Perception-Action Learning Toolbox

A handbook for designing
perception-action learning studies

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REPAIRS

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1. Introduction to Toolbox

Objectives

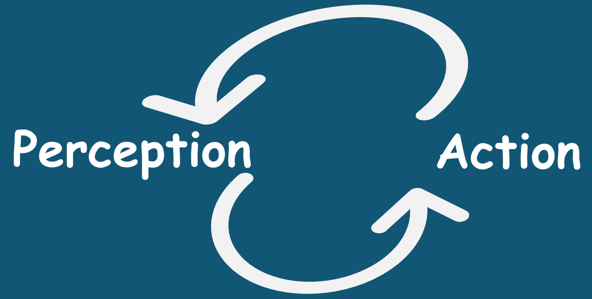
Enhance Understanding of Perception-Action Learning

The focus is on providing a foundational understanding of perception-action learning, enabling researchers and students to grasp its principles for learning movement coordination.

Guide Effective Study Design

This toolbox provides ideas on improving methodological rigor in experimental design, to help design studies that are effectively structured to yield valid and reliable results in perception-action learning.

2. Perception-Action Coupling



Perception and action are continuous and reciprocal processes between an individual and their environment, where perception and movement are tightly linked.

(Gibson, 1966)

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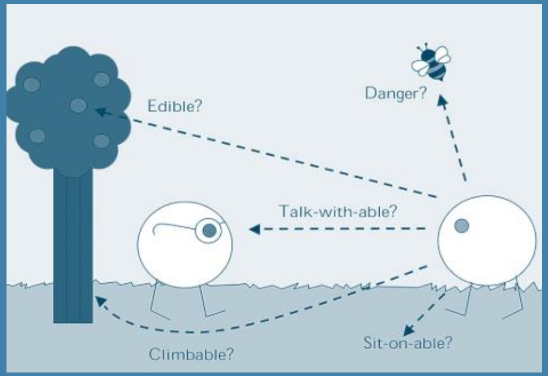


Instead of treating perception as a passive process that merely informs action, perception and action evolve together in real time to support adaptive behavior.

Movement emerges from the ongoing detection of environmental information, and actions are adjusted based on this information as it changes.

(Turvey, 1990)

* *Image adapted from Blau & Wagman, 2023*

Perception in Action & Action in Perception

Example

A tennis player continuously attunes to the ball's movement and directly picks up information specifying opportunities for action. They perceive the ball's speed, spin, and trajectory in real time and coordinate their movements accordingly.

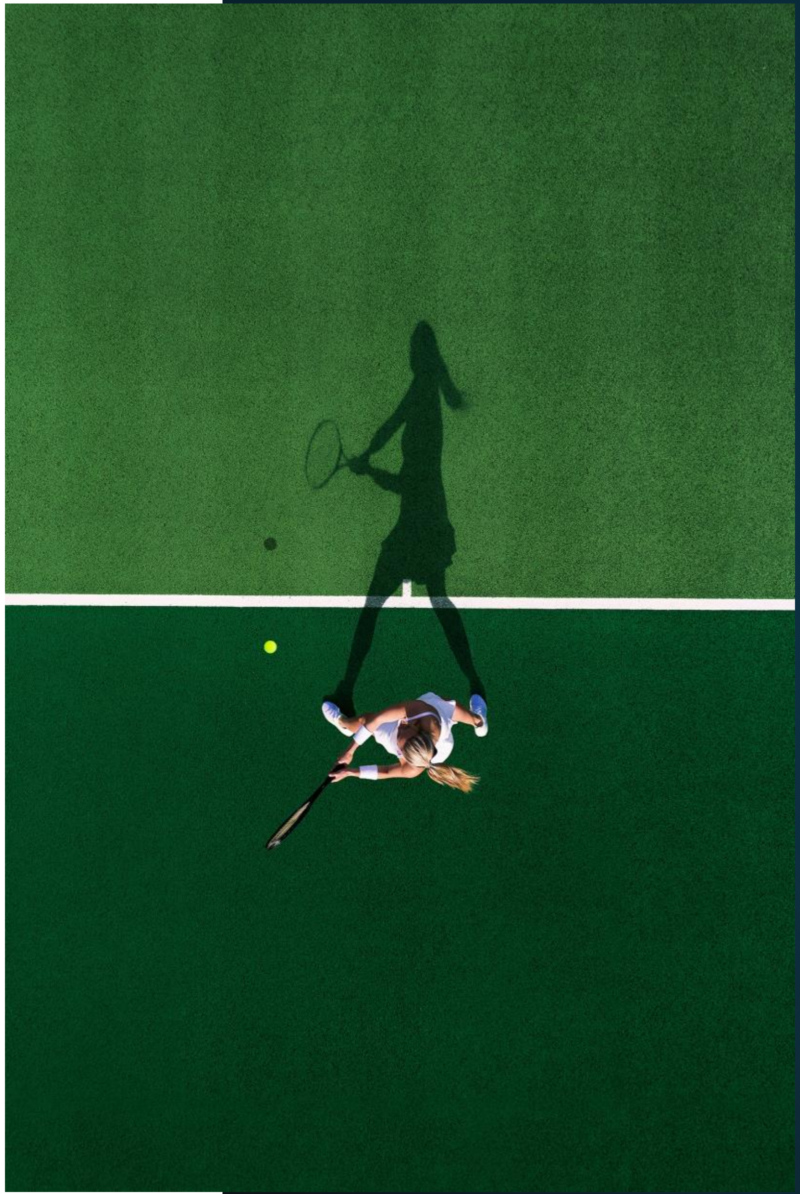
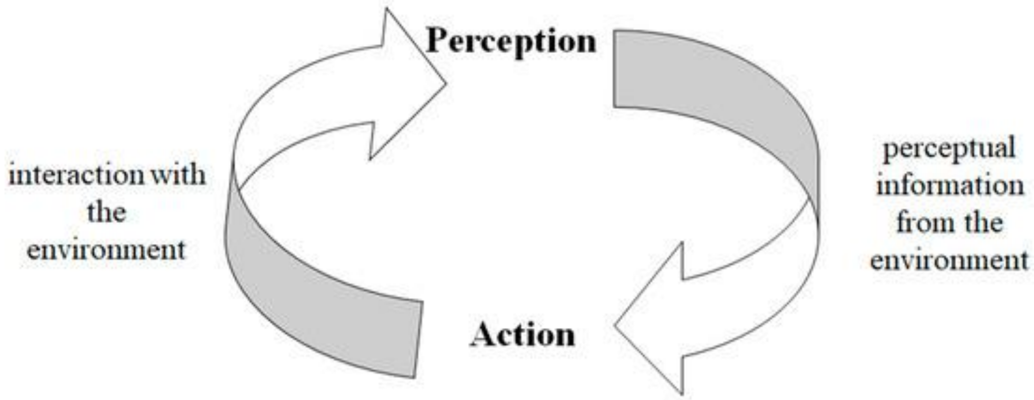


Image from Microsoft Stock Images

3: Definition of Perception-Action Learning

Perception-action learning is the process through which individuals develop and refine the ability to coordinate their movements in response to perceptual information from the environment. Rather than acquiring fixed movement patterns, perception-action learning emphasizes the emergence of functional coordination through repeated interaction with dynamic environmental and task conditions.

(Gibson, 1979; Michaels & Carello, 1981)



4: Types of Experimental Task

	Skilled Learning Task	De-Novo Learning Task
Perception–action learning tasks can be studied in single-agent or multi-agent settings.	Refinement of existing skills • Adaptation of coordination pattern • Calibration of information	Formation of new perception-action couplings • Forming new coordination patterns • Picking up new information sources
Individual Task 	Example: 1. Improving baseball batting (Gray, 2025) 2. Wall climbing (Seifert et al., 2015)	Example: 1. Virtual ball catching (Mehta et al., 2025) 2. Reaching and grasping with sensory substitution glove (Bilal et al., 2025)
Interpersonal Task 	Example: 1. Multiagent shepherding task (Nalepka et al. 2017)	Example: 1. Ball and board joint action task (Cheillan et al., 2025) 2. Ball and beam task (Hafkamp et al., 2025)

5: Overview of Experimental Design in Perception-Action Learning

Effective experimental design in perception-action learning studies is crucial for accurately assessing skill performance. This involves:

- Meticulously planning pretests and posttests
- Defining practice conditions
- Implementing retention and transfer tests
- Incorporating suitable design considerations
- Identifying appropriate learning measures

5a: Experimental Design

Experimental Design

Pretest/ Posttest

- Pretest and posttest are scheduled immediately before and after the practice session respectively to gauge the change in skill performance. These tests are crucial in assessing the effectiveness of a practice intervention.
- Ideally, pretest and posttest should be the same and incorporate all the possible practice variations included in the study for productive comparisons.

1

2

Practice

A practice session refers to the structured period during which participants engage in repeated trials of a motor task to facilitate learning. Some key aspects that need attention during design of practice session are ***number of trials***, ***practice conditions,*** and ***practice schedule.***

3

Retention measures how well a motor skill can be recalled and performed after a delay, without additional practice. To ensure comparability, retention tests usually follow the same design as the pretest and posttest.

4

Transfer refers to the ability to apply a learned perceptuomotor skill to a new, different, but related situation or task. It tests the adaptability and generalizability of the learned skill. (Pacheco & Newell, 2018)

Experimental Design: Practice

1

No. of Trials:

There is no fixed guideline on how many trials to include in the practice phase. This is task dependent and should be estimated through proper piloting.

2

- Practice Conditions
  - Constant
  - Variable

3

- Practice Schedule
  - Blocked
  - Serial
  - Random

Experimental Design: Practice

Practice Conditions

Constant Conditions: Practicing a task under identical conditions

(e.g., reaching and grasping the target object of same size from a same distance)

Implication: Skill refinement for similar conditions but is less flexible in transferring to other conditions

Variable Task Conditions: Practicing a task under different conditions

(e.g., reaching and grasping the target object of different sizes from different distances)

Implication: Perform better retention and transfer across novel contexts

(For example: Bilal et al., 2025; Huet et al., 2011)

Experimental Design: Practice

Practice Schedule

The traditional hypothesis on practice scheduling is termed as ***Contextual Interference hypothesis*** that posits better performance during practice with blocked practice but improved performance in retention and transfer tasks with random practice. However, there is considerable debate within the field on the robustness and generalizability of this hypothesis.

(Brady,2008; Magill & Hall, 1990)

Experimental Design: Practice

Practice Schedule

Blocked Practice:
Practicing one skill repeatedly for a block of trials before moving on to another skill

(e.g., A-A-A, B-B-B, C-C-C)

Serial Practice:

A predictable and repeating order of multiple skills

(e.g., A-B-C, A-B-C, A-B-C)

Random Practice:
Practicing multiple skills in a randomized, order within a single practice session

(e.g., A-B-C, C-A-B, B-C-A)

(For example: Gray, 2017; Mehta et al., 2025)

5b: Design Consideration

Design Considerations

Sample size Sufficient power (0.95) of the study depends on having the appropriate sample size. Sample size can be calculated apriori by using G-Power or GLIMMPSE.

Instructions to participants The key element of performing a perception-action learning study is to give accurate and consistent instructions to the participants at the start of the experiment.

Feedback During the experiment Feedback can be provided in two primary ways:

1. *Knowledge of results* (e.g., success or error)

2. *Knowledge of performance* (e.g., movement patterns, end effector or joint angles)

Mixed Design Include both repeated measures and between group comparisons. This allows to study the effect of between group experimental manipulations not only on the test scores but on how this interaction changes with practice during learning.

5c: Measure of Learning

Measure of Learning

1 **Performance Metrics:**

- Success
- Error
- Learning Rate

2 **Movement Behavior Metrics:**

- Movement Time
- Movement Trajectory
- Movement Coordination
- Exploration

Measure of Learning: Performance Metrics

- **Success:** A binary measure of whether the task goal is accomplished or not. For example (object is grasped or not, target is hit or missed)

- ***Error:** A measure of how well the task is performed.
  - Constant Error: Measure of average directional bias of error, computed as the mean of signed errors across all trials
  - Variable Error: Measure of consistency that tells you how much the performance fluctuates across trials
  - Absolute Error: Measure of overall accuracy ignoring the direction and is computed as mean of the absolute value of the errors

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- **Learning Rate:** Fit of an exponential function to the performance data and the slope of the function is the measure of how fast one learns (Newell et al., 2009)

* *Check appendix for calculations*

Measure of Learning: Movement Behavior Metrics

Movement time: Duration between movement initiation and termination. Movement time is expected to reduce with practice.

Movement Trajectory: The path taken by the end effector through space during a movement. Depending on the task, the movement trajectory usually becomes smoother and shorter after practice.

Movement Coordination: Structured spatial and/or temporal relations between movement elements (joints, segments, muscles etc.) to achieve the task goal. Different methods can be used to measure movement coordination for example cross-correlation (Dean & Dunsmuir, 2015), uncontrolled manifold analysis (Latash et al., 2007), and principal component analysis (Lee & Ranganathan, 2019).

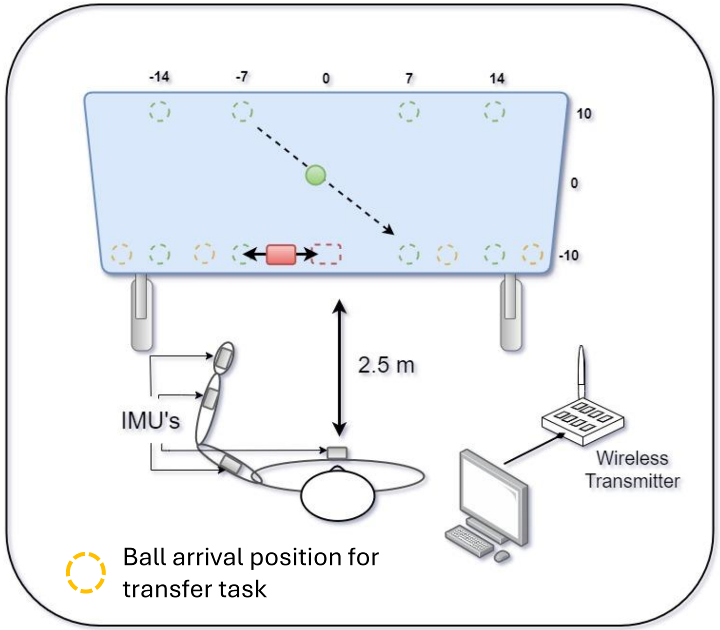
Exploratory Behavior: Purposeful trial to trial variation of movement strategies undertaken by an individual to discover effective coordination patterns and pick up of relevant information from the environment for achieving a task goal. It can be measured by computing the deviations of a behavioral variable on two successive trials.

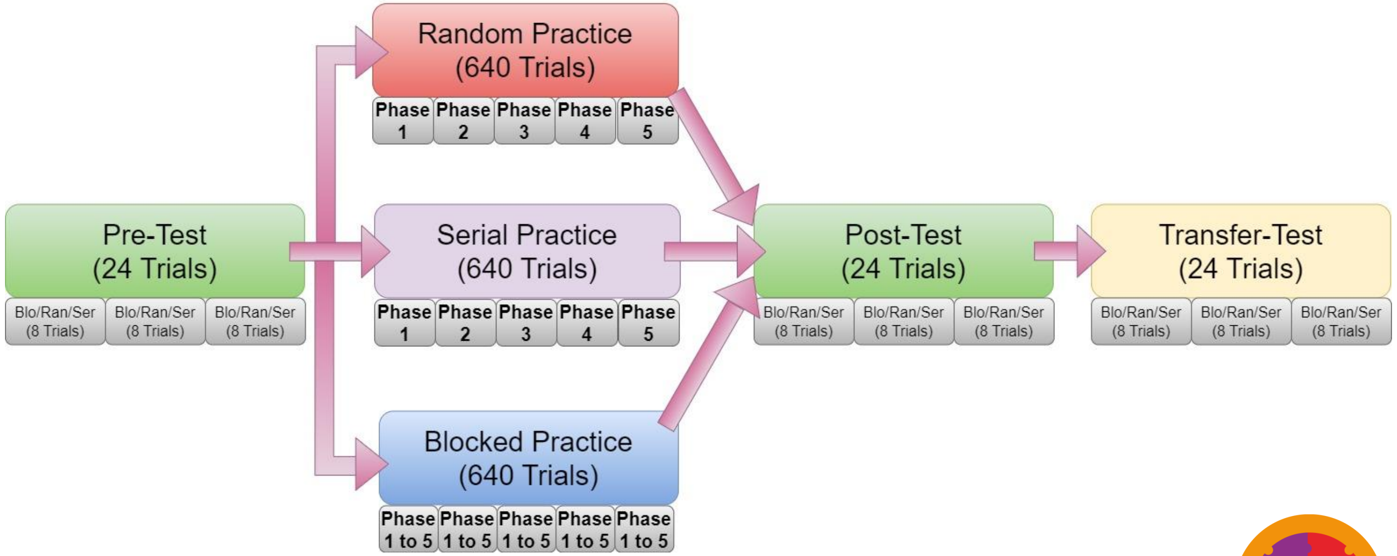
5d: Study Design Examples

Study Design: Example 1

Task: Virtual lateral interception task. The ball (green, solid circle) and the paddle (red, solid rectangle) along with the possible ball departure positions (dashed circles on top) and ball arrival positions (dashed circles on the bottom).

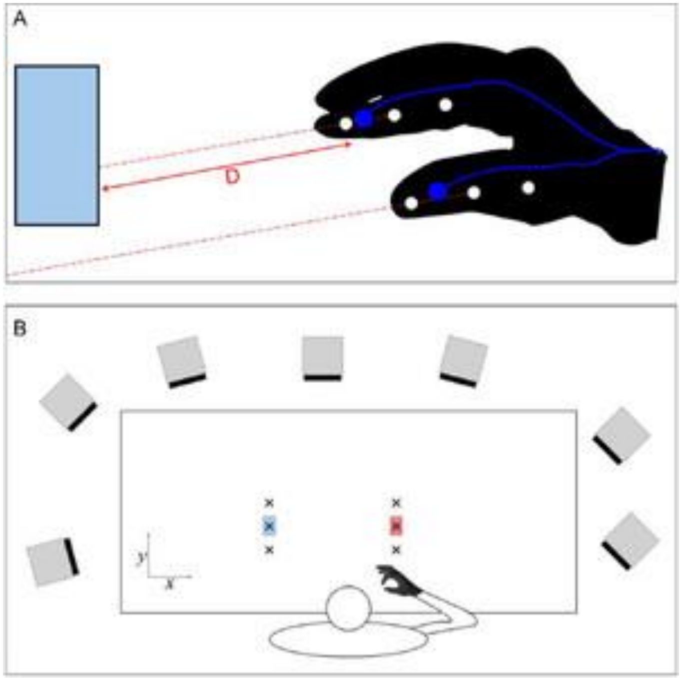
Goal: In the given example, the goal was to evaluate the influence of variability in practice schedules on the search for new movement coordination patterns in de-novo perception-action learning task.





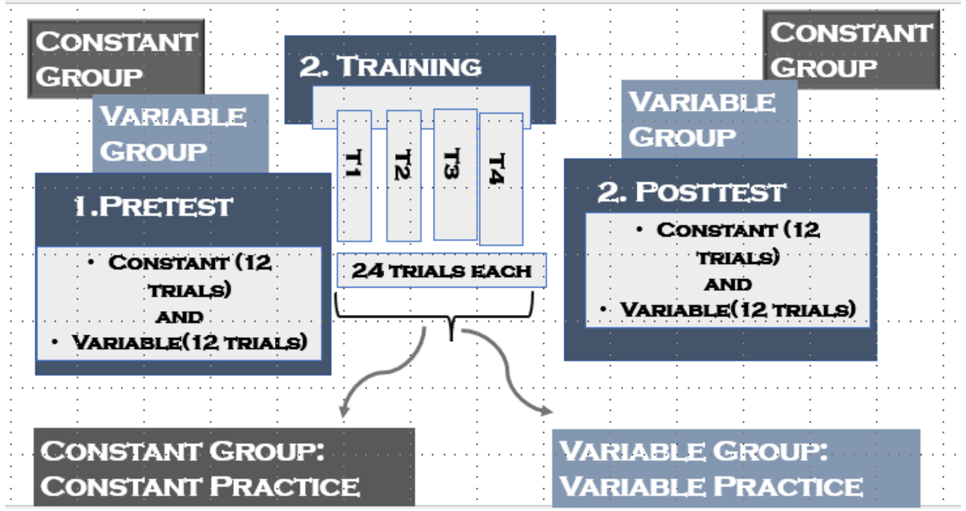
Study Design: Example 2

Task: Reaching and grasping with a sensory substitution glove (SSG). The red (right) and blue (left) rectangles represent the initial and target objects, respectively, and the × symbols represent possible positions of the objects in the experiment.



(Bilal et al., 2025)

Goal: The goal was to accurately reach for and grasp a target object based solely on the vibrotactile information provided by the glove, assessing how different practice conditions (constant vs. variable) influence skill acquisition, exploration behavior, and information detection with SSG.



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Appendix : Error Calculation

Constant Error	$CE = \left(\frac{1}{N}\right)\sum_{i=1}^{N}(X_i - T)$
Variable Error	$VE = \sqrt{\left(\frac{1}{N}\right)\sum_{i=1}^{N}(X_i - \bar{X})^2}$
Absolute Error	$AE = \left(\frac{1}{N}\right)\sum_{i=1}^{N}\lvert X_i - T\rvert$

X_i = performance on individual trial
T = target, N = total number of trials
$\bar{X}$ = mean performance across all trials