Visual Perception as a Dynamic System
Updating Our Theories of Development and Change

“Chaotic Occupational Therapy”
“It is high time to move from the lens of linearity to the kaleidoscope of chaos in occupational science and occupational therapy”

Charlotte Brasic Royeen, PhD, OTR, FAOTA, 2003
Eleanor Clarke Slagle Lecture

Examples of Dynamic Systems in Therapy

Social systems:
Autism and transition: A nonlinear dynamics systems perspective. (Davis, 2009) (OT)

Sensory integration:
Dynamic systems theory: Relevance to the theory of sensory integration and the study of occupation. (Spitzer, 1999) (OT)

Rehab:
Bridging the gap between theory and practice: Dynamic systems theory as a framework for understanding and promoting recovery of function in children and youth with acquired brain injuries. (Levac & DeMatteo, 2009) (PT)

Overview
1. Theoretical models – overview
2. Proposed dynamic systems model for visual perception
3. Close look at chaos and complexity of vision
4. How this applies to understanding visual tasks in occupational therapy terms

Why Theory?
• Determines how we see a problem, how we plan to address it and how we interpret change.
• BIG THEORY: an overarching explanation of nature
  — example: development and change
• Little theory: used to explain limited phenomena
  — example: how do muscles get stronger

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Conclusion (preview)
• Theory that sees ocular motor skills as fundamental to visual perception ability
  – Focus of therapy: development of ocular motor skills
• Theory that sees many complex, dynamic systems interacting to achieve a goal
  – Focus of therapy: the goal or task

Arguments:
• “Theories come and go; I’ll stick with what I understand.”
• “But what you are talking about is cognitive, I work on underlying visual skills.”
• “But we are getting good results with the models we’re using.”

Reductionist Theories
• Mechanistic: Can understand behaviors by understanding their component parts
• Linear: Outcomes are proportional to inputs
• Hierarchies: Certain functions underlie and are essential to higher level functions.

Familiar Reductionist Models

Systems Theory
• Many parts interact
• Internal, personal factors
• External, environmental factors
• Cannot understand a part separate from the system
• The whole is more than the sum of its parts.

Dynamic Systems
• “Dynamic” – changes over time
  – Short time scale: moment by moment.
    • Present state is due to preceding state and will influence next state
  – Long time scale: development.
    • History of the person, experiences, is the starting point for current activity.
Dynamic Systems Theory

- Complexity
- Non-linearity
- Chaos
- Self-organization

Dynamic Systems in Development

- Complexity: Humans are infinitely complex
  - Genetic coding
  - 100 billion neurons, trillions of synapses
  - Day-to-day experiences
  - Culture
  - Environment
  - Motivation
  - Individual’s history

Dynamic Systems in Development

- Non-linear:
  - No predetermined order
  - General patterns, but impossible to accurately predict outcome
  - All variables co-effect each other; nothing changes in isolation
  - Example: In general, quality preschool for disadvantaged children increases chances of graduating high school.


Dynamic Systems in Development

- Chaos theory
  - Originated with study of weather patterns (Lorenz, 1960's). Extremely complex and interrelated forces make weather impossible to accurately predict.
  - “Butterfly effect”: a butterfly flaps its wings in the Amazon and changes the course of a tornado in Texas.
  - System is never the same twice
  - No two people are the same
  - No person is in the same state twice
  - Disorganized-reorganized-disorganized


Dynamic Systems in Development

Self-organization emerges out of the chaos

- “Soft assembled”
- New set of interconnected neurons fire to produce a thought or an action
- Stable patterns emerge
  - Resistant to change
  - Short-term dynamics leads to long-term change
- Goal directed

Guastello et al. (2009), Thelen (2000)

Proposed Model

Dynamic Systems in Visual Perception
Sample Task

- Visual task
- Overall goal: find match
- Moment-by-moment goal:
  - Look for specific contour, check with target

Fractals

Fractals in Nature

Fractals in Neurological processes

- See complexity in terms of multiple processes being dynamically assembled
- Look more closely, within these processes is another level of complexity with multiple processes being dynamically assembled
- Can go down to the level of neurons with multiple synapses being dynamically assembled
- But, an underlying pattern exists
Goal Directed

• Action cannot be understood by its component parts
• Available processes are dynamically assembled for that moment’s goal
• “Whole is greater than the sum of its parts”

Attention

• Definition: not a separate thing or process, it is the activity, the cognitive energy, of the moment.
• Attention: directs the soft-assembly of all components to achieve the goal
• Has a limited capacity: about 4 items at one time

How can we do so much?

• The stable states that develop over time make it possible to do more with limited attention.
• “Attractor states”
• Skill development: short-term dynamics lead to long-term change
  – Stable components can be used to create larger dynamic ↔ stable processes.
  – Components get larger to enable faster, more complex behaviors (reverse fractal).

How can the system change?

• If the aim is to change that stable state, a great deal of attention will be needed
  – Example: walking
• Change the task
  – Example: pencil grasp

Environment is Interpreted

• Environment – acts on us but is also interpreted by us, and we act on it – we decide where to focus, what to attend to
• Interpreted through experience, knowledge
• The world you see is different than the world I see
• Children see much less

Thelen (2000); Thelen & Smith (1994)
Stability and Change

Strong attractor state
Assembly of known hand-finger-wrist patterns associated with pencil and writing.

Change = weak attractor
Requires much attention, easily reverts back to strong attractor state

... or change the task
Soft-assembly
New task parameters leads to disorganization. Self-organization of different muscle patterns to achieve the goal.

Complexity of Vision

Eyes as Information Gathering Tools

Eye Dominance Experience
Which eye is dominant? (credit to Laurie Kalb)
Developmental Changes in Fixations

• Fixation counts: Children > Adults
• Fixation duration: Children > Adults
• Difficult items > easy items on both number and duration of fixations: Children more affected
• (Propose) With development:
  – Stable states for scanning emerge
  – Increased knowledge allows faster recognition
  – Interaction between cognitive and ocular motor

Attention without direct visual focus:

Parafoveal Vision

> 10° peripheral vision
2° - 10° parafoveal vision
1° - 2° foveal vision

Perceptual Span

• Foveal + Parafoveal vision work together
  – Evidence from reading
  – Evidence from expert vs. novice research
• Changes moment by moment, task by task
  – When tasks are harder (ex: harder words)
Inattentional Blindness

- Even though focus is directed toward a feature, without attention that feature will not be seen.

Visual Attention?

- Perfect visual focus is not sufficient, it may not even be necessary, for gathering information
- Attention uses vision, a part of a dynamic assembly, to achieve the goal

Dynamic Interactions

- Ocular Skills
  - Fovea is moved feature-to-feature using sequence of saccades and fixations, typically about 3 per second
- Early Visual Processes
  - Some early working memory is involved
- Knowledge/experience
  - Strategies for optimizing information intake are needed
- Posture/Movement
  - The act of moving the eyes contributes some information to the brain about the scene
- Motivation

Another Fractal?

“Visual Attention”

- The big picture (on-task behavior)
  - Series of fixations (selection, sequencing)
  - Length of individual fixations (amount of information)
  - Distance between two fixations
  - Pupil dilation/constriction
  - Perceptual span – parafoveal vision
  - Guiding visual behavior
  - All changing moment-by-moment as task demands change
- Vision and knowledge co-effect each other
Early Visual Processing

• Suggested by cognitive psychologists: 10% of what we perceive comes from actual vision.
  – This likely varies by individual and task.
  • Children likely rely more heavily on vision (more fixations, longer duration) than adults
  • New or detailed tasks may also require more precise vision
  – Knowledge fills in the rest
• Limited attention: ↑ vision demands ↓ other aspects
  – Inattentional blindness
  – Distractors

Two Visual “Streams”

• Ventral
  – “What”
  – Form, color, objects, faces
  – Favors foveal vision – detailed

• Dorsal
  – “Where” or “how”
  – Location, motion, sensorimotor output
  – Favors parafoveal and peripheral vision
  – Dorsal more prone to damage.

Rethinking Assumptions

Two Research Studies

From a psychology viewpoint:

“Reading acquisition enhances early visual process of contour integration”
Szwed, et al. (2012). Developmental Science

Acquisition of reading impacts visual processes, comparing illiterate adults with those who learned to read as adults.
Contour Integration

Two Research Studies

From optometry viewpoint:

"Is there a common linkage among reading comprehension, visual attention, and magnocellular processing?"


Peripheral vision less sensitive in poor readers, vision therapy may help reading.

Perceptual Span

• Increasing perceptual span leads to improved reading in some children.

Which is Correct?

Which is Correct?

• Reading and visual skills co-effect each other
• In a goal-directed task the soft-assembly of all components is strengthened, stabilized.
• Some new stable states may be useful for other goals (strength a tool).

How to think about complex tasks

• Small scale:
  – head position, length of fixations
• Medium scale:
  – strategies for scanning,
  – direct focus of attention to relevant features,
  – peripheral vision aids in directing saccades,
• Medium/Large scale:
  – goal of the task, understanding instructions, previous experience, recheck answer
• Large scale:
  – general competence on overall testing, self esteem, expectations
  – Build knowledge to apply to other tasks
Theory

- Old theories are being reconsidered in terms of dynamic systems theory
  - Piaget: development of action and cognition
  - Eleanor and James Gibson: movement and development of perceptual knowledge
  - Embodied cognition

Important Concepts from DST

- Everything counts, no process or subsystem is primary
- No separation of cognitive and motor, or cognitive and emotional
  - "Embodied cognition"
- Dynamic stability: constant change but underlying stability
- Attractor states: those patterns that have become stable, difficult to change – must work to engage the whole system to evoke change.
- SELF-ORGANIZED, GOAL-DIRECTED ACTIVITY

References for Dynamic Systems Theory


*Recommended reading

Other References