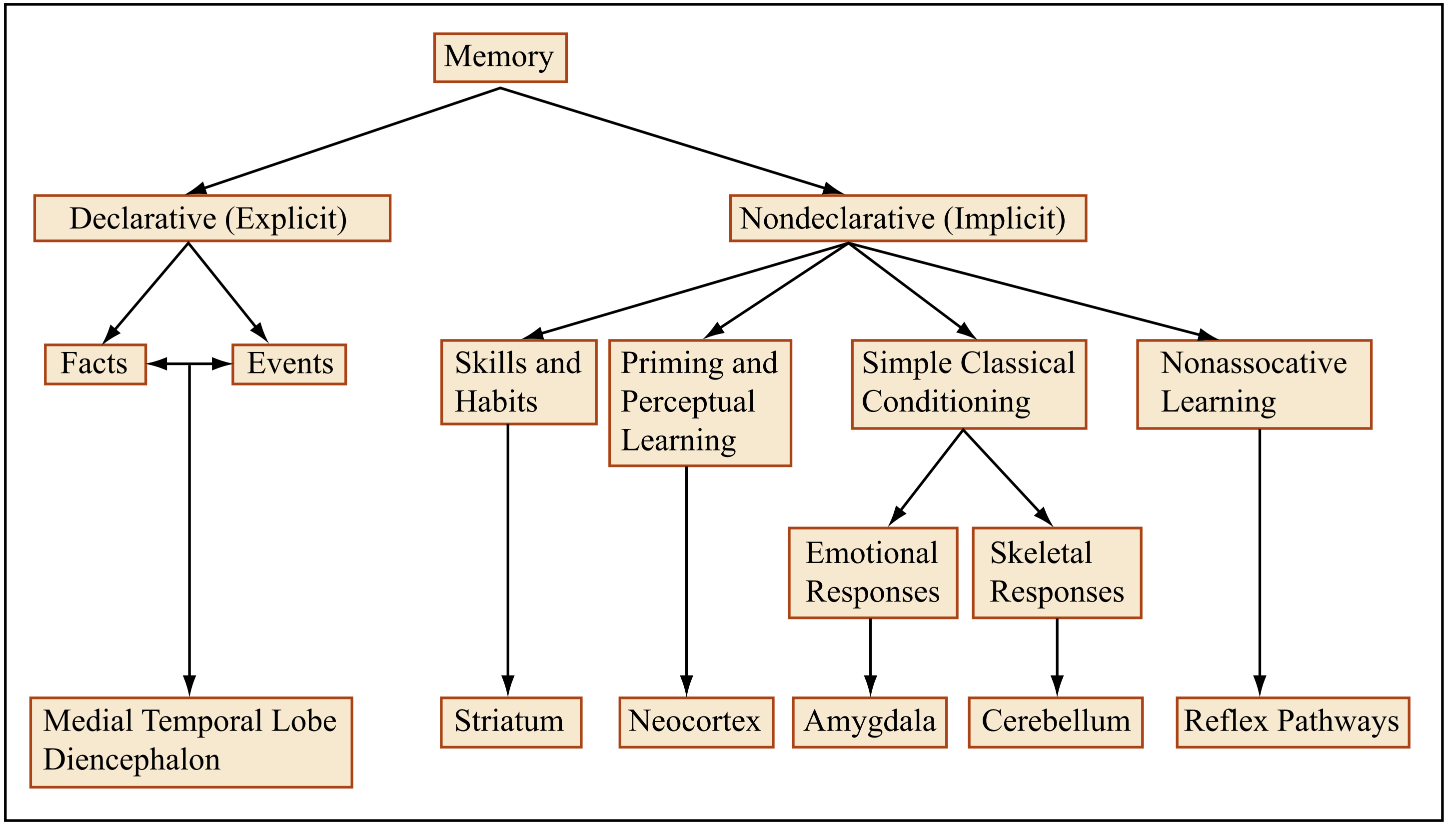


Figure by MIT OpenCourseWare.

Squire and Knowlton (2000), p. 776

Some psychophysical and neuronal properties of perceptual and motor learning

1. Power law of learning
2. Two-stage learning model
3. Task-specificity of learning
4. The genetics of skill learning

1. Time Course of Learning

Power law of learning: law of diminishing return
The number of additional practice trials necessary to improve a skill increases dramatically as the number of completed practice trials increases (Gluck, Mercado, Myers, p. 134).

$$p(n) = A + B(n+n_o)^k; \quad k<0$$

where $p(n)$ is a measure of performance, n is the number of completed practice trials
A, B, n_o and k are constants

More simply...

Most of learning accomplished early in the course of training; then performance plateaus.

Power law of learning in motor learning experiment (skill acquisition)

Task: oppose fingers to thumb

Trained (T)

Control (C)

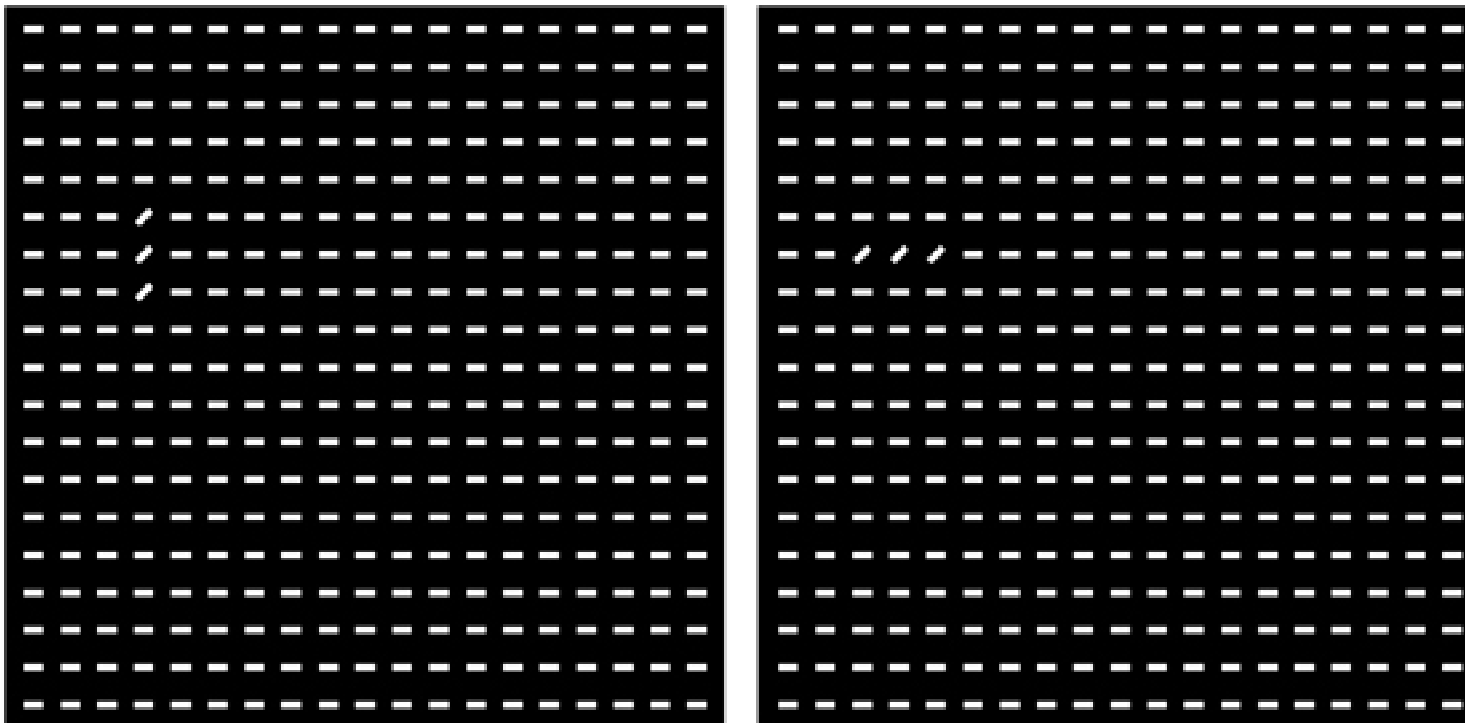
Fig. 1 from Karni, A., Gundela Meyer, Peter Jezzard *et al.* "Functional MRI Evidence for Adult Motor Cortex Plasticity during Motor Skill Learning." *Nature* 377 (1995): 155-158.

week

No transfer
of learning
to other hand

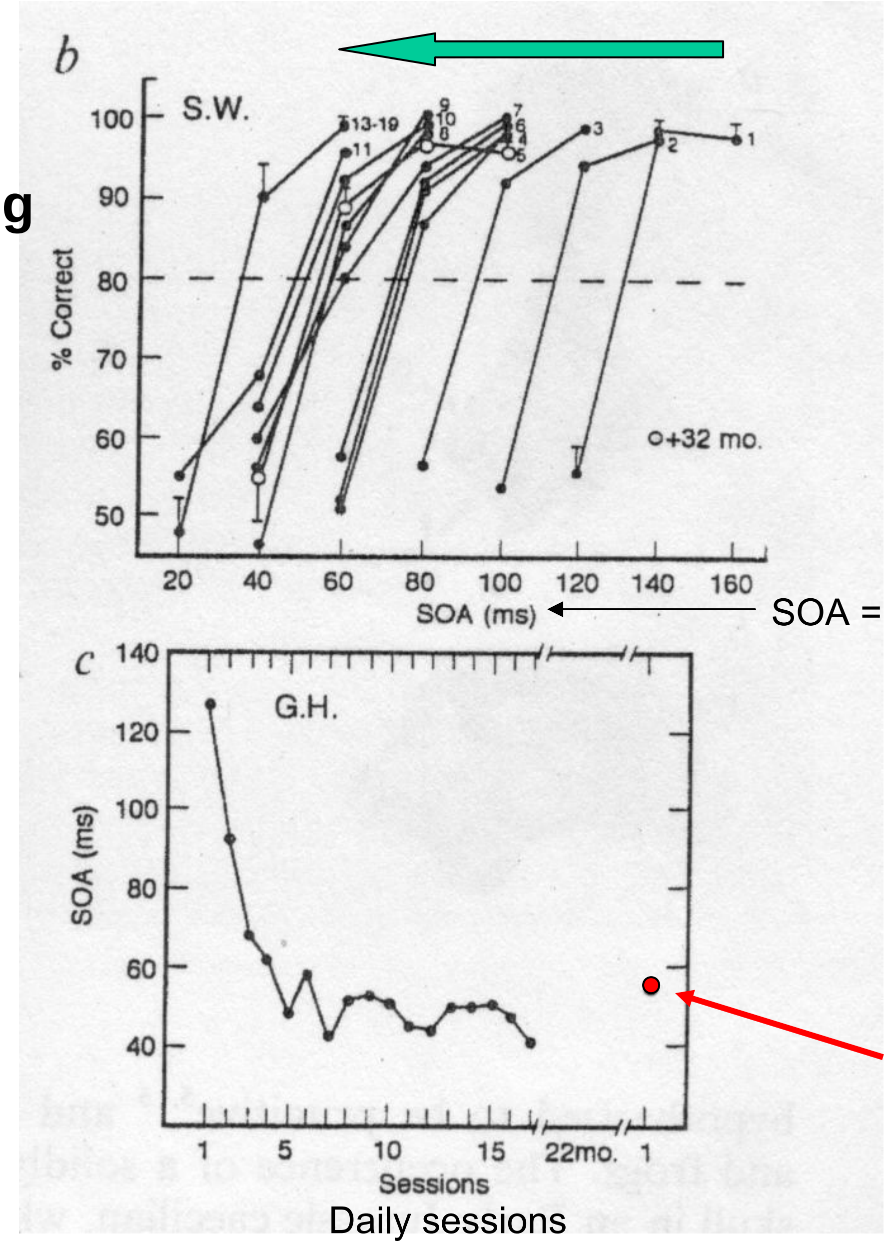
Control sequence
(no practice)

Example: perceptual learning experiments of Karni and colleagues (1991, 1993)



Was the foreground target arranged horizontally or vertically?

Power law of learning in perceptual learning experiments:



SOA = visual processing time allowed

Probe session after 22 months without practice

Daily sessions

Karni and Sagi (1993), fig. 1

2a. The general three-stage model of skill learning

1. **<u>Cognitive stage</u>:** active thinking required to encode skills

2. **<u>Associative stage</u>**: stereotyped actions; rely less on memories of rules

3. **<u>Autonomous stage</u>**: skill or sub-components of skill becomes part of **motor program**

Gluck, Mercado, Myers, p. 143
Fitts (1964)

2b. The two-stage learning model

Fast v.s. slow perceptual learning

- Fast within-session learning observed when very large visual processing time allowed

- Slow between-session learning observed for smaller visual processing time

Image removed due to copyright restrictions.
Fig. 2 in A. Karni, and D. Sagi. "The Time Course of Learning a Visual Skill." *Nature* 365 (1995): 250-252.

Blocks of trials
within session

Blocks of trials
within session

Time course of slow learning:

Performance
of probe trials

Image removed due to copyright restrictions.
Fig. 3 in A. Karni, and D. Sagi. "The Time Course of Learning a Visual Skill." *Nature* 365 (1995): 250-252.

Hours after initial training session

~ 8 hours of "latent period"
with no learning

- "Consolidation"
Performance gain across a silent period with no additional training (off-line learning)

- Gain magnitude independent of additional training during latent period

Consolidation of perceptual-motor skills:

1. <u>off-line</u> between-session improvement in performance

2. transformation from fragile to solid state, as evidenced by memory's <u>resistance to interference</u>

- Right: evidence of consolidation in motor learning (student presentation)

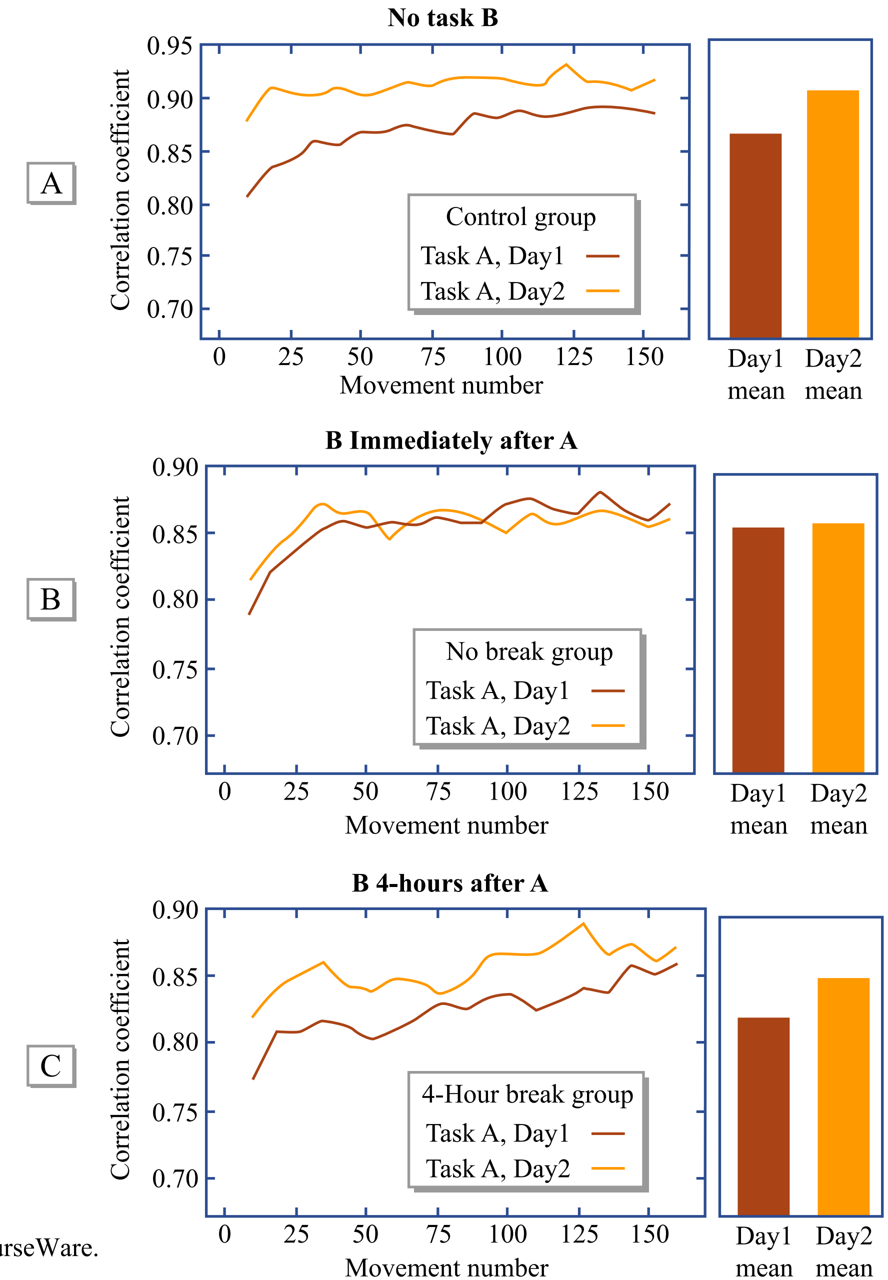


Figure by MIT OpenCourseWare.

Brashers-Krug, Shadmehr, Bizzi (1996) *Nature* 382:252.

• Like declarative memory, during the consolidation period, motor skill memory is also susceptible to disruption by another similar task.
(read Gluck, Mercado, Myers, p. 139)

• Disruption effect: retrograde (or retroactive) interference

• Very recent result (Overduin *et al.*, *J Neurosci*, 26:11888, 2006):

- in force-field learning paradigm, presence of catch-trials facilitates consolidation of motor memories
- results echo the idea that variable practice leads to better retention and performance than constant practice
(Gluck, Mercado, Myers, p. 135)

- **The two-stage model of perceptual/motor learning:**

Fast stage: setting up a task-specific routine for solving perceptual/motor problem at hand; initiating later learning

Slow stage (consolidation): perhaps reflects structural modification of basic perceptual module or motor control system

Gluck, Mercado, Myers, p. 135:

- **Massed practice** - concentrated continuous practice - generally produces better performance in the short term

- **Spaced-out practice** - leads to better retention in the long run; also, more efficient learning (Baddeley and Longman, 78).

Student Presentation:

- Post officers trained to use a letter-sorting machine
- Different training schedules for different groups

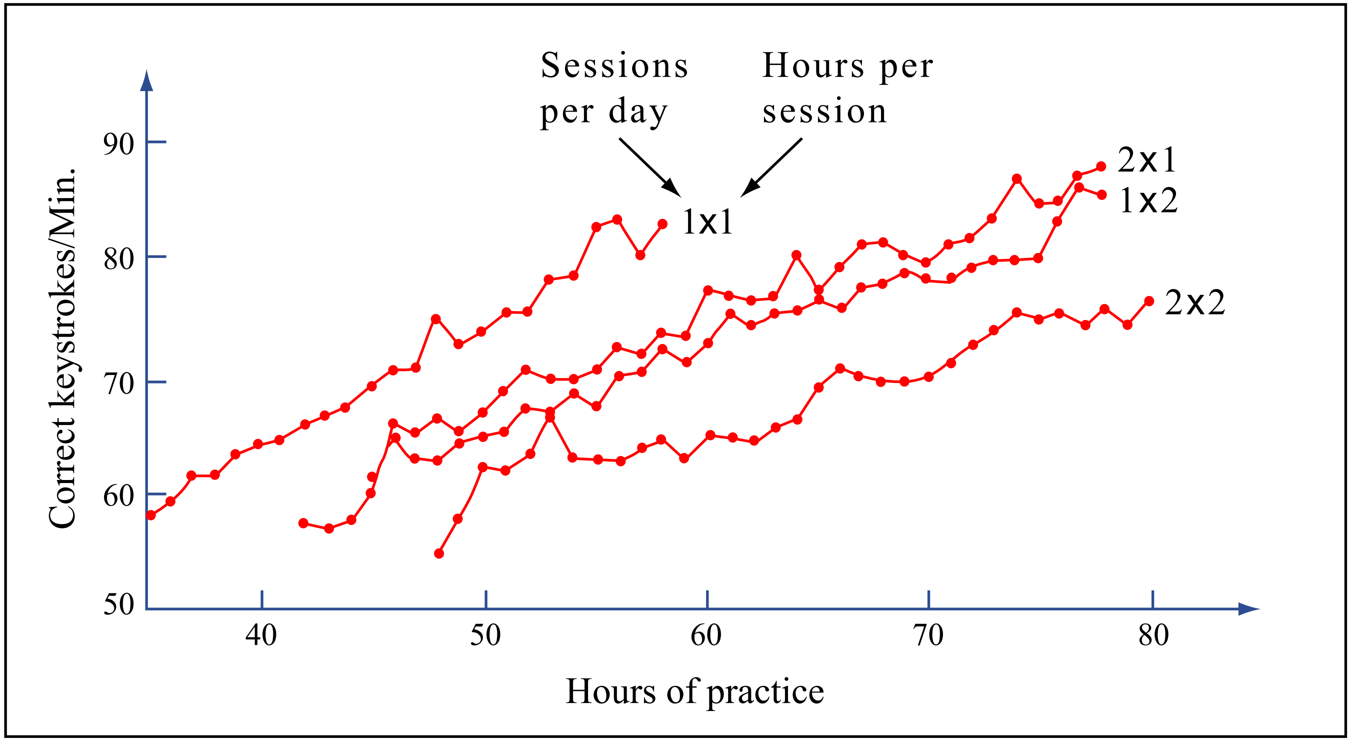


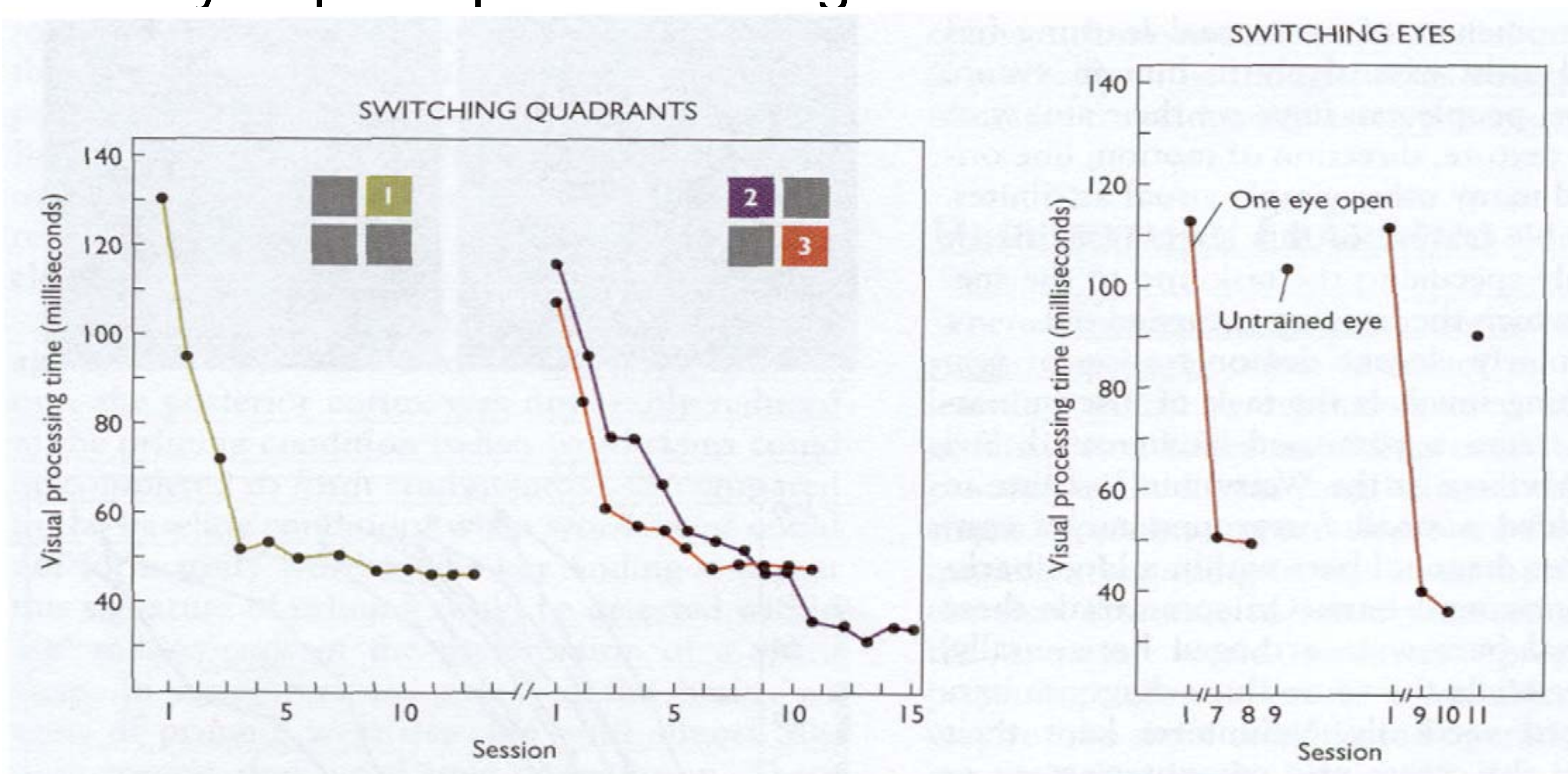
Figure by MIT OpenCourseWare.

3. Task-specificity of perceptual/motor learning

(Gluck, Mercado, Myers, p. 140)

- Highly task-specific, i.e., learning generally ***does not generalize*** from one learning condition or set of stimuli to another (with exceptions).

Specificity of perceptual learning:



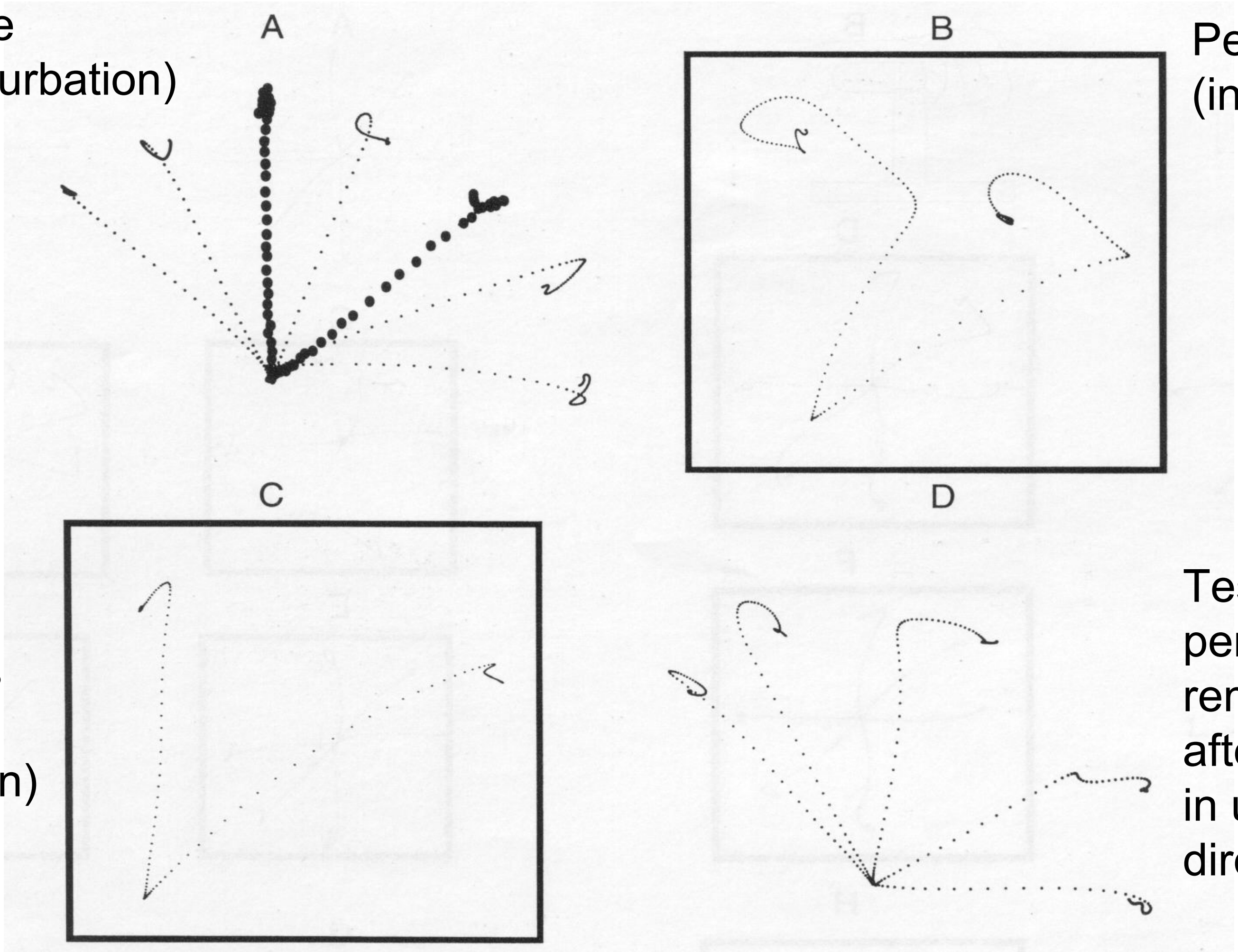
Courtesy of National Academy of Sciences, U. S. A. Used with permission. Source: Karni, et al. "Where Practice Makes Perfect in Texture Discrimination: Evidence for Primary Visual Cortex Plasticity." *PNAS* 88 (1991): 4966-4970.

Some extent of learning generalization in motor adaptation:

Manipulandum experiments, with perturbation along specified targets only

Baseline
(no perturbation)

Perturbed
(initial trials)



Adapted
trajectories
(with
perturbation)

Testing:
perturbation
removed;
after-effects seen
in untrained
directions

Summary:

• Both perceptual and motor learning share some very similar psychophysical properties, including:

1. Power law of learning
2. Fast stage and slow stage
3. Consolidation: off-line improvement and stability
4. Relatively task-specific

• A spaced-out practice schedule can result into more efficient learning (less total practice hours for a given result).