Cognitive Strategies to Improve Upper Limb Motor Performance

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Learning Objectives

- Determine at least three ways that executive function, attention, and interoceptive/autonomic processes influence upper limb motor performance in individuals with neurological conditions
- Implement at least two objective measurement tools (e.g., heart rate variability, surface EMG, smartwatch heart rate monitoring) and one subjective assessment (e.g., NASA-TLX) to assess cognitive or attentional workload during motor performance
- Modify therapeutic tasks by grading cognitive and attentional demands to enhance motor planning and performance in upper limb rehabilitation

Learning Objectives (cont.)

- Interpret data from cognitive and physiological workload tools to inform clinical decision-making during task progression
- Apply clinical strategies, including attentional cueing, dual-tasking, and breath-focused regulation, to promote generalization of upper limb skills to real-world settings
- Prepare a treatment plan that incorporates cognitive and interoceptive strategies into an existing upper limb neurorehabilitation protocol to address barriers to carryover in daily activities

Chapter 1

Cognition, Attention, and Regulation: the Brain's Role in Movement

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Cognitive-Motor Neuroscience and Workload

- **Cognitive-motor neuroscience** explores how the brain's executive and attentional systems shape the planning, coordination, and adaptability of movement
- **Cognitive workload** can be defined as the recruitment and allocation of cognitive-motor resources in response to task demands[1–3]

1. Gentil et al., 2011
2. Gentili et al., 2015
3. Shuggi et al., 2018

Cognitive Workload and Task Performance

Cognitive Workload ↓

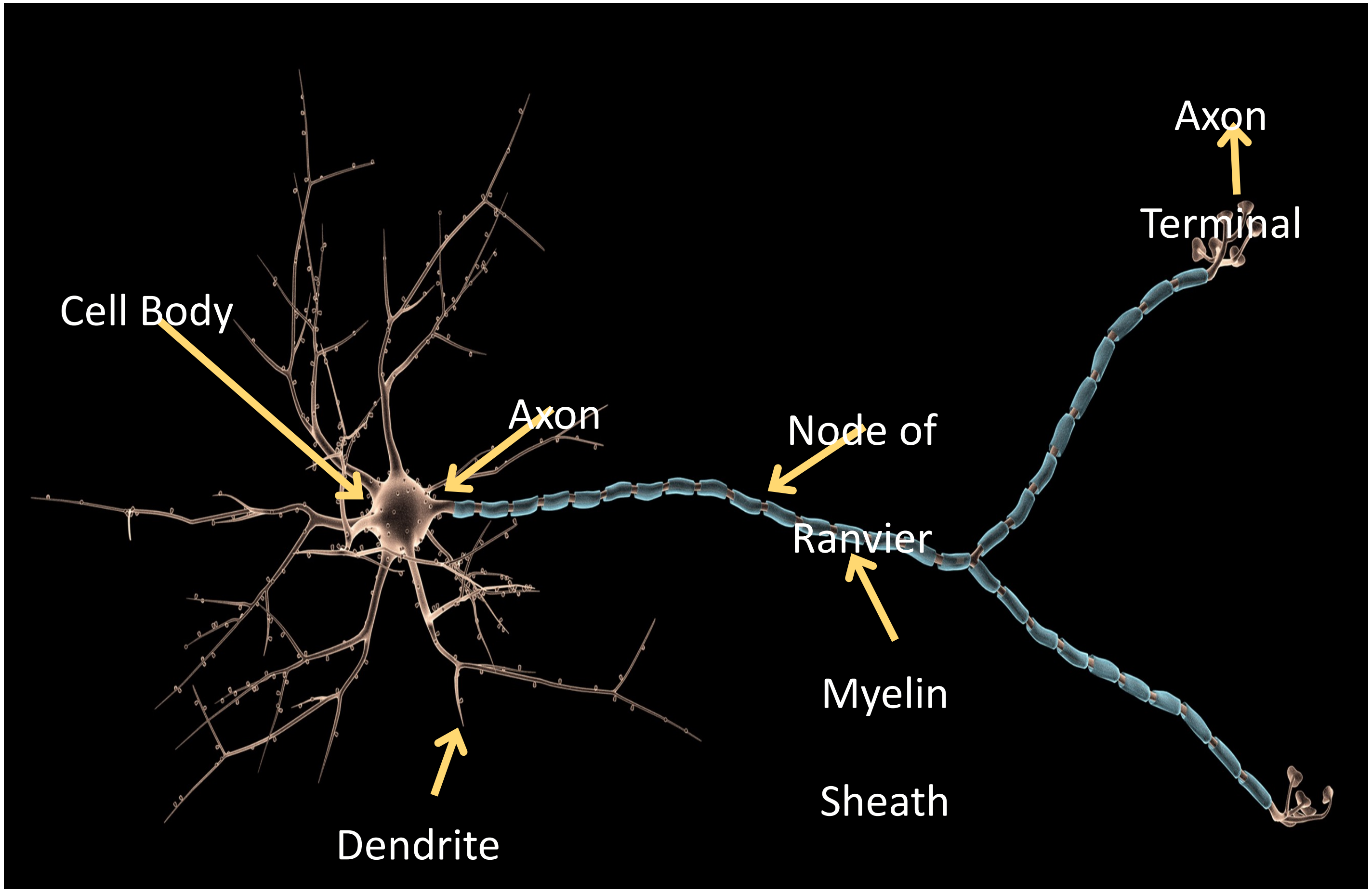
Cognitive-Motor Performance ↑ →

Cognitive Workload ↑

Cognitive-Motor Performance ↓ →

1. Gentili et al., 2011
2. Gentili et al., 2015
3. Shuggi et al., 2018
4. Shaw et al., 2018

Anatomy of the Neuron



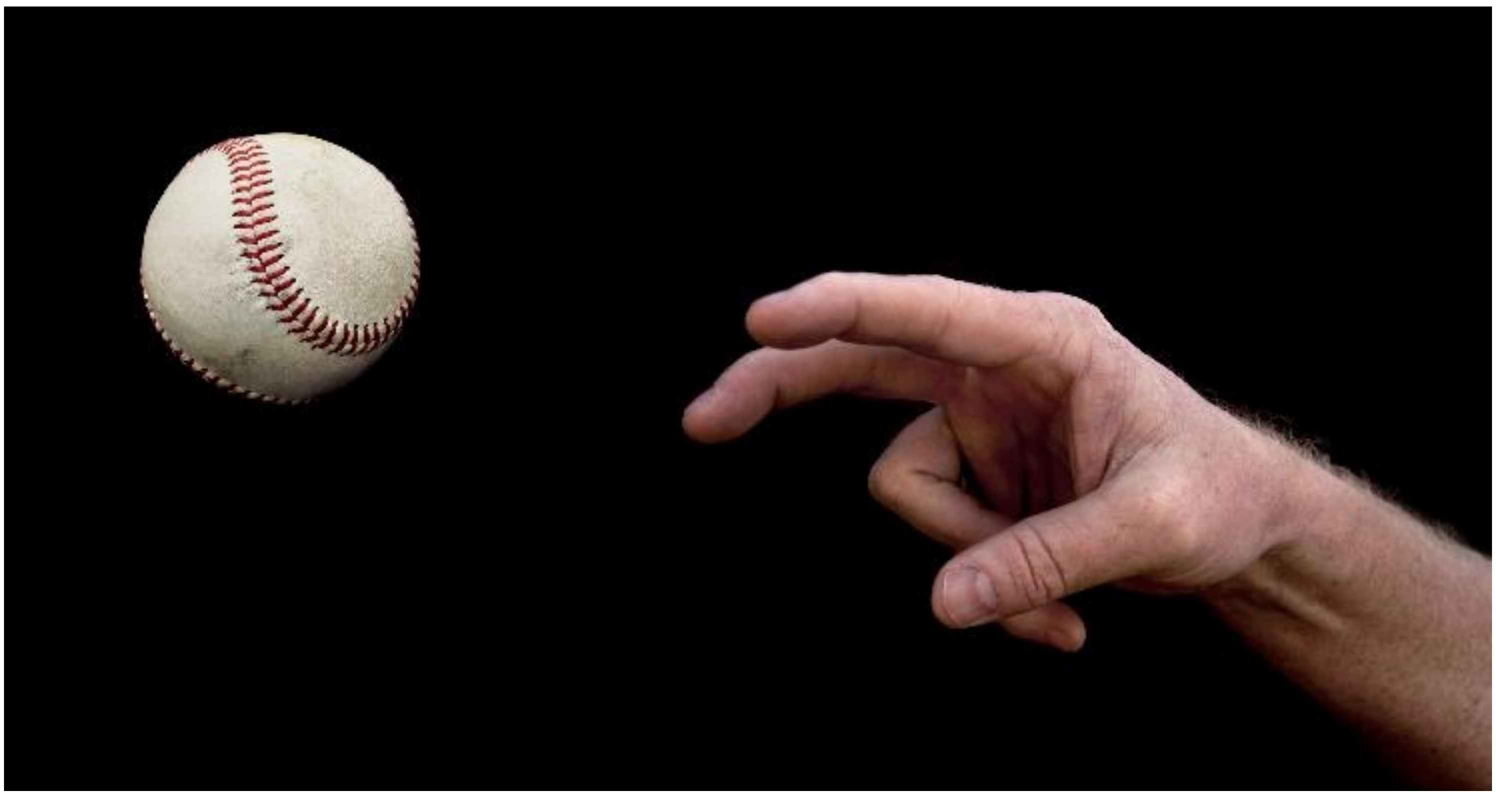
Brain Waves

- **Theta (4–7 Hz):** working memory, attentional processing, error-monitoring
- **Low-Alpha (8–10 Hz):** general arousal
- **High-Alpha (11–13 Hz):** task-relevant cognitive-motor processing
- **Beta (14–35 Hz):** sensorimotor processing

1. Ismail et al., 2025
2. Gentili et al., 2014
3. Pfurtscheller et al., 1996
4. Zaepffel et al., 2013

Attentional and Cognitive Processing

Goal-directed attention is key for visuospatial processing, motor planning, and control.

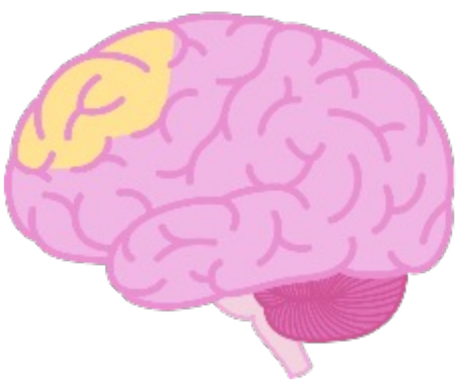


1. Lee & Kim, 2023
2. Parr et al., 2019

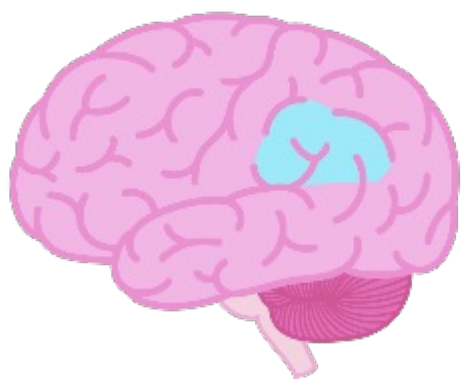
Frontoparietal Network

Allows for flexible cognitive-motor control in response to task demands.

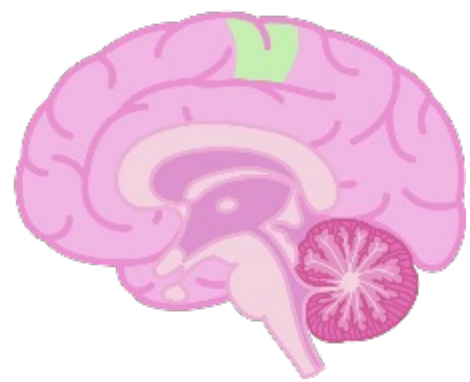
Dorsolateral Prefrontal Cortex



Inferior Parietal Lobule



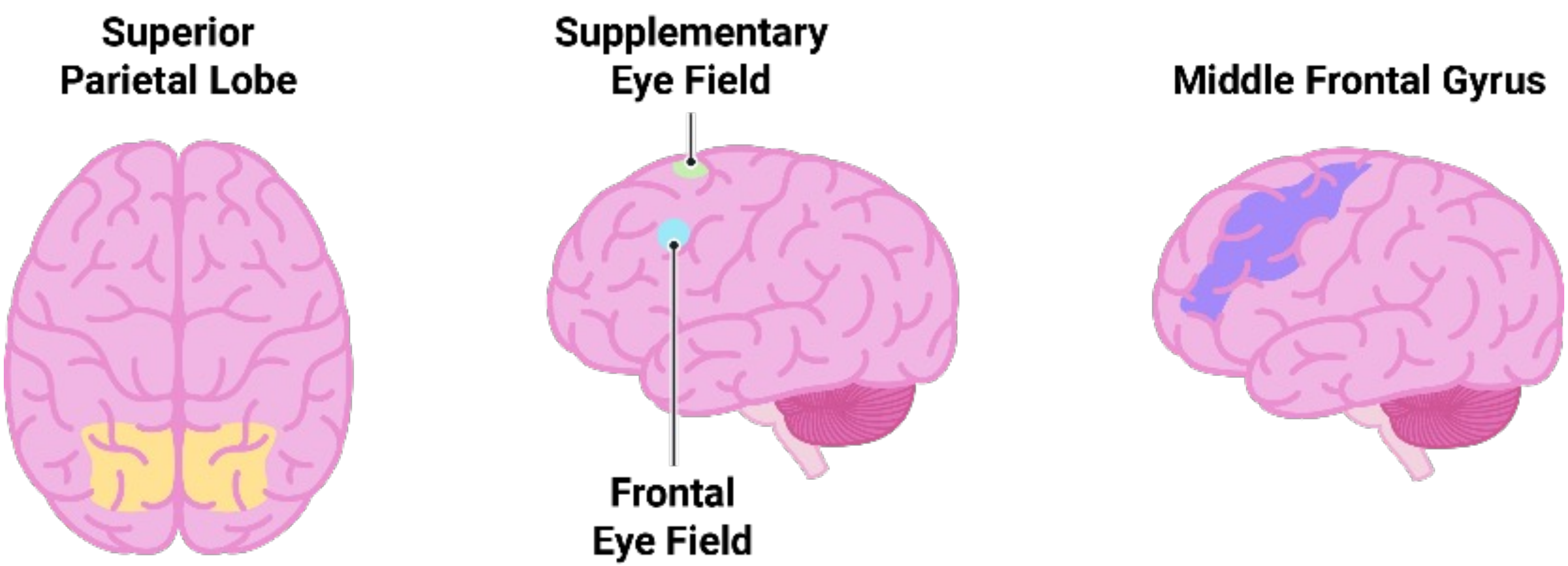
Supplemental Motor Area



1. Lee & Kim, 2023
2. Mattos et al., 2023

Dorsal Attention Network

Modulates top-down, voluntary attentional resources as prerequisite for goal-directed motor activity.



1. Lee & Kim, 2023

2. Mattos et al., 2023

Default Mode Network

Internal thought, mind-wandering, and self-referential processing.

Medial Prefrontal Cortex | **Precuneus** | **Posterior Cingulate Cortex** | **Lateral Temporal Cortex**

- Active during rest and internal thinking **(not focused on external environment)**
- **Impaired deactivation** of this network may cause competition for cognitive resources during goal-directed upper limb motor performance

1. Lee & Kim, 2023
2. Mattos et al., 2023

Cognition Is Essential to Motor Recovery

- **108 subacute ischemic stroke patients** underwent resting-state functional MRI two weeks post-stroke onset
- **Fugl-Meyer assessment:** two weeks post-stroke onset and three months post-stroke

Lee & Kim, 2023

Cognitive Networks Associated With Motor Recovery

- The cognitive-related networks, Dorsal Attention Network (DAN) and Default Network (DEF) were significantly associated with motor recovery in patients with weaker motor-related networks

Lee & Kim, 2023

Heart Rate Variability May Reflect Vagal Nerve Control

- **Heart rate variability (HRV)** is a measure of the variation in time between consecutive heartbeats
- Reflects the adaptability of the autonomic nervous system, an interplay between the sympathetic and parasympathetic branches
- Parasympathetic mediation via the vagal nerve is linked to interoception and motor performance

Sethi et al 2016

Understanding Heart Rate Variability

- **High HRV:** greater adaptability, efficient parasympathetic (vagal) regulation, improved emotional, and motor control
- **Low HRV:** reduced autonomic flexibility, often associated with poorer motor recovery, stress, and neurological dysfunction

Sethi et al., 2016

Understanding Heart Rate Variability (cont.)

- A narrative review found that HRV is positively associated with motor outcomes three months post-stroke
- Lower HRV associated with greater assistance levels in activities of daily living (ADLs) and poorer responses to motor rehab
- Improved HRV after rehab was found to have better motor performance and grip strength

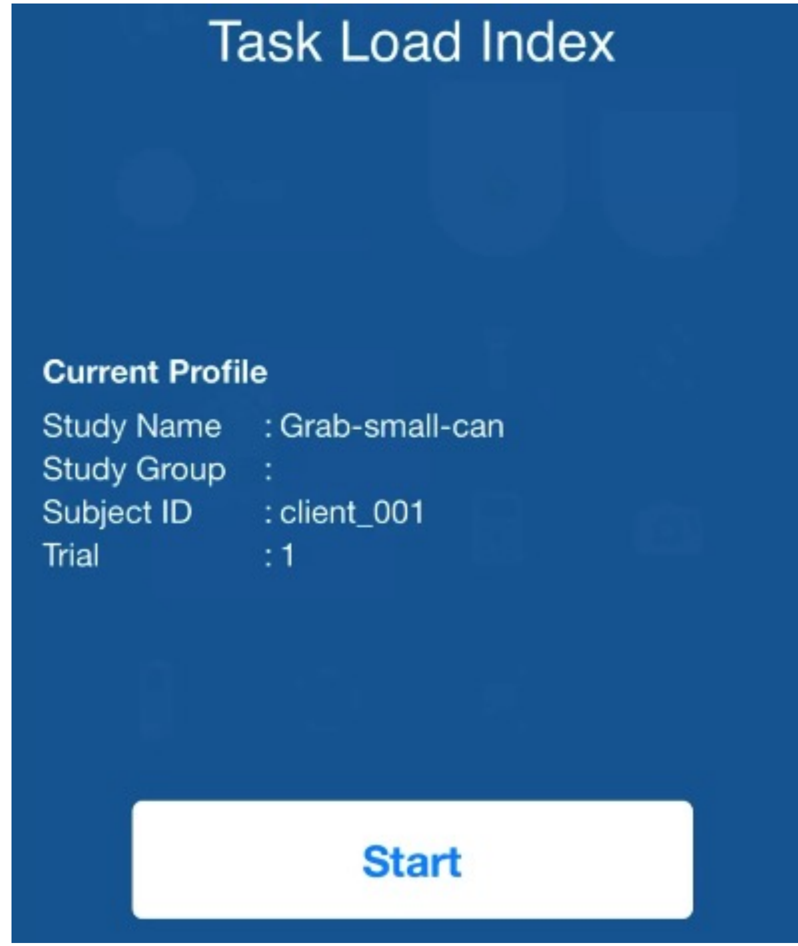
1. Lago et al., 2025
2. Scherbakov et al., 2020

Heart Rate Variability Measurement

	Sensor Type	Suitable for Upper Limb Movement Tasks?	Suitable for Interoception Training
emWave Pro	Photoplethysmography (PPG) via ear or finger measure	No: sensitive to movement artifacts	Yes: excellent for biofeedback, breathwork
Polar H10	Electrocardiogram via chest strap	Yes: accurate for dynamic movement	Moderate
Apple Watch	PPG with HRV	Limited: somewhat sensitive to movement artifacts	Moderate
Garmin Forerunner	PPG	Limited: somewhat sensitive to movement artifacts	Limited: some models offer stress scores

NASA Task Load Index

- Measures workload across six dimensions
  - Mental demand
  - Physical demand
  - Temporal demand
  - Performance
  - Effort
  - Frustration
- Each domain scored on a 0–100 scale



Hart & Staveland, 1988

NASA Task Load Index (cont.)

History | Rating Scale

Study Name: **Grab-small-can**
Study Group:
Subject ID: **client**
Trial: **001**
Type: **Rating Scale**
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	Rating	Weight	Adjusted
Mental Demand	60	2	120
Physical Demand	70	2	140
Temporal Demand	70	3	210
Performance	85	2	170
Effort	80	2	160
Frustration	40	4	160

Weighted Rating: 64.00

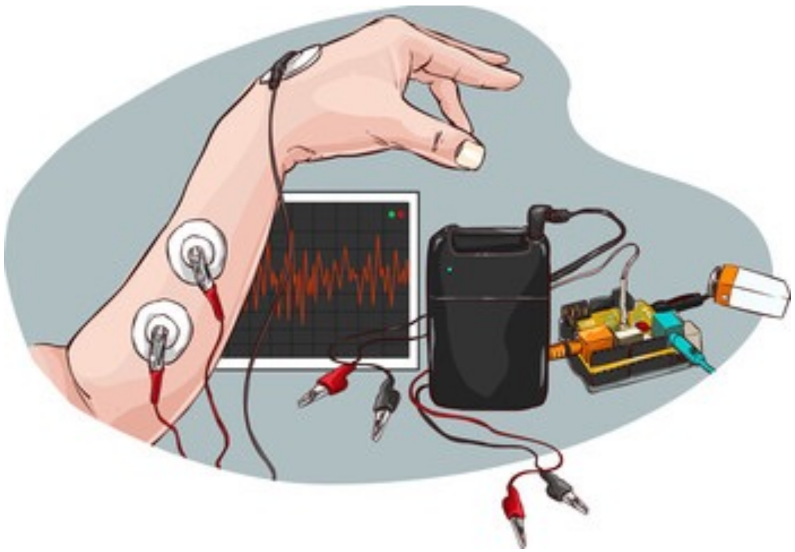
Surface Electromyography (sEMG)

- Increases awareness of muscle activity and motor control
- Provides visual biofeedback to help clients understand when a muscle is on or off
- Facilitate relaxation of antagonist muscles and promote reciprocal inhibition

1. Woodford & Price 2007

Surface Electromyography (sEMG) Products

- mTrigger Biofeedback system
- NeuroTrac Simplex EMG Biofeedback
- Trigno from Delsys
- Myopro (orthosis powered by EMG with visual biofeedback)



Chapter Summary

- **Executive function**
  - Layering contextual cognitive demands on top of upper limb motor task increases frontoparietal network activation
  - May facilitate generalization of upper limb tasks into more dynamic, social environments
- **Attention**
  - Eye gaze activates the dorsal attention network and is key for visual-motor planning and reach and grasp endpoints
  - Eye gaze on hand during task suggests greater cognitive load, increased error monitoring, and reliance on visual feedback
  - Eye gaze on target reflects lower cognitive load, and predictive motor planning

Chapter Summary (cont.)

- **Interoception:** enhanced bodily perception and awareness may inhibit the default mode network, decrease competing cognitive resources, and facilitate recruitment of cognitive resources to goal-oriented upper limb tasks
- **HRV measurement**
  - Proxy for measuring interoception
  - Higher HRV levels indicate increased parasympathetic (vagal) activity
  - Vagal influence increases cortical inhibitory control and reduces spinal reflex hyperexcitability via dampened gamma motor neuron excitability
  - May lead to increased voluntary control, reduction in muscle tone
  - More clinical studies are needed

Chapter Summary (cont.)

- **sEMG:** visual feedback of muscle activity can enhance interoceptive accuracy
- **Antagonist muscle:** voluntary suppression of hyperactive muscle group
- **Agonist muscle:** reciprocal inhibition
  - Activation of agonist muscle causes inhibition of the antagonist muscle
- **NASA-TLX:** validated tool to quantify subjective mental workload across six domains (mental demand, physical demand, temporal demand, performance, effort, and frustration)
  - Effort and frustration domains may indirectly capture interoceptive awareness
  - Useful for grading task difficulty, monitoring progress, and adjusting interventions based on perceived demands

Chapter 2

Grading Cognitive Load and Attentional Demands in Therapy

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Cognitive Load

- **Intrinsic load:** inherent task complexity
- **Extraneous load:** external task demands
- **Germane load:** cognitive effort toward learning and schema development

Sweller, 2010

Intrinsic Load Modulation

Sequence Demand

Increase Number of Steps

Sweller, 2010

Extrinsic Load Modulation

Increase Environmental Attentional Demands

Sweller, 2010

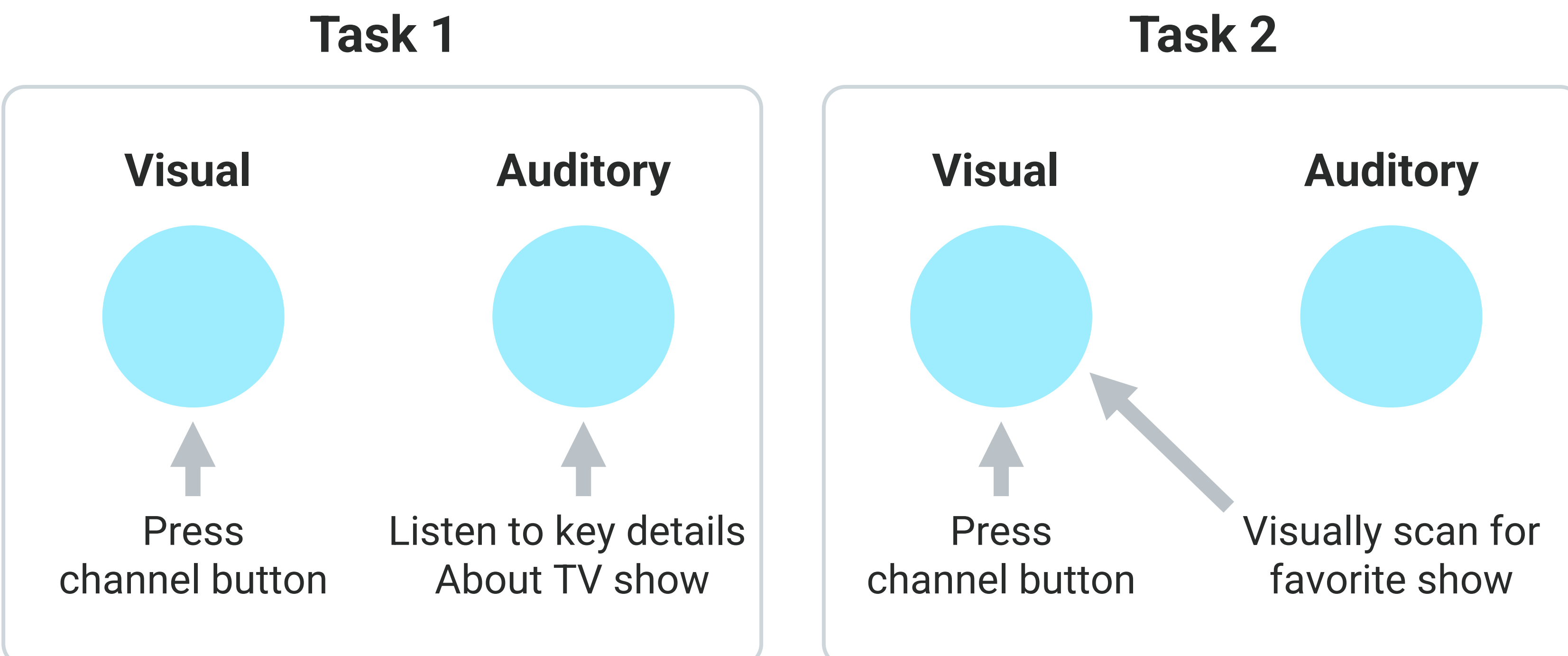
Attention Types

- **Selective attention:** focus on one stimulus
- **Sustained attention:** maintaining focus over a period of time
- **Divided attention:** split focus across various activities

Sweller, 2010

Dual-Task Progression

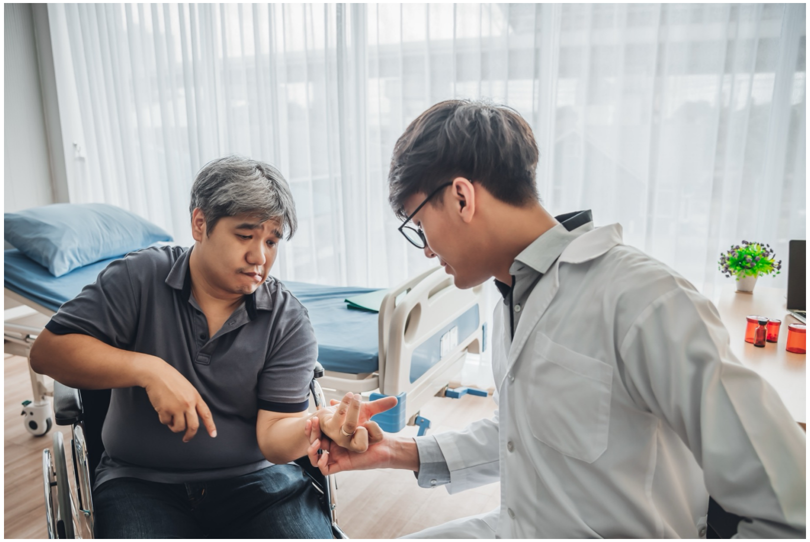
Tasks that have overlapping resources significantly increase mental workload.



Wickens, 2008 2. Petrillo et al. 2023

Case Study: Grade Cognitive and Attentional Demands

- **Our patient:** James, 50-year-old male stroke survivor
- **Diagnosis:** left middle cerebral artery stroke, three months post-onset
- **Presentation:** right UE weakness, mild flexor spasticity, mild cognitive impairment, reduced processing speed
- **Goal:** improve reach and grasp ability during self-feeding



Case Study: Grade Cognitive and Attentional Demands (cont.)

- **Our patient:** James, 50-year-old male stroke survivor with right side hemiparesis
- **Goal:** improve reach and grasp ability during self-feeding
- **Task setup:** three mugs placed on countertop, identical in shape/size, but each with a different quote or phrase

Reach for Mug: Dual-Task Strategies for James

Low Ecological Validity

- Count aloud by 2s while reaching for a mug
- Identify whether the number taped to the mug is odd or even before reaching
- Name the color of each mug before grabbing it

High Ecological Validity

- Retrieve the mug while remembering a grocery list
- Reach for the mug while stirring food with the other hand
- Reaching while having a conversation

Interoception and Breathwork Strategies James

- After several reaching repetitions and increased exertion, James reports fatigue. You notice he struggles to open his hand more now, and he cannot fully extend his arm.
- **What interoception awareness strategies can we incorporate into the plan of care to facilitate vagal nerve influence and movement preparation?**

Interoception and Breathwork Strategies James (cont.)

- **Box breathing:** inhale, hold, exhale, hold. Do each phase for four seconds.
- **Physiological sigh:** two short inhales through the nose, then a prolonged exhale through the mouth.
- **Pursed-lip breathing:** inhale slowly through the nose, exhale slowly through pursed lips.
- **Tip:** consider incorporating breathwork during active rest breaks, which may include motor imagery, deep proprioceptive cues, and electrical stimulation.
- **Tip:** active rest breaks are an ideal time to do HRV training.

1. Liang et al 2023

Interoception and Breathwork Demo

Task Specific Training – Open refrigerator door with incorporation of deep breathing to

- decrease bodily tension
- increase time in motor planning phase
- Deepen intentionality
- Refine motor execution phase

Chapter Summary

- Clinicians can optimize upper limb rehabilitation by intentionally modifying cognitive load through
  - Variation of attentional demands
  - Contextual dual-tasking
  - Intrinsic load manipulation (task complexity)
  - Extrinsic load manipulation (environmental distractions)
  - Interoceptive strategies, like HRV monitoring and breathwork, enhance self-regulation and may be useful to reduce tension and help the brain "reset" after periods of strenuous upper limb work

Chapter 3

Measuring and Translating Cognitive Load for Functional Outcomes

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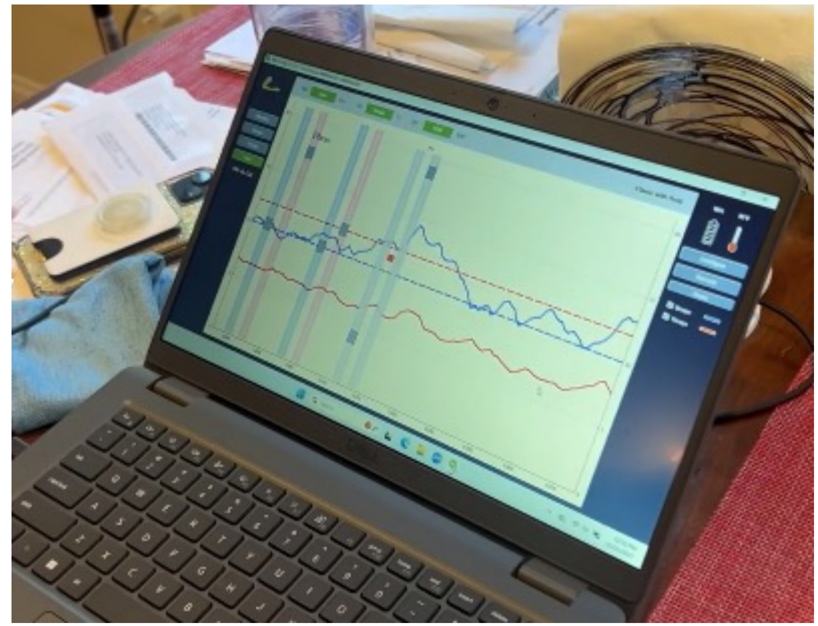
Effect of Breathwork on Muscle Activity

- Blue line represents bicep activity (flexor spasticity)
- Deep breathing
- Inhibitory response in muscle activity when eyes closed



Are There Standardized Values for Physiological Measures Like sEMG and HRV?

- Not necessarily
- **A meaningful change is the client's ability to modulate HRV or muscle activity in response to cognitive-motor task demands or interoceptive awareness**
- While HRV or sEMG can be used as a biofeedback tool, typically it is billed as 97530 or 97112, depending upon the therapeutic context
- Avoid biofeedback CPT code 90901

Shaffer & Ginsberg, 2017

NASA-TLX as a Grading Tool

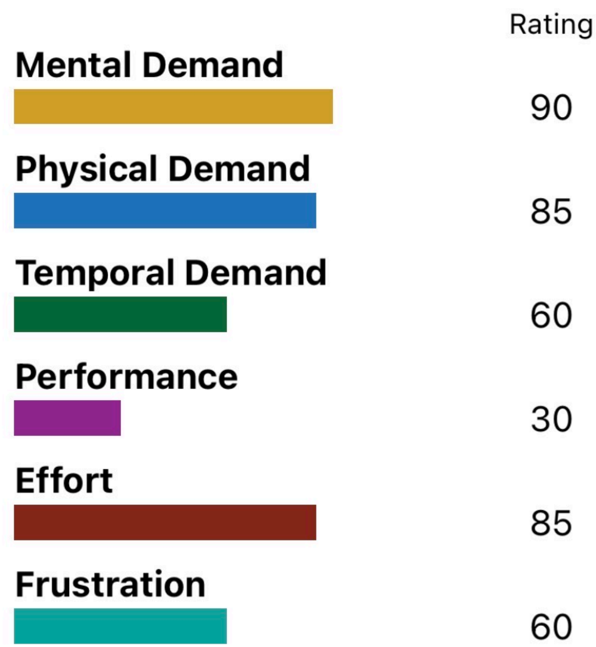
- Quantify mental workload at various time points during skill acquisition
- Quantify the task demands between two different tasks
- Quantify the cognitive demand of external stimuli during task completion

Hart & Staveland, 2008

Compare Cognitive Load Between Two Tasks

Sweller, 2010

Open Refrigerator

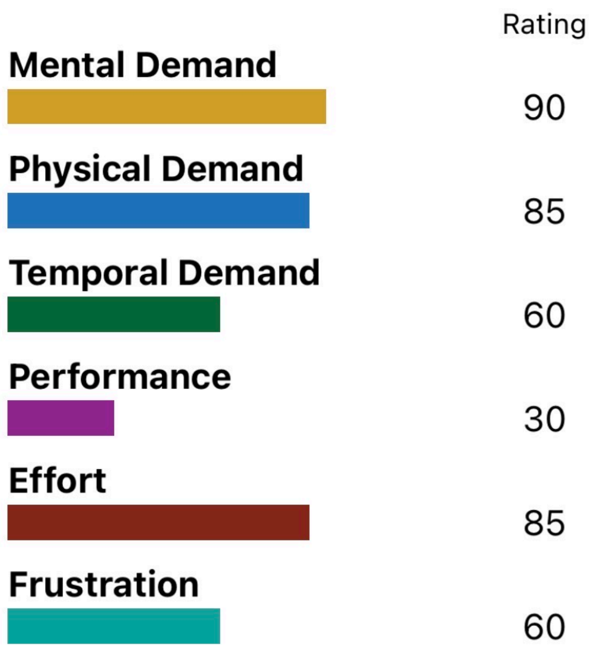


Turn on Faucet

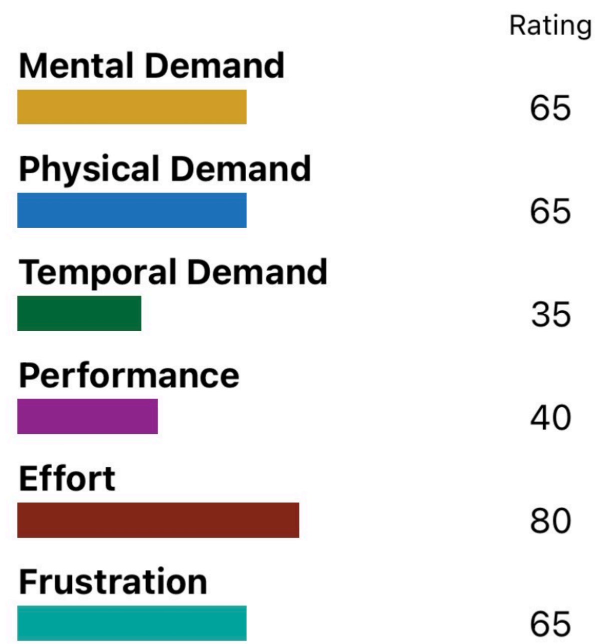
	Rating
Mental Demand	65
Physical Demand	65
Temporal Demand	35
Performance	40
Effort	80
Frustration	65

Cognitive Load Comparisons

Open Refrigerator



Turn on Faucet



Measurement Challenges and Outlook

- No minimally clinically significant difference (MCID) or minimally clinically difference (MCD) values for NASA-TLX
- Physiological measures are more expensive (HRV, sEMG)
- However, these measures provide deeper context into the attentional and cognitive processes of upper limb motor function that enhance motor control
- Evidence suggests that monitoring and modulation of cognitive processes enhance motor learning and motor outcomes

1. Gomes et al. 2021 2. Rudd et al. 2023

Chapter Summary (to be added)

- Quantify cognitive workload at various timepoints, environments and between tasks
- Observation of physiological responses enhance interoception and may help clients modulate their motor activity from a top-down approach
- Patient reported outcome (PRO) measures such as the NASA-TLX may help quantify various demands within a task (e.g. mental vs temporal demand)

Course Summary

- **Upper limb motor performance is strongly shaped by executive, attentional, and interoceptive brain networks**, including the frontoparietal, dorsal attention, and default mode networks
- **Cognitive load can be systematically graded** through intrinsic task complexity, environmental (extrinsic) demands, and dual-tasking to improve motor planning and carryover to real-world function

Course Summary (cont.)

- **Physiological and perceptual tools** (HRV, sEMG, smartwatch heart rate, NASA-TLX) provide clinically useful insight into mental workload, autonomic state, and interoceptive awareness during movement
- **Breathwork, attentional cueing, and interoceptive strategies** can support vagal regulation, reduce excess muscle activity, and prepare the nervous system for more efficient upper limb movement

Course Summary (cont.)

Integrating cognitive-motor neuroscience into the therapeutic approach enables therapists to build more adaptive, generalizable, and functionally meaningful neurorehabilitation programs

1. Jacques et al 2023 2. Gomes et al 2021

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