Neuroplasticity and Motor Learning

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Neuroplasticity

- Definition:
  - Ability of neurons to change function, chemical profile or structure
  - A natural innate process within the nervous system underlying learning and adaptation
  - An essential function of the nervous system to recover from damage
  - Occurs throughout the lifespan
  - Not inherently “good”
  - Can be adaptive or maladaptive

Neuroplasticity

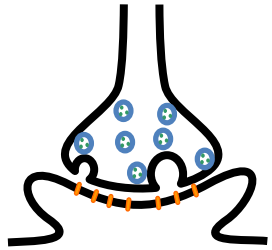
- Is the change that happens in the brain that results in changes in function (memory, movement, reaction time, skill improvement, skill reduction….)

- The idea of neuroplasticity was first proposed by William James in 1890
  - "Organic matter, especially nervous tissue, seems endowed with a very extraordinary degree of plasticity..." The Principles of Psychology

Neuroplasticity

- Another important theory on neuroplasticity was proposed by Donald Hebb in 1949
  - *"When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased."* The Organization of Behavior (1949)
- Cells that fire together, wire together

Synaptic Plasticity

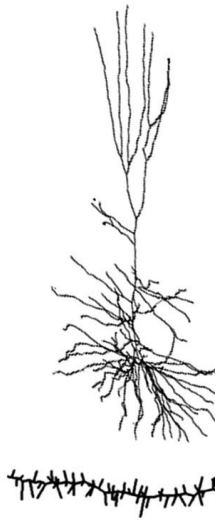


- Plasticity at the synapse take the form of:
  - Alterations in amount of neurotransmitters
  - Alterations in number, density and type of receptors
  - Alterations in membrane excitability

- Taken together these plastic changes will increase or decrease the efficacy of current synapses
  - Think long term potentiation/depression
  - Sensitization and Habituation

Structural Plasticity

- Structural Plasticity can take the form of:
  - Axonal sprouting, regeneration, or atrophy
  - Dendritic sprouting or atrophy
  - Dendritic spine alterations
  - Alterations in number of neurons
  - Alterations in blood supply



Wang et. al. 2011

- Taken together these structural plastic changes will:
  - Increase or decrease the number of synapses
  - Create new circuits or breakdown old ones

Functional Plasticity

- Functionally, these forms of neuroplasticity are the mechanisms underlying
  - Habituation
  - Sensitization
  - Classical Conditioning
  - Adaptation
  - Learning and Memory
  - Motor Learning
  - Recovery from Injury

Factors That Affect Neuroplasticity

- Activity
- Sleep
- Mood
- Hormones
- Diet
- Cardiorespiratory Function/Fitness
- Genetics
- Gender
- Pharmaceuticals
- Stimulation
- Disease
- Injury

Factors That Affect Neuroplasticity

- Genetics
  - Variations (polymorphisms) in the gene for the neurotrophin BDNF are known to alter neuroplasticity and motor learning
  - Variations in the gene for dopamine are known to alter motor learning and responses to L-Dopa
  - Variations of the ApoE gene are known to affect neurodegenerative and neuroplastic changes

Stewart and Cramer 2017

Factors That Affect Neuroplasticity

- Stimulation
  - Noninvasive brain stimulation such as transcranial magnetic stimulation and transcranial direct current stimulation have been shown to alter excitability of the nervous system

Huang et al 2018

Factors That Affect Neuroplasticity

- Activity
  - Activity has been shown to be a powerful mediator of neuroplasticity in both animals an humans.
  - It appears to be guided by certain principles

Kleim and Jones, 2008

The Principles of Activity Dependent Neuroplasticity

1. Specificity
2. Repetition
3. Intensity
4. Salience/Attention
5. Timing
6. Age
7. Difficulty/Complexity

Image from pixabay.com

Modified from Kleim and Jones, 2008

Specificity

- Description:

‘The nature of the training experience dictates the nature of the plasticity.’

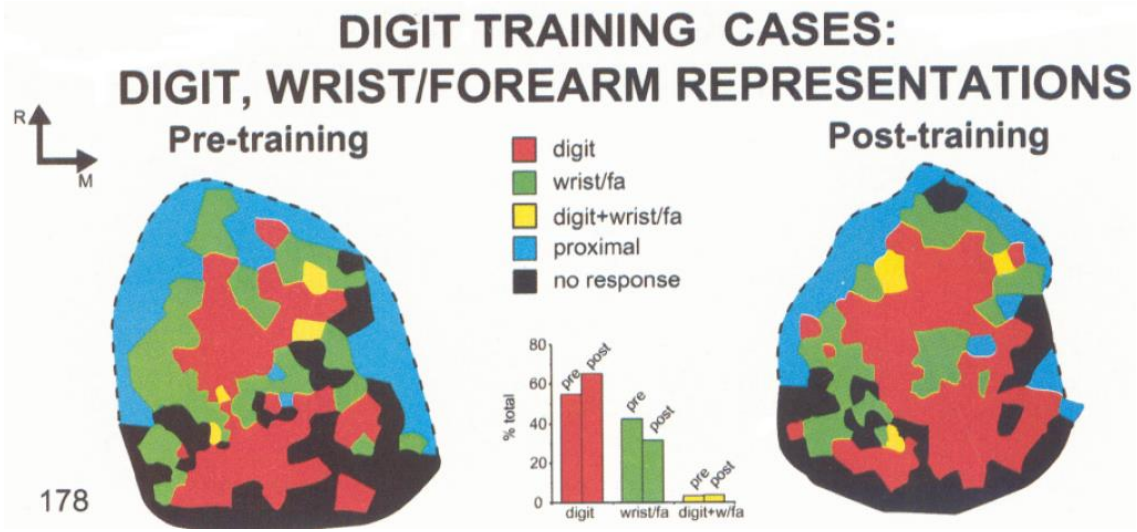
SAID Principle: Specific Adaptation to Imposed Demands

Kleim and Jones, 2008

Specificity

Pellet retrieval task: encouraged increased use of the digits

- Increase in representational area devoted to fingers (flexion and extension)
- Decreased representational area devoted to wrist (wrist abduction)



Nudo et al., (1996) J. Neurosci 16(2) 785-807

Repetition

- Description

‘Induction of plasticity requires sufficient repetition.’

Kleim and Jones, 2008

Repetition

- 9,600 retrievals over 4 weeks (Nudo et al., 1996)
- 2,500 hand movement repetitions over 5 days in healthy controls and people with stroke (Boyd et al., 2003; 2004; 2010)
- 31,500 repetitions of a finger sequence over 35 days (Karni, 1995)
- 1000+ per day x 18 sessions finger tracking (Carey et al., 2002; Kimberley et al, 2004)
- 12-14 hrs x 14 days = 196 hrs of opportunity to use affected arm/hand (Taub et al., 1993; Wolf et al., 1989)

Intensity

- Description:

‘Induction of plasticity requires sufficient training intensity.’

Kleim and Jones, 2008

Intensity

- High Intensity interval training can increase serum BDNF levels in healthy humans (Saucedo Marquez et al., 2015)
- High Intensity interval training improves recovery and promotes upregulation of anti-inflamatory and pro-plasticity markers in the brain after ischemic stroke in rats (Pin-Barre et al 2017).
- A single bout of intense cardiovascular exercise may reduce interhemispheric imbalances in excitability in chronic stroke survivors (Nepveu et al 2017)

Salience/Attention

- Description:

‘The training experience must be sufficiently salient to induce plasticity

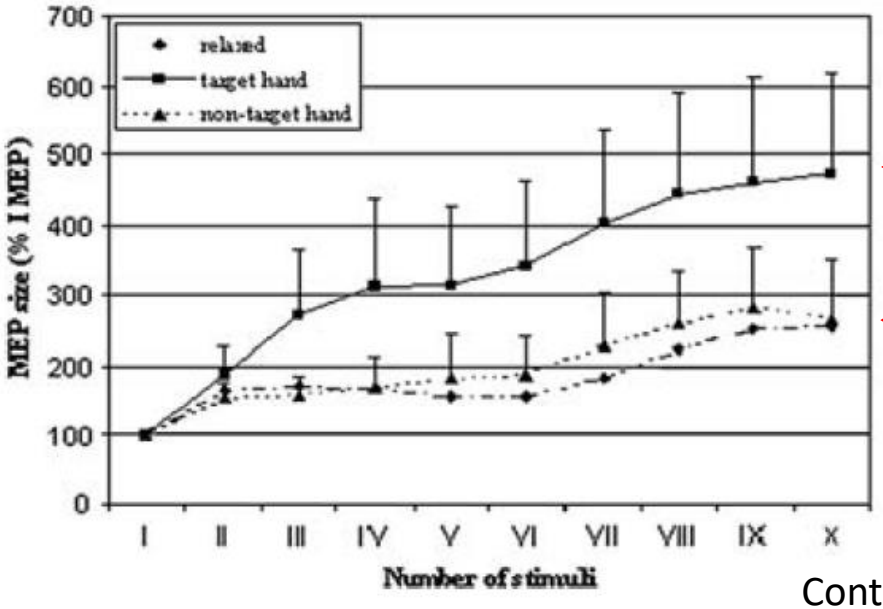
Kleim and Jones, 2008

Salience/Attention

- Evidence suggests that experience dependent plasticity is enhanced
  - when the patient is attending to the activity
  - the activity has significance for the patient

Salience/Attention

– Multiple studies have demonstrated that responses to non-invasive brain stimulation increase with attention.



Attention on target hand

Non target hand or
No attention on target hand

Conte et al 2007; Ridding and Ziemann, 2010

Salience/Attention

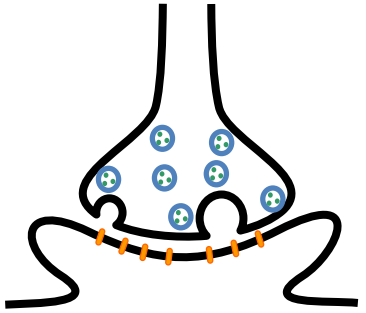
- The Ventral Tegmental Area of the Brainstem is rich with dopaminergic neurons that project to many areas of the brain including the limbic system and hippocampus

- This circuitry is thought to play a large role in motivation, attention, learning, memory, reward, and addiction

- Research has demonstrated that stimulation of this circuitry via drugs, electrical stimulation and activity can produce lasting plastic changes and significantly alter behavior

Lüscher and Malenka, 2011; Mameli and Lüscher, 2011

Timing



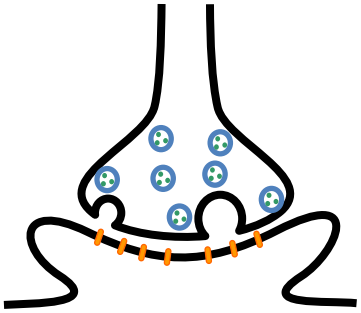
- Description:

The timing of pre and postsynaptic neuronal firing alters the connectivity of the neurons

Referred to as Spike Timing Dependent Plasticity

Feldman 2012

Timing



- High frequency pairing of pre and post synaptic firing (<20ms) tends to lead to LTP and a strengthening of the synapse
- Lower frequency pairing of pre and post synaptic firing (20-100ms) tends to lead to LTD and a weakening of the synapse
- Usually 60-100 repetitions of the stimulation are required to produce the changes.

Feldman 2012

Difficulty/Complexity

- Description:

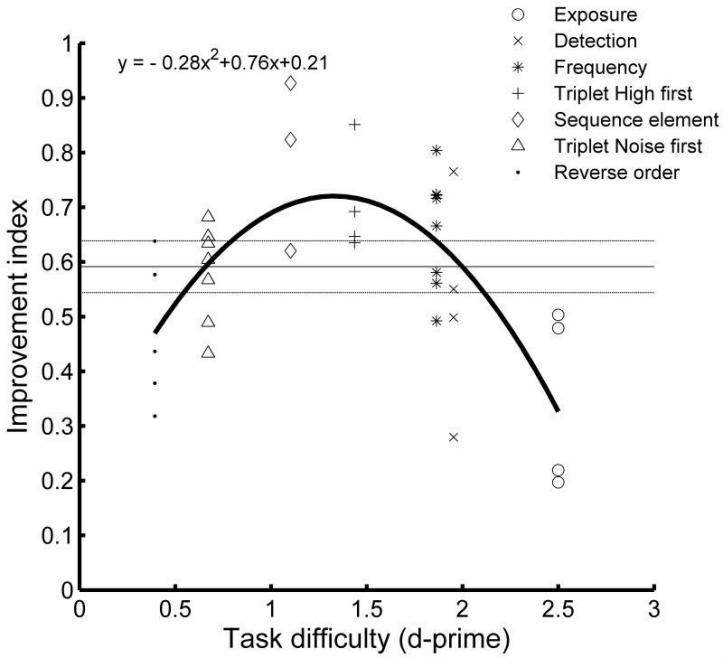
There is an optimal amount of difficulty/complexity of a task that drives plasticity

“The Goldilocks Zone”

Kleim 2011

Difficulty/Complexity

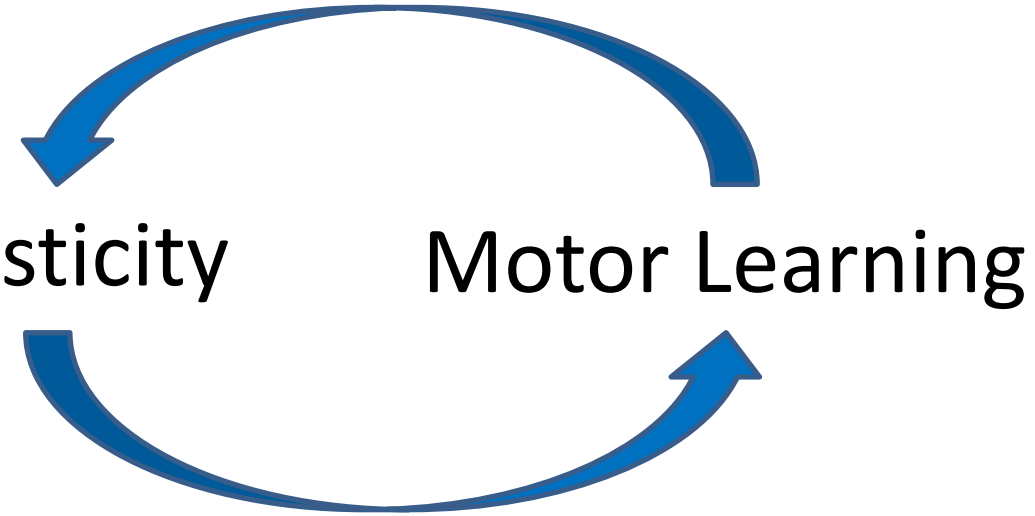
- In rats trained on auditory discrimination tasks, the maximal amount of cortical plasticity was observed during tasks of intermediate difficulty



Engineer et al. 2012

Activity Dependent Plasticity and Motor Learning

- Activity dependent plasticity is thought to be the mechanism that underlies motor learning
- And, in fact, motor learning has been shown to drive plasticity



The Principles of Motor Learning

Slides modified from Tara McIsaac PT, PhD

Motor Learning

- Characteristics of Skill Learning
  - Improvement - better
  - Consistency – little variability
  - Stability – resists perturbation
  - Persistence (Retention) – maintained over time
  - Adaptability (Transfer) – in different contexts

Motor Learning

- Gentile Stages:
  - Early
    - Develop the pattern
    - Requires cognitive processing
    - Involves trial and error
  - Late
    - Consistency
    - Adaptability to situation
    - Economy of effort

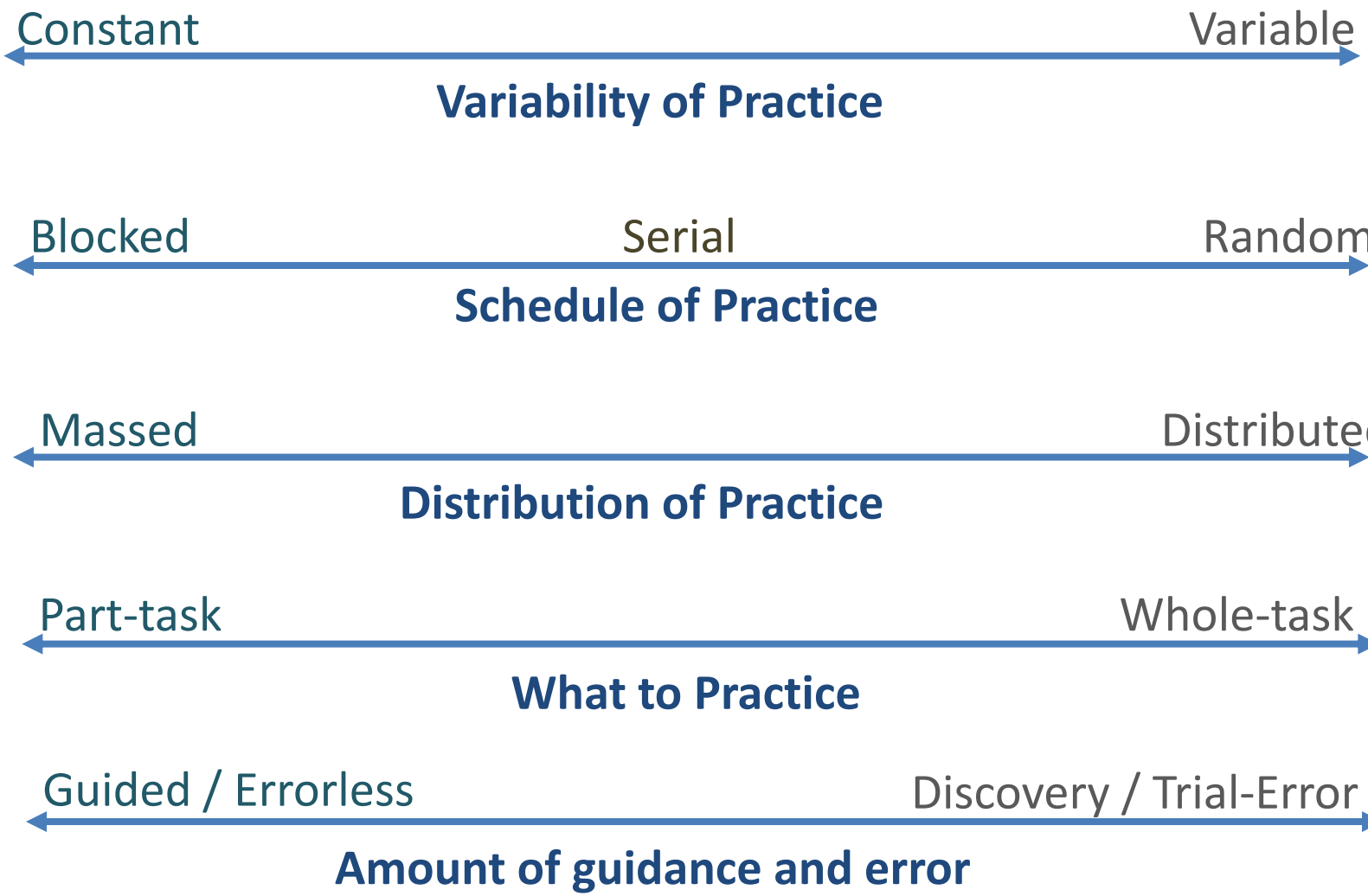
Welford (1988) & Gentile (1987)

Motor Learning

- Practice
  - Constant vs. Variable
  - Blocked vs. Random
  - Massed vs. Distributed
  - Part vs. Whole
  - Guidance and Error
  - Contextual Interference

Magill 2010

Practice Conditions in a Session - continuums



Motor Learning

- Feedback
  - Knowledge of Results (KR)
    - information about the *outcome of the movement in the environment*
  - Knowledge of Performance (KP)
    - information about the *nature of the movement pattern*

Schmidt & Lee 1999

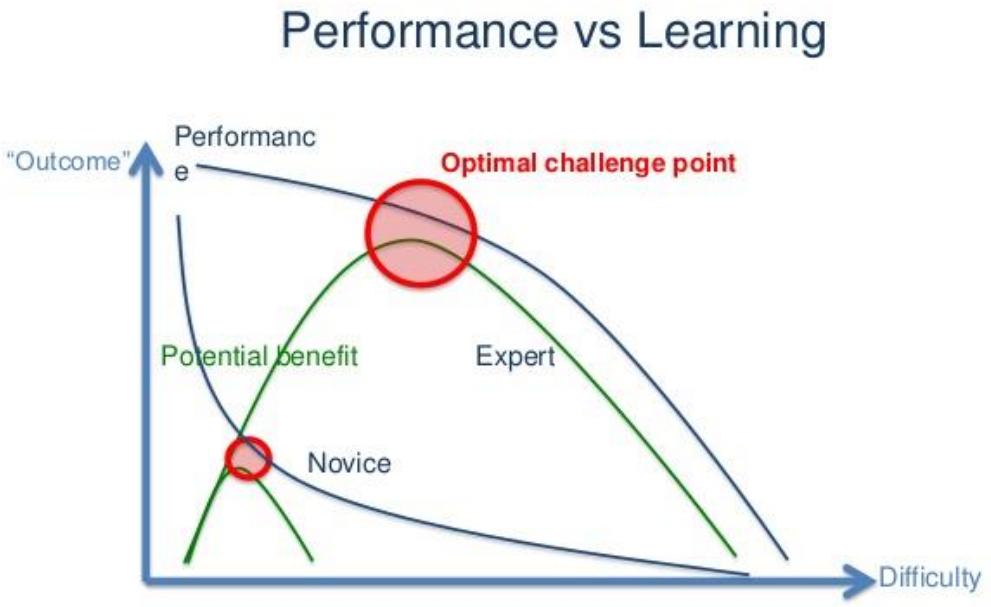
Motor Learning

- Feedback
  - Faded Feedback
    - Frequency reduces as skills develop
  - Bandwidth Feedback
    - Given only when movement falls outside of a bandwidth of correctness

Schmidt & Lee 1999

Motor Learning

- Challenge Point Framework
  - There are levels of task difficulty that maximize learning
  - These levels are different for novice and experts

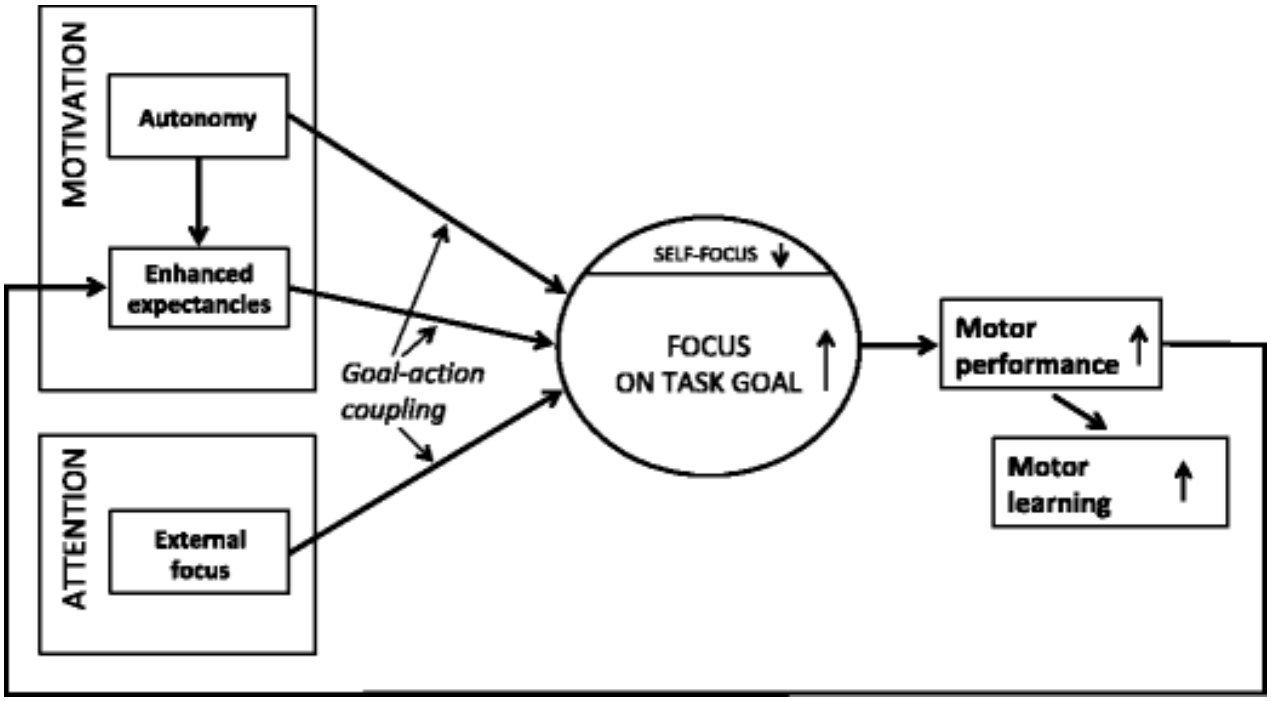


Theory adapted from: Guadagnoli, M. The application of the challenge point framework in medical education. Medical Education 2012, 46:447-453

Guadagnoli and Lee 2004

Motor Learning

- OPTIMAL Theory



Wulf & Lewthwaite 2016

OPTIMAL Theory

1. Enhanced Expectancies
   - Self-efficacy
   - Positive feedback
   - Social-comparative feedback
   - Self-modeling (video of self)
   - Perceived task difficulty
   - Conceptions of ability
   - Extrinsic rewards ($)
   - Positive affect (PANAS)

Wulf & Lewthwaite 2016

OPTIMAL Theory (cont.)

2. Autonomy
   - Control over practice conditions
   - Instructional language
   - Incidental choices

3. External focus of attention (vs internal focus)
   - Balance
   - Accuracy
   - Movement efficiency (including inc power with lower emg)
   - Movement form
   - Promotes automaticity (Constraint Action Hypothesis – internal focus constrains and inhibits automatic control processes and leaves use of the slower voluntary control processes.

Wulf & Lewthwaite 2016

Motor Learning: Summary

- Optimization of Motor Learning Depends Upon:
  - Initial Skill Level/Impairment
    - Novice, Intermediate, Skilled, Expert
    - Severely, Moderately, Mildly Impaired
  - Stage of Learning
    - Early vs. Late
  - Attention and Motivation
  - Practice
    - Continuum of Conditions
  - Feedback/Reinforcement
    - Type, Schedule and Variability
  - Interaction with Environment/Context
  - Task Orientation
  - Level of Difficulty (Challenge Point Framework)
  - Autonomy, Enhanced Expectancies, and External Focus (OPTIMAL)

Theoretical Application of Principles

- Incorporate principles of both neuroplasticity and motor learning into practice
  - Practice the task (or parts of task) you want to improve
  - Training should be of sufficient repetition and intensity
  - Customize types of practice to patient (Continuum of practice)
  - Find the “sweet spot” for difficulty/complexity (errors)
  - The task should be meaningful for the patient
  - Emphasize personal motivation and autonomy
  - Provide appropriate feedback and reinforcement
  - Incorporate context into practice
  - External Focus (i.e. task goal)

Summary

- The human nervous system is plastic
- This ability is retained throughout the lifespan
- Activity dependent neuroplasticity is governed by specific principles
- Plasticity is and underlying mechanism for motor learning
- Motor learning drives neuroplasticity
- Incorporating the principles of both neuroplasticity and motor learning into practice should improve the effectiveness of therapy

Questions?