Cognitive Functions:
Principles, Assessment
Techniques and Implications

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Outline:

1. Principles of cognition.

2. Techniques of cognitive assessment.
   1. Bedside
   2. Advanced

3. Age-related changes of cognition and its implications.
What is Cognition?

Process by which knowledge and understanding is developed in the mind.

– Oxford advanced dictionary
Evolution of the study of cognition
How to ‘study’ cognition?

- The **behavioural psychologist** knows that cognition is *in operation*, from the *behavioural manifestations* of the individual.

- The **cognitive neuroscientist** wants to know more:
  - The brain-basis of cognition.
  - i.e. *neural correlates and mechanisms* of cognition.
Cognitive Neuroscience: an integrated approach to study cognition

- **Cognitive neuroscience** helps to gain an understanding of the human cognitive system by reconstructing it, process by process.
- Helps to understand cognition in health and disease.

- **Cognition** is the *stepwise (serial and parallel) processing of discrete pieces of information.*
Cognitive processing: the Path from Perception to Action
Figure 11.26  Movements may vary in terms of the contribution of internal and external sources of information. The external loop, including the cerebellum, parietal lobe, and lateral premotor cortex (PMC), dominates during visually guided movements. The internal loop, including the basal ganglia and supplementary motor area (SMA), dominate during self-guided, well-learned movements.
Cognitive Domains

1. Perception
   - primary and association sensory areas

2. Attention
   - fronto-parietal networks

3. Learning and Memory
   1. hippocampus (memory consolidation)
   2. basal ganglia (procedural memories)
   3. neocortex (long-term memory storage)
4. Executive Functions: Cognitive functions that enable *goal oriented-behaviour* ↔ prefrontal cortex

- Planning
- Reasoning
- Decision-making
- Inhibitory control
- Attentional set-shifting
Testing Cognitive Functions
Techniques in cognitive neuroscience

- Neuropsychological (human / animal)
- Neuroimaging
- Neurophysiological
- Histopathological
- Computer modelling
Cognitive changes of ageing
Cross-sectional estimates of age-related changes of cognitive domains (Schale 1996)
Patterns of changes in normal ageing:

1. **Life-long stability:**
   1. Autobiographical memory
   2. Automatic, over-learned procedures

2. **Decline only in very late life:**
   1. Semantic knowledge
   2. Vocabulary
   3. Short-term memory
   4. Sustained attention (vigilance)
   5. Recognition memory

- **Decline throughout adult lifespan:**
  - Processing speed
  - Encoding of episodic memory
  - Working memory and executive functions
1. Information processing speed

- Prominent, linear decline. Affects other cognitive functions.

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**Digit symbol substitution test**

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Memory

- Atkinson and Shiffrin 1968
2. Long-term Memory:

- **Semantic memory:**
  - Factual knowledge
  - E.g. When did the Japanese bomb Colombo?
  - Relatively preserved until later life

- **Episodic memory:**
  - Memory of specific events
  - E.g. What were you doing when you first heard about 2004 tsunami?
  - Encoding of new episodic memories declines during the adult lifespan
3. Short-term memory

- Relatively preserved until late life
4. Working Memory

- More complex than short-term memory.

- Working memory is active manipulation of information in short-term storage.

- Prominent decline with advancing age.
6-Y-D-3-7-K

Letter-Number Sequencing Test
5. Executive Functions

- Cognitive functions that enable goal oriented-behaviour
  - Planning
  - Reasoning
  - Decision-making
  - Inhibitory control
  - Attentional set-shifting

- Closely linked with working memory.
**Stroop test: inhibitory control**

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Name the colours of the word as quickly as you can.
Stroop test

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Stroop test and inhibitory control

- Difference in performance between the two parts = **interference**

- Why interference? Subject has to suppress a habitual response and execute the task-relevant behaviour

- Interference increases with advancing age

- Neuroimaging studies: activation of lateral pre-frontal cortex and anterior cingulate cortex
Hands-on Exercises

○ **Exercise 1:**
  ● Time and complete TMT-A
  ● Write down your age and test completion time (in seconds)
  ● Plot age vs. completion time graph

○ **Exercise 2:**
  ● Time and complete TMT-B
  ● Write down your age and test completion time (in seconds)
  ● Plot age vs. completion time graph
Selective attention (Trail making test A)
Attentional set-shifting: TMT-B
TMT-B performance impaired in the elderly.

- Neuroanatomical correlates: prefrontal cortex
Neural changes in normal ageing
1. Decline in white matter volume

- Mainly prefrontal cortex and anterior corpus callosum
- Histological changes: demyelination of neuronal tracts
- Depletion of the density of dopaminergic pathways

⇒ slowing of processing speed

Figure 3 | Diffusion tensor images of anisotropy of white matter in young and normal elderly subjects. Group-averaged diffusion tensor images of anisotropy of white matter in young

Head D. et al. 2004
2. Decline in grey matter volume

- Primarily due to lowering of synaptic densities, not due to cell death.

- Most prominent decline in pre-frontal areas: 5% per decade (→ executive functions).

- Striatum 3% per decade (→ degeneration of dopaminergic pathways)

- Medial temporal lobe structures: 2-3% per decade (→ memory consolidation)
2. Decline in grey matter volume

Figure 2 | Cross-sectional estimates of age-related volumetric change in lateral prefrontal cortex, visual cortex and hippocampus measured with magnetic resonance imaging. Points on each scatterplot indicate volumetric estimates from individuals, and the line of best fit is shown. Lateral prefrontal cortex volume declines steadily across the adult lifespan, while hippocampal volume has a curvilinear slope, with its largest declines occurring after age 60. Other areas, such as primary visual cortex, have only slight age-related volume declines. Data from REF. 25; figure courtesy of N. Raz.

Raz et al. 2004
3. Degenerative changes of neuroglia

Accumulation of degenerative material ➔ loss of glial cells ➔ impaired ‘housekeeping’ activities of the brain

- microglia
- oligodendrocytes
- Astrocytes
Neurophysiological changes in normal ageing
Memory consolidation in hippocampus occurs due to *long-term potentiation* where synaptic strength is increased by,

1. Increasing the sensitivity of postsynaptic non-NMDA receptors to glutamate
2. Increasing presynaptic release of glutamate
3. Synthesis of AMPA receptors

Neural changes in learning: Impaired in old age
1. Age-related changes in action potential: evidence from animal electrophysiology

- Stronger stimulation is required to bring the cell into threshold level ➔
- Lower chance of neuronal depolarisation ➔
- Impaired long-term potentiation ➔
- Poor memory consolidation
2. Changes in cognitive event-related potentials (ERPs) in humans

ERPs = Brain EEG potentials corresponding to different cognitive processes
Example: Studying Age-related Changes of Sensory Memory with ERPs

- Sensory memory: Stores sensory representations of information rather than meaning-based representations = a buffer of sensory information
- Has greater capacity than short-term memory
- Formed even if the person does not pay attention to stimuli.
- Decays very rapidly.
  - Visual sensory memory = iconic visual store (400-500ms, max 1000ms)
  - Auditory sensory memory = echoic store (up to few seconds)
- Important in time-restricted tasks such as driving.
Studying Sensory memory using Mismatch negativity (MMN)

Experimental paradigm:
1. The subject watches e.g. a silent movie.
2. Two types of tones are randomly emitted through headphones at brief inter-stimulus intervals:
   1. Standard
   2. Deviant
3. Record event-related potentials (ERPs) separately for standard and deviant sounds
Observation: Deviant sound elicits a larger negativity than the standard sound. The difference is called **MMN**

**Interpretation of MMN:** standard tone create an echoic memory trace in auditory cortex. The deviant tone presented subsequently does not match with the existing trace

Observation: The difference disappears as the inter-stimulus interval increases (say after 6 seconds)

**Interpretation:** Sensory memory trace disappears after 6 seconds so both the deviants and standard tones are not different to the auditory cortex

**Conclusion:** ISI where MMN disappears = duration of sensory memory
Observation: MMN disappears at shorter inter-stimulus intervals in the elderly than in the young.

Interpretation: Duration of retention of information in sensory memory is shorter in the elderly.
Different ERP components

Psychophysiologists have isolated a multitude of ERP components that correspond to different types of cognitive processes:

- Auditory sensory memory: **Mismatch negativity (MMN):** Schizophrenia, recovery from unconsciousness

- Language functions: N400 (semantic processing), P600 (syntactic processing): language disorders, autism

- Error detection: ERN (Error-related negativity): executive dysfunction

- Motor preparation: CNV (contingent negative variation)

- Attention: P1, N1
Age-related changes in event-related potentials:

- Prolongation of latencies of ERP components related to selective attention, working memory etc. → reduced processing speed

- Decreased amplitude of ERP components (e.g. related to working memory and executive functions) → reduction of neural resources allocated to respective cognitive functions

Wild-Wall et al. 2011
Cognitive changes ageing

- Neuropsychological changes
- Neuroanatomical changes
- Neurophysiological changes
Normal ageing vs. Alzheimer’s

Normal ageing
- Executive impairment is most prominent initially
- Atrophy begins in fronto-striatal networks
- Mainly reduced synaptic densities

Alzheimer’s disease
- Memory impairment is most prominent initially
- Atrophy begins at entorhinal cortex and hippocampus
- Prominent loss of cells
Possible compensatory mechanisms in the elderly
Figure 5 | **Neural activations in prefrontal cortex during a memory encoding task.**
Activations are shown for young adults, low-performing older adults and high-performing older adults. Low-performing older adults exhibit a similar pattern as do young adults, with lower overall levels of activation. High-performing older adults exhibit greater bilateral activation. RF, right frontal; LF, left frontal. Data from REF. 93.

**Do high-functioning adults use both hemispheres to compensate for the loss?**
Implication of age-related cognitive impairment
- Impaired processing speed, attentional switching affect time constrained tasks such as driving.

- Impaired episodic memory encoding → Individual is not sure whether the event actually happened or whether he/she just heard or thought about the event.

- Impaired working memory and executive functions may affect instrumental activities of daily living → increasingly important in Sri Lanka as more and elderly parents are expected to live alone, looking after themselves.
Can we slow down age-related cognitive impairment?
Stay intellectually engaged
At best, mental activity seems to protect against age-related declines and progression to Alzheimer’s disease. At worst, it increases an individual’s baseline level so that age-related declines begin to affect everyday functioning later in life. Enriched environments stimulate neurogenesis in aged rats, indicating a possible mechanism for the benefits of cognitive stimulation.

Maintain cardiovascular physical activity
Exercise aids executive function, reduces declines in tissue density in frontal, parietal and temporal cortex, and might have global effects on the brain.

Minimize chronic stressors
Proneness to distress, measured by the personality trait of neuroticism, is associated with increased risk of Alzheimer’s disease and a faster rate of cognitive decline. Increased glucocorticoid levels, which accompany stress, might damage hippocampal neurons over the lifespan. Cortisol administration reduces glucose metabolism in the hippocampus in normal older adults.

Maintain a brain-healthy diet
A diet that is high in poly- and mono-unsaturated fatty acids (as found in fish and olive oil), vitamin E (REF. 140) and polyphenols and antioxidants (found in citrus and dark-skinned fruits and vegetables) might slow cognitive decline and prevent progression to Alzheimer’s disease.