How each EYE functions,
How the PERSON functions

Smith-Kettlewell – September 2019

August Colenbrander, MD - San Francisco
Vision is a complex phenomenon

- In-depth analysis can reveal different layers
Broad Aspects of Visual Functioning

Each EYE
- Structure
  - Tissue
  - Scar
  - Atrophy
  - Loss
- Function
  - Organ
  - Acuity
  - Field
  - Contrast

The PERSON
- Abilities
  - Person
  - Reading
  - Mobility
  - ADLs
- Consequences
  - Society
  - Participation
  - Quality of Life

Comprehensive Care asks for TEAM work, including the PATIENT
Different Viewpoints

How each EYE functions

- Structure
  - Tissue
    - Scar
    - Atrophy
    - Loss
  - Organ
    - Acuity
    - Field
    - Contrast

How the PERSON functions

- Function
  - Person
    - Reading
    - Mobility
    - ADLs
  - Society
    - Participation
    - Quality of Life

but viewpoints differ

Comprehensive Care requires attention to ALL aspects

but viewpoints differ
Different Viewpoints

How each EYE functions

<table>
<thead>
<tr>
<th>Structure</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue</td>
<td>Organ</td>
</tr>
</tbody>
</table>
  * Scar   | Acuity    |
  * Atrophy| Field     |
  * Loss   | Contrast  |

How the PERSON functions

<table>
<thead>
<tr>
<th>Abilities</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person</td>
<td>Society</td>
</tr>
</tbody>
</table>
  * Reading |
  * Mobility|
  * Activities of Daily Living|
  * Quality of Life|
  * Participation|
  * Safety|

The patient’s view

*Doctor, I cannot read*

How each EYE functions

How the PATIENT functions
Different Viewpoints

How each EYE functions
- Structure
  - Tissue
    - Scar
    - Atrophy
    - Loss
- Function
  - Organ
    - Acuity
    - Field
    - Contrast

How the PERSON functions
- Abilities
  - Person
    - Reading
    - Mobility
    - ADLs
- Consequences
  - Society
    - Participation
    - Quality of Life
    - Safety

The “eye” doctor’s view
- The patient lost 3 lines

Doctor, I cannot read
- How each EYE functions
- How the PERSON functions
Different Objectives

How each EYE functions
- Structure
- Function

How each EYE functions
- VISUAL FUNCTIONS
- Acuity
- Field etc.

How the PERSON functions
- Abilities
- Consequences

How the PERSON functions
- FUNCTIONAL VISION
- Reading
- ADL etc.

Underlying causes

Societal consequences
Embrace both Objectives

How each EYE functions
- Structure
- Function

How the PERSON functions
- Abilities
- Consequences

Protecting Sight
Empowering Lives

AMERICAN ACADEMY™ OF OPHTHALMOLOGY
Different Interventions

How each EYE functions
- Structure
- Function

MEDICAL / SURGICAL TREATMENTS
- RESTORE what is LOST

How the PERSON functions
- Abilities
- Consequences

REHABILITATIVE INTERVENTIONS
- BUILD on what REMAINS
Different Interventions

How each EYE functions
- Structure
- Function

RESTORE what is LOST
- Glasses: restore focus
- Cataract surgery: restore clarity
- Glaucoma Rx, surgery: restore pressure
- Strabismus: restore alignment

How the PERSON functions
- Abilities
- Consequences

BUILD on what REMAINS
- Residual acuity: magnification
- Hearing: talking books
- Touch: Braille
- Haptic: Cane travel
Different Scales

**How each EYE functions**
- **Structure**
- **Function**

**How the PERSON functions**
- **Abilities**
- **Consequences**

**Scale of LOSS**
- No loss
- Total loss

**Scale of ABILITY**
- Full ability
- No ability

**Typical for medical scales**

**Dis-ability = Loss of ability**
What happens at the red line?

**How each EYE functions**
- Structure
- Function

**How the PERSON functions**
- Abilities
- Consequences

**INPUT**
- Visual stimuli

**VISUAL SYSTEM** as a black box
- two eyes → one brain

**OUTPUT**
- Visually-guided behavior

**Visual Functions**
- "How each EYE functions"
- Visual Impairment

**Functional vision**
- "How the PERSON functions"
- Visual Ability
- or Dis-ability
Different categories

- Acuity
- Field
- Contrast
- Color, etc.
- Strictly visual

- Reading
- Writing, drawing
- Grasping, reaching
- Navigating, etc.
- Visual + Motor

Different measurement methods

- Each eye separately
- Manipulate stimuli: size, contrast, etc.
- Threshold: 50% correct

- How to measure
- What to measure
- Criterion

- Both eyes open
- Observe performance: speed, errors
- Sustainable: Near 100% correct
What happens inside the black box?

<table>
<thead>
<tr>
<th>INPUT</th>
<th>VISUAL SYSTEM as a black box</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual stimuli</td>
<td>→ two eyes → one brain</td>
<td>Visually-guided behavior</td>
</tr>
</tbody>
</table>
What happens inside the black box?

How each EYE functions
- Structure
- Function

How the PERSON functions
- Abilities
- Consequences

INPUT
Visual stimuli

VISUAL SYSTEM as a black box
- two eyes
- one brain

OUTPUT
Visually-guided behavior

The brain combines outside information with stored knowledge.
Environment

Retinal image

Short term Memory

Retinal Image and Memory Concepts must match to create a

Mental Model

Perception, Recognition

Long term Memory

Concepts
Environment

Retinal image

Fleeting

Differences

Mental Model
of the environment

Perception

Short term Memory

Long term Memory

Concepts

Stable
<table>
<thead>
<tr>
<th>Retinal image</th>
<th>PERCEPTION</th>
<th>Concepts in memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image of the environment moves across my retina</td>
<td>I move through a <strong>stable</strong> environment</td>
<td>Concept of the environment is <strong>STABLE</strong></td>
</tr>
</tbody>
</table>

**Movement** derives from the retinal image  
**Stability** of the environment derives from stored concepts
Environment \rightarrow Retinal image

Fleeting

Triggers the Mental Model

Short term Memory

Mental Model of the environment

Recognition

Long term Memory \rightarrow Concepts

Stable

Interprets the retinal image
Matches the retinal image to concepts in memory

Retinal image

PERCEPTION

Concepts in memory

“window”

“giraffe”
Environment

Retinal image

Fleeting

Triggers the Mental Model

Mental Model of the environment

Experience

Long term Memory

Concepts

Short term Memory

Stable

Interprets and understands the retinal image

Recognition
Environment

Retinal image

Fleeting
Triggers and updates the Mental Model
Has gaps

Mental Model
of the environment

Recognition
Short term Memory

Long term Memory

Concepts

Stable
Interprets and understands the retinal image
No gaps
Glaucoma patients were asked to select the image that best reflects their vision ...

How Does Glaucoma Look?
Patient Perception of Visual Field Loss
Crabb et al. Ophthalmology, 2013
26% were NOT aware of any change.

Asked about their vision ...

26% were NOT aware of any change.

How Does Glaucoma Look?
Patient Perception of Visual Field Loss
Crabb et al. Ophthalmology, 2013
As asked about their vision, 70% described blurred or missing parts.

How Does Glaucoma Look?
Patient Perception of Visual Field Loss
Crabb et al. Ophthalmology, 2013
Asked about their vision ...

NONE described black parts.

How Does Glaucoma Look?
*Patient Perception of Visual Field Loss*
Crabb et al.  *Ophthalmology*, 2013
These images reflect the RETINAL image, but NOT the PERCEPTION which is based on a MENTAL MODEL.

How Does Glaucoma Look?
Patient Perception of Visual Field Loss
Crabb et al. Ophthalmology, 2013
You can HEAR people yelling.

You cannot HEAR an island of silence.

Similarly, you cannot SEE a blind spot.
Environment

Retinal image

Mental Model
of the environment

Recognition

Short term Memory

Fleeting

Triggers and updates the Mental Model

Has gaps

Strictly visual

Long term Memory

Concepts

Stable

Interprets and understands the retinal image

Visual

Tactile

Auditory

Smell

Multi-sensory

No gaps
Sometimes, the match is wrong. We call that an optical illusion.
Environment

Retinal image

Short term Memory

Mental Model
of the environment

Long term Memory

Concepts

Fleeting
Triggers and updates the Mental Model
Has gaps
Strictly visual
May be ambiguous

Stable
Interprets and understands the retinal image
No gaps
Multi-sensory
Discreet choices
Two interpretations can alternate rapidly. They cannot co-exist.

Especially when depth is involved.
Many models consider only the INPUT side.

They ignore the OUTPUT, for which VISION exists.
<table>
<thead>
<tr>
<th>Tactile</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>Non-existent</td>
</tr>
<tr>
<td>Non-existent</td>
<td>Prominent</td>
</tr>
<tr>
<td>3D objects</td>
<td>Retina: 2D shapes</td>
</tr>
<tr>
<td>Constant</td>
<td>Depends on distance</td>
</tr>
<tr>
<td></td>
<td>Parallel lines converge</td>
</tr>
<tr>
<td>Glass</td>
<td></td>
</tr>
<tr>
<td>Shadow</td>
<td></td>
</tr>
<tr>
<td>Content</td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td></td>
</tr>
</tbody>
</table>
Visual Perception is based on a Mental Model that has TWO sources

- The Retinal Image
- Concepts in Memory
How are the two sources combined??

Short term Memory

Mental Model
of the environment
Matching requires back-and-forth between the two sources

Retinal image —— Tentative Interpretation

Verify match —— Adjust interpretation

Verify adjustment —— Final interpretation

Verification process is modifiable by Intention
Different scan patterns

Scan patterns vary, depending on the type of interpretation requested

Free viewing / rich or poor family / ages / what they were doing / clothes / position of people / how long was visitor away

Yarbus - 1967
Environment concepts mental model of the environment

Relative contributions may differ

Mental Model

Retinal image

Relies on the current retinal image not on memory

Navigating a complex dynamic environment

Long term memory concepts
Relative contributions may differ

Mental Model of the environment

Seeing an image in a cloud

Relies mainly on stored imagery

Environment

Retinal image

Long term Memory

Concepts
According to research at an English university, it doesn't matter in what order the letters in a word are, the only important thing is that first and last letters are at the right place. The rest can be a total mess and you can still read it without problem. This is because we do not read every letter by itself but the word as a whole. Ceehiro
**Mental Model of the environment**

- **Environment**
  - Retinal image

- **Long term Memory**

- **Concepts**

**Proofreading mode**
- **Serial** processing, letter sequence matters
- Content suffers
- **Speed / Accuracy trade-off** is an intentional decision
- **Reading with context** is about 3x faster than reading without

**Short term Memory**
- **Fast**
  - Does the content make sense?
    - **Parallel** processing, letter sequence doesn’t matter
    - Typos are overlooked

- **Slow**
  - Retrieve spelling
  - Processing
Matching the two sources

- Retinal image
- Verify match
- Verify adjustment
- Tentative Interpretation
- Reflex-like action
- Reading what makes sense
- Adjust interpretation
- Final interpretation
- Intentional action
- Correcting spelling errors
Take-home messages

- Models based on a **single stream** from visual stimulus to perception are too simplistic.

- The **MENTAL MODEL** concept
  
  - implies TWO sources: retinal image and stored concepts
  
  - And a constant **back-and-forth** on a TWO way street.
VISION supports ACTION

Normal vision: Salient peripheral stimulus sends alert

→ fixation movement
→ central vision recognizes
→ appropriate action.

Central scotoma: Alert → fixation → object disappears

→ frustration → develop PRL, seek help

Peripheral field loss: Peripheral stimulus not seen → NO alert

→ NO recognition → NO action
→ NO awareness
Conscious processing for Recognition
Connects to vast repositories of stored information and experience
Allows conscious decisions and intentional actions
Conscious vision is only the tip of the iceberg

Autonomous processing for Motor control
Connects directly to various motor systems
Can react faster
Reactions are reflex-like, autonomous, not under conscious control
Most bodily functions (breathing, heart rate) are processed this way
Conscious / Autonomous processing

Autonomous processing for motor control
- Connects directly to motor systems
- Serves fast motor actions
- “WHERE“ system

Conscious processing for Recognition
- Connects to stored information
- Serves interpretation
- “WHAT” system

Both systems are needed and are tightly interconnected:

Reading:
- Move eyes from word to word
- Understand words, context

Mobility:
- Avoid obstacles, potholes
- Where am I? Where do I go?
Size and location for recognition

RECOGNITION does not care about absolute size or location
Size and location for recognition

RECOGNITION does not care about absolute size or location
**Size and location - Autonomous**

**Reading:** Saccades must match the visual span

**Grasping:** Hand position must match the object

**Walking:** Foot movements must match the terrain

**MOTOR reactions require accurate size and location**
Vision-Motor Coordination

**AUTONOMOUS**

Limb–Eye Coordination

- Involves body, leg, arm movements
- "Mobility" (peripheral vision)

- Based on 3D Mental Model
- Can be completed with **eyes closed**
- Requires **absolute** references
- Often involves a timed motor sequence

**INTENTIONAL**

Hand–Eye Coordination

- Requires continuous feedback
- Can only be done with **eyes open**
- Requires **relative** references
- Can be interrupted and resumed

- Involves finger, hand, wrist movements
- "Manipulation" (mostly central vision)
## Terminology

<table>
<thead>
<tr>
<th>How each EYE functions</th>
<th>How the PERSON functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual acuity</strong></td>
<td><strong>VISION</strong></td>
</tr>
<tr>
<td>ocular aspect of detail vision</td>
<td>(→ visually-guided behavior)</td>
</tr>
<tr>
<td><strong>Visual field</strong></td>
<td><strong>Detail vision</strong></td>
</tr>
<tr>
<td>map of retinal sensitivity</td>
<td>detail and shape recognition</td>
</tr>
<tr>
<td>precludes eye movements</td>
<td><strong>Surround vision</strong></td>
</tr>
<tr>
<td></td>
<td>visually-guided spatial awareness</td>
</tr>
<tr>
<td></td>
<td>requires scanning and search</td>
</tr>
<tr>
<td><strong>Central vision</strong></td>
<td><strong>Color vision</strong></td>
</tr>
<tr>
<td><strong>Peripheral vision</strong></td>
<td><strong>Movement, etc.</strong></td>
</tr>
<tr>
<td>describe retinal topography</td>
<td></td>
</tr>
</tbody>
</table>

**Dorsal stream**

describe cerebral topography
Surround vision – three modes

Top – down conscious, intentional

• **Intentionally** move attention to a target in the Mental Model
• Then, use **central vision** to examine the target more closely

  Target must exist in the Mental Model.

  Target may be outside the visual field.
  Action is NOT limited by field restriction.

  Intentional action involves **ventral stream** in brain.

  Starts and ends consciously.
Surround vision – three modes

Bottom – up  occasional, reflex-like

• A “salient” event in the **retinal image** triggers an alert to the central vision system

• **Central vision** is used to examine the object more closely

  Target must exist in the **retinal image**, therefore, it is limited by field restrictions.

  This action occurs only **occasionally**.

  Starts in the **dorsal stream**, ends in the **ventral stream**.
Surround vision – three modes

**Autonomous** continuous monitoring

- Objects in surround are detected and screened.
- If considered to be an obstacle, a command is sent to the motor system to avoid it.
- Conscious awareness is not required.

This screening occurs **constantly**.

Starts in the **dorsal stream**, ends in the **motor system**.
Take-home messages

- **Matching** the retinal image to stored concepts requires a **back-and-forth** on a TWO way street.
- Much of the processing occurs **in parallel** it is **autonomous** and bypasses consciousness.
- **Visual-spatial relationships** occur in TWO distinct modes
  - absolute parameters for body movements
  - relative localization for perception and manipulation.
- **Visually-guided actions** can occur in THREE different modes
  - Intentional
  - Reflex-like, occasional, triggered by salient stimuli
  - Autonomous, constant monitoring for obstacles.
Thank you

gus @ ski.org

www.ski.org / Colenbrander