

# The New Neuroscience of Learning and Behavior

Richard G. Petty MD, MSc,  
MRCP(UK), MRCPsych,  
Promedica Research Center,  
Georgia State University College of  
Health Sciences,  
Loganville, Georgia,  
USA

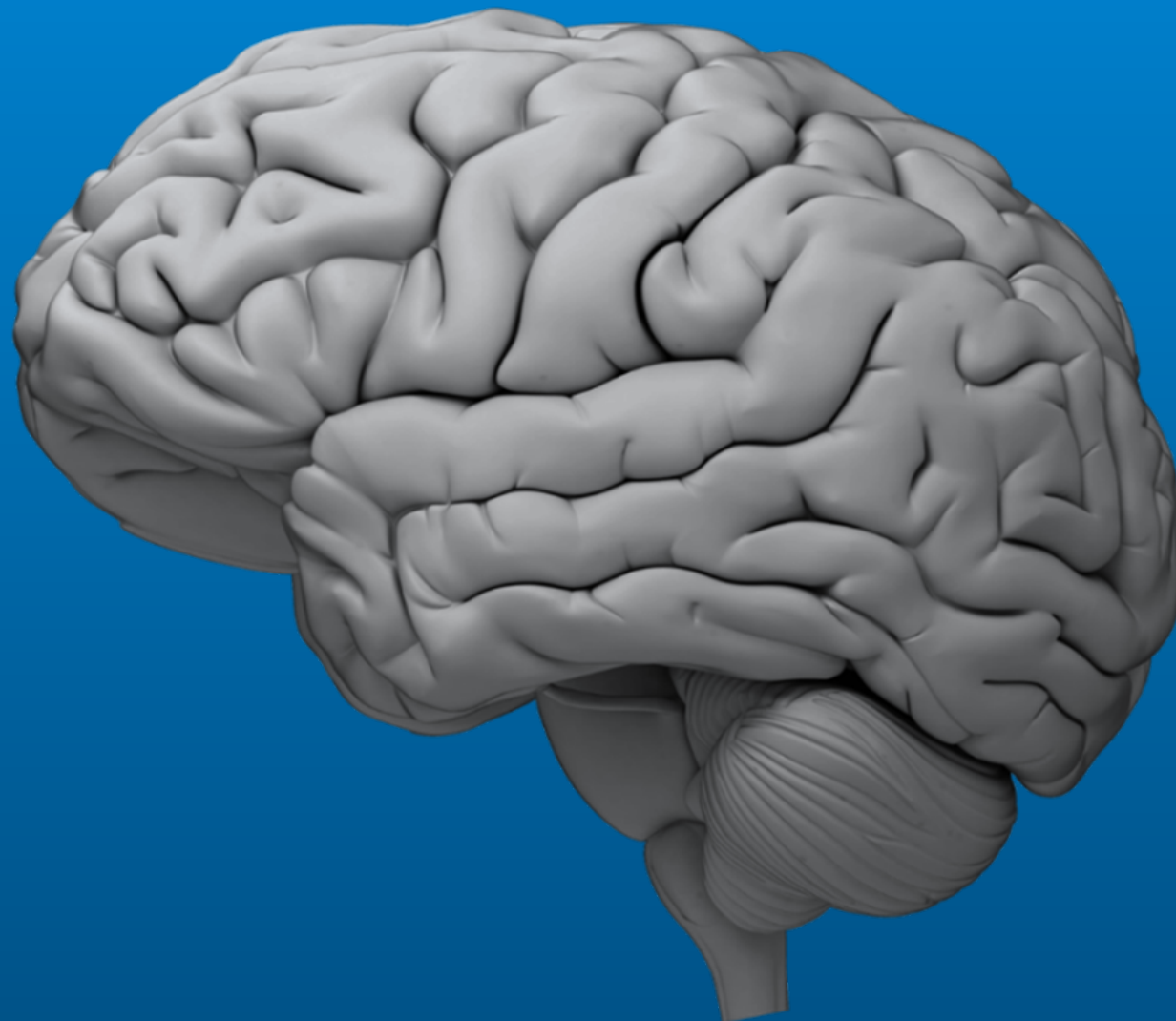
*RichardPettyMD.com*  
*rpettyus@aol.com*



# The New Neuroscience of Learning and Behavior

- A Child's Brain is Not a Machine
  - ★ Why does it matter?
- Your Divided Brain
  - ★ Why does the brain have two sides?
- Your Predictive Brain
  - ★ "As important to neuroscience as evolution is to biology"<sup>1</sup>
- Interoception and the Bi-Directional Brain
  - ★ The hidden sense behind feelings and behaviors

# A Child's Brain Is Not a Machine



# How Can We Say That the Brain Is Not a Machine?

- There are at least ten reasons why the brain cannot be considered to be a machine, including:
  - ★ Emergence: it follows rules that cannot be predicted from the study of individual cells
  - ★ Boundaries: unlike a machine, the brain has no precise boundaries: it interacts with - and is constantly changed by - the world and the body
  - ★ Learning: the child's brain teaches itself to learn; even Alpha Zero needed to be taught how to learn
  - ★ Growth: a machine has limits to learning, in the brain, the more that you know, the easier it is to learn new information

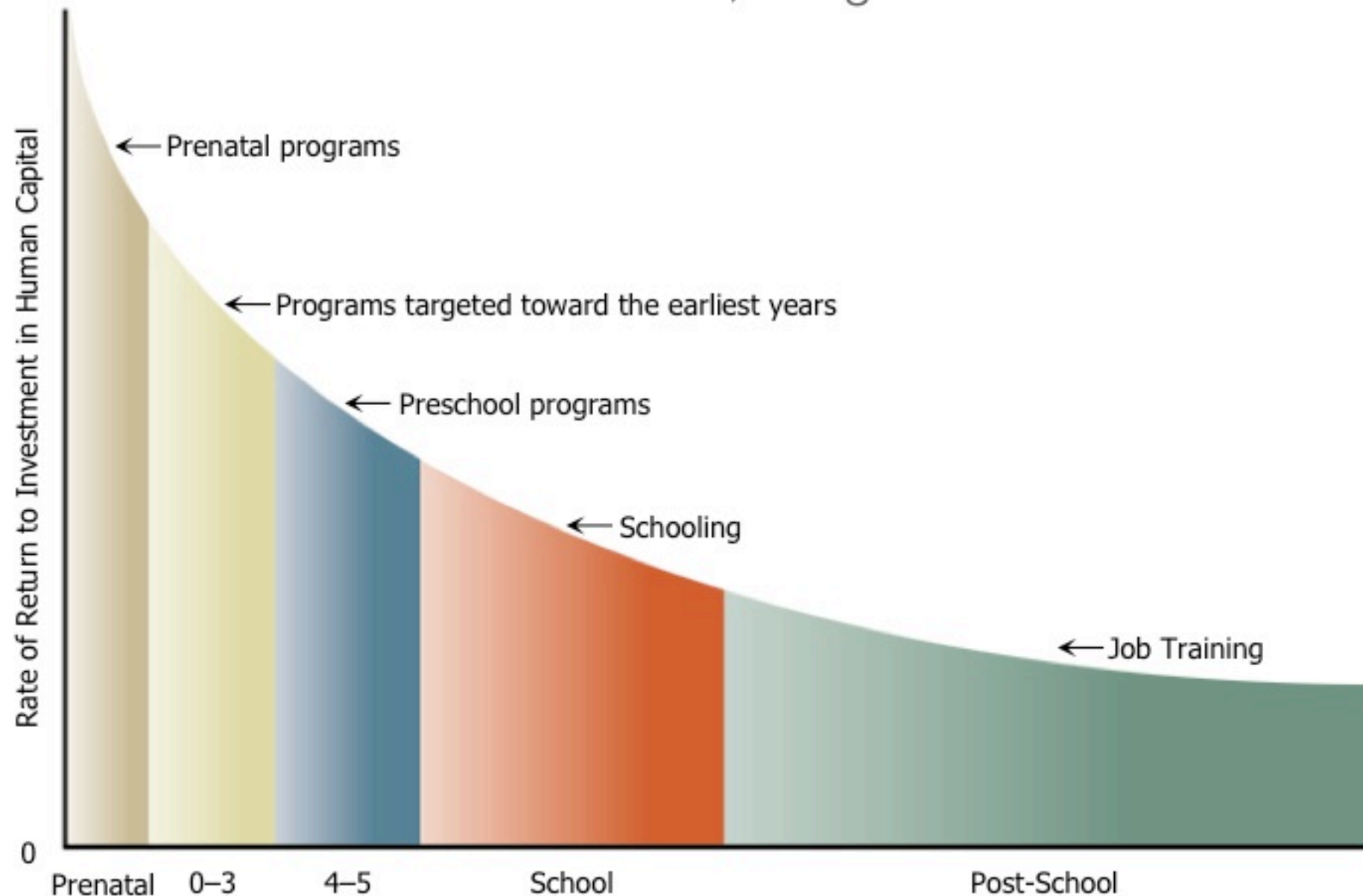


# A Single, Integrated, Highly Dynamic System

- For more than a century, the brain has been described as a series of levels and modules that have specific roles or are recruited when needed
- Instead an event anywhere in the brain is connected to, and may have consequences for, any other regions
- These in turn may respond to, propagate, enhance or develop that initial event, or whether to inhibit it, or take another action
- This is all part of a continuously flowing process that mediates the relationship between the world, the brain and the body
- This helps explain why learning anything occurs throughout the brain, and connections - especially in different senses - are crucial to consolidating information

# EARLY CHILDHOOD DEVELOPMENT IS A **SMART INVESTMENT**

The earlier the investment, the greater the return



Source: James Heckman, Nobel Laureate in Economics

# Can We Explain the Heckman Graph?

- The prenatal period, infancy and early childhood are marked by intense phases of self-organization and learning
- Factors including micronutrients and appropriate guidance can foster this early development
- Environmental pollutants, including hydrocarbons, pesticides and marijuana can have potent negative effects on white matter pathways in the developing brain

# The Brain is Social

- Brains are functionally and reflexively social
- The “social brain hypothesis” suggests a link between the size of the cortex and mean group size<sup>1</sup>
- The brain is social in the way it learns, and has evolved not merely to process information, but to facilitate social interaction, social learning, imitation, cultural assimilation, and empathy
- Therefore nervous systems are not discrete and bounded, but integral parts of other more complex systems, ranging from molecules to selves to societies



# Movement and Learning

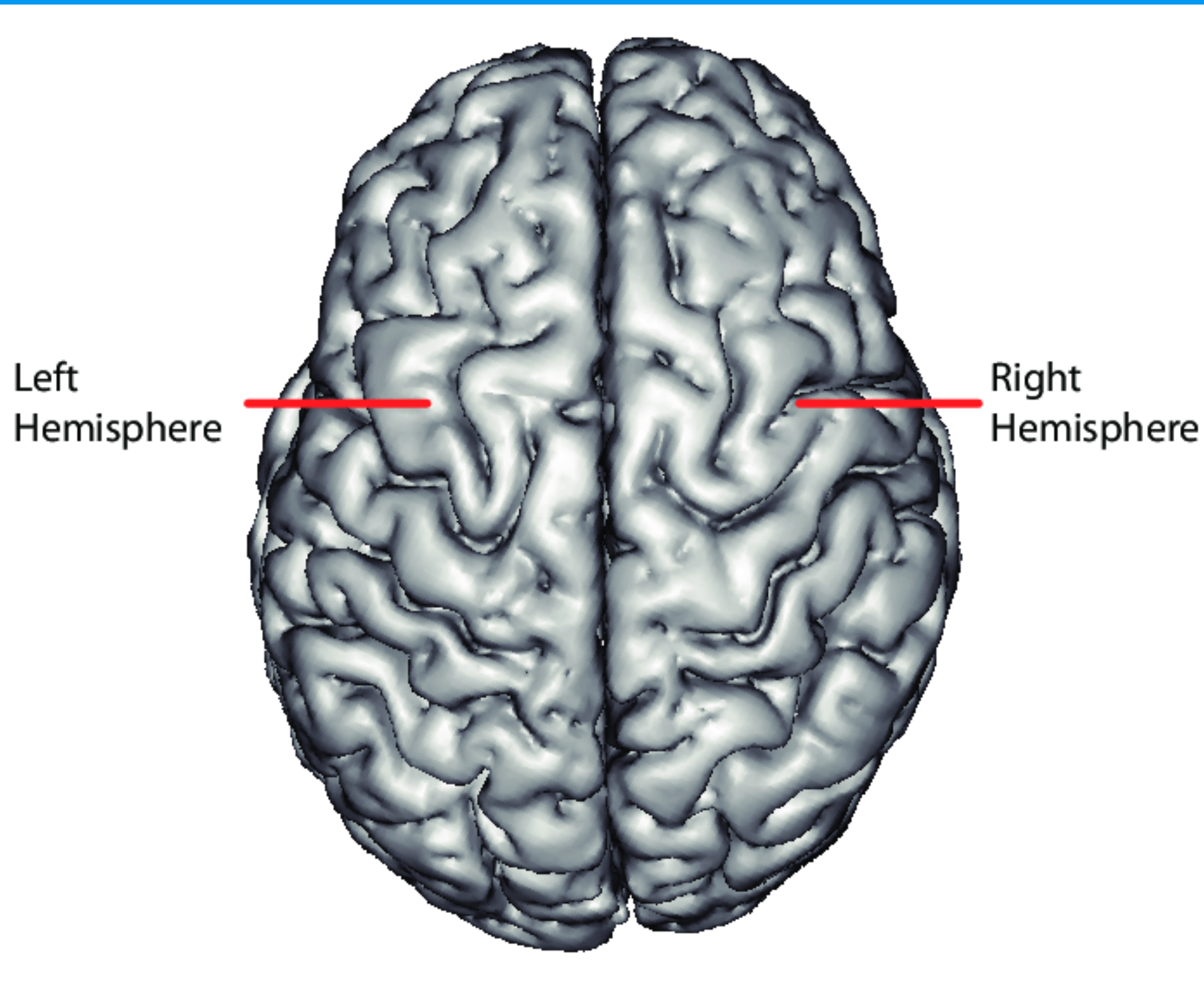
- Close link between cerebellar and vestibular and hippocampal function: movement, balance, cognition, attention, learning and memory
- Learning and even “thinking” is not only something that occurs in the brain, it is generated by multiple parts of the body and specific types of movement enhance learning:
  - ★ Complex finger movements
  - ★ Writing: a 2014 paper, “The Pen Is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note Taking,” found that students who write remember
  - ★ Speech and gesture are generated by overlapping parts of the frontal cortex; if a student or teacher combines them, learning is enhanced

# Why Can't You Remember Being a Baby?

- “Infantile” amnesia - the lack of autobiographical memories from early childhood - occurs not only in humans, but also in many other altricial species
- Countless theories to account for the phenomena, but increasing evidence indicates that it has to do with hippocampal maturation
- Why should the hippocampus mature later?
- The onset of independent locomotion prompts alignment of hippocampal place cells and grid cells to the environment and hippocampal development
- The ability to discriminate locations provides a stable cue for memories
- A reduction in self-locomotion and exploration with age may be one factor in cognitive decline in some older people
- In older people, riding a stationary bicycle with a virtual tour buffers against MCI, while also elevating brain derived neurotrophic factor, compared with riding alone, without the visual tour

# Your Bilateral Brain







## LEFT

LOGIC SKILLS

DAILY ACTIVITIES

LANGUAGE & GRAMMAR

MEMORY

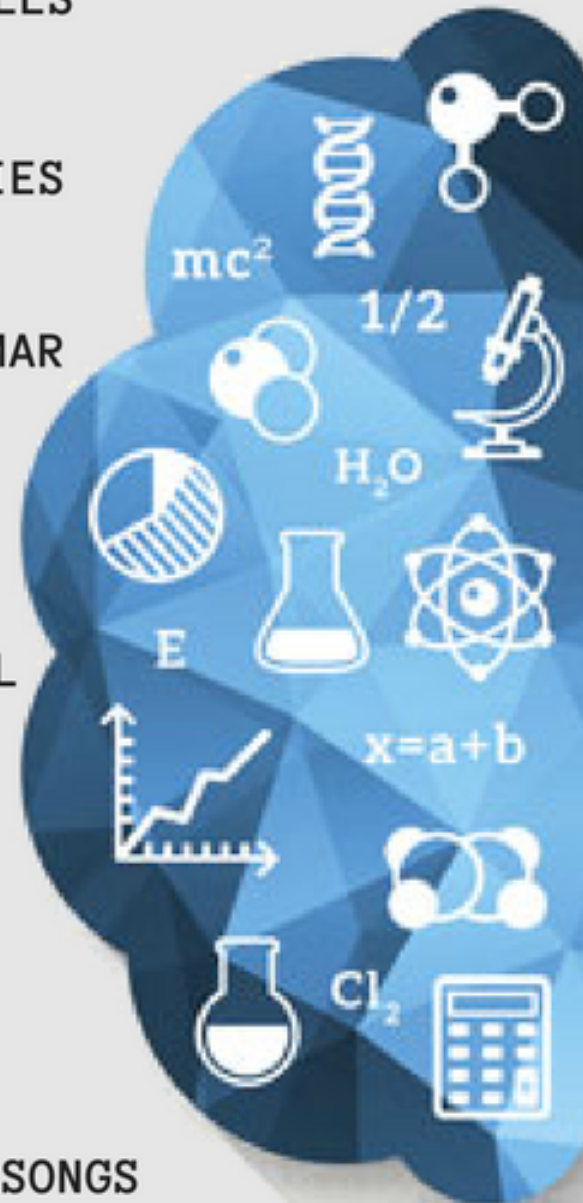
ANALYTIC & DETAIL

SCIENCE

STRATEGY

FACTS

WORDS OF SONGS



## RIGHT

CREATIVITY

FEELINGS

CONCENTRATION

PHOTO MEMORY

VISUALIZATION

IMAGINATION

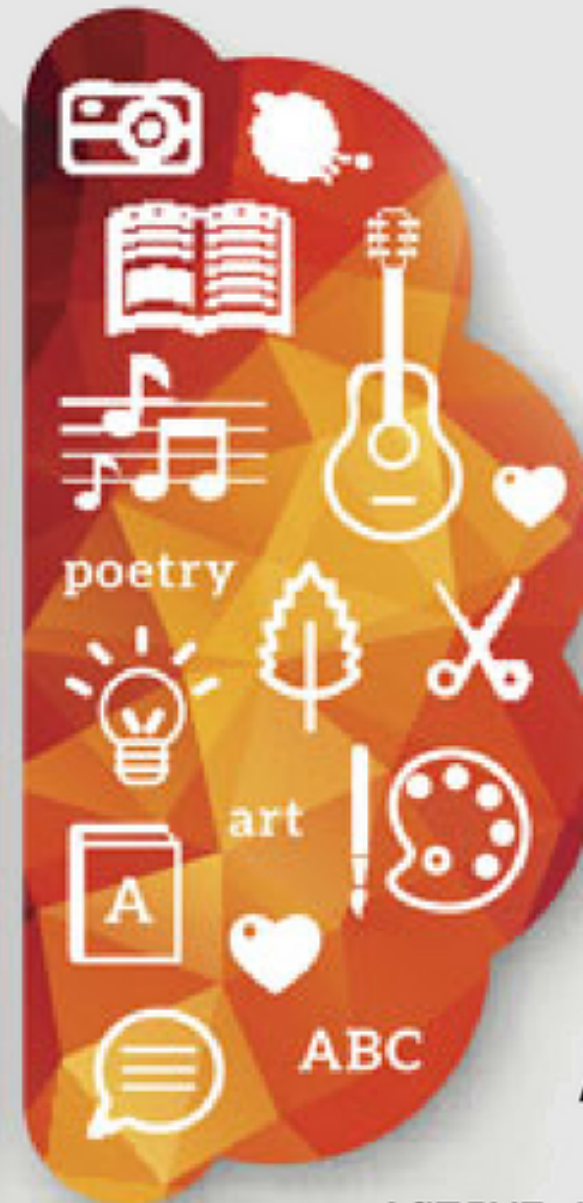
DECISION MAKING

MULTITASKING

INTUITION

ARTS & RHYTHM

ACTIVE LISTENING SKILLS



IAIN MCGILCHRIST

'A landmark new book ... it tells a story  
you need to hear, of where we live now'  
—Bryan Appleyard, *Sunday Times*



# The MASTER and his EMISSARY

The Divided Brain and the  
Making of the Western World



# The Bilateral Brain

- Asking, “What does each hemisphere do?” Is not best
- Ask, instead, “What is it like?”
- Attention is more than a type of cognition, it is the way in which we relate to the world, so an aspect of conscious experience
- Each hemisphere attends differently, so it has a different “take” on the world
- Even in birds, the right hemisphere is constantly scanning to look for danger in the environment
- The left is focused on precisely calibrated efforts to get food, which means differentiating and classifying

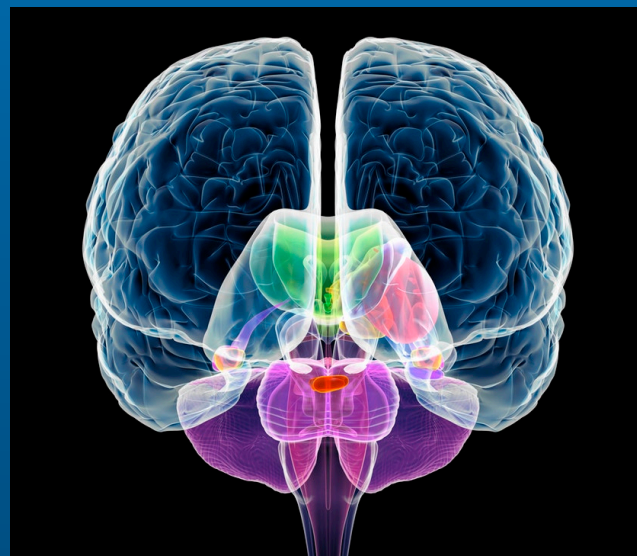
# The Bilateral Brain

- The nature of right-hemisphere attention means that whatever we experience comes to us first in the right hemisphere
- New experience of all kinds – whether music, words, imaginary constructs, objects in the environment, even skills – comes to us first from the right hemisphere
- It is dealt with by the left hemisphere only later, once it becomes familiar



# The Development of the Two Sides

- The right hemisphere matures earlier than the left
- So babies and young children are more reliant on the right hemisphere
- The corpus callosum - which connects the hemispheres - does not myelinate until the end of the first year of life
- The left hemisphere uses the corpus callosum to inhibit the right
- As children get older, left-hemisphere function becomes increasingly important, so the corpus callosum separates the activities of the two hemispheres



# The Bilateral Brain and the Body

- The right hemisphere is in touch with the body: it has the multimodal 'body image'
- The body image is a sense of the body as a coherent, living whole, something that is part of us
- The left hemisphere sees the body as an assemblage of parts, more like a machine
- The right hemisphere has richer connections with the body via the limbic system, which integrates thought with feelings and information from the body
- The right also integrates physical responses via the hypothalamic-pituitary-adrenal axis and autonomic nervous system
- The right hemisphere enables us to feel ourselves to be part of the living web of experience, as "embodied beings in a concrete, incarnate world"<sup>1</sup>

# The Bilateral Brain

- The face is the common mediator of two of the most significant aspects of the right hemisphere's world:
  - ★ The uniqueness of the individual
  - ★ The communication of feeling
- The right hemisphere is involved in identifying not just the facial expression of emotion, but the emotion as it relates to an individual face
- This begins in children and is the principle medium for the child's growing sense of identity, through interaction with the mother's face
- There is also a region on the right that allows the child to appreciate the mother's voice



# Left-Cradling

- 60–90% of right *and* left handed women hold an infant to the left of the vertical midline of their own body
- Men do not, until they become fathers, then 80% do as well
- The left half of the face - or “hemi-face” - which is controlled by the right hemisphere, is more involved in emotional expression
- Emotions are also more strongly perceived when expressed by the left hemi-face
- If the infant’s face is to the left, it will fall within the field of attention of the adult's right hemisphere
- The infant is exposed to the adult’s own more emotionally expressive left hemi-face



# Why Does This Observation Matter?

- It corresponds with the observation that during pregnancy there is an increase in the activity of the region of mother's right hemisphere related to emotional skills
- It also provides strong evidence of the importance of emotional communication with infants, likely including eye contact
- If mother is unable to participate in this interaction, does it impact the child?
- Women struggling with depression tend not to left-cradle, which *may* explain some of the impact of maternal depression on an infant

# The Bilateral Brain

- The two sides of the brain are equally important, and each is involved in everything that we do
- The trouble has been that the left hemisphere's way of doing things has become the rule
- The right hemisphere needs to be given its due
- Since it is intimately involved in the body there are ways of fostering its activity
  - ★ Mindful movement
  - ★ Rhythm
  - ★ Music and song

# Your Predictive Brain

# The Predictive Brain

- Automatic processes play a central role in the mind, allowing us to predict events quickly and accurately as they arise
- Learning, experience and consciousness constantly improve our implicit, or unconscious, predictions, and we take note of events only when the predictions fail
- We only become conscious of circumstances when they merit our attention
- This automaticity enables us to function smoothly in the world, and becoming conscious when predictions fail, enables us to avoid the pitfalls of automatic processing and adjust to changes in our environment



# Some Predictions from the Predictive Brain

- Prediction operates at the controlled (conscious), and unconscious levels
- Both of the core systems operate primarily on habit, so in situations that appear familiar, we act without thinking
- Habits define who we are, and they can be changed
- We breathe automatically, we see automatically, but we think, decide and act habitually
- Habits are driven by the limbic system and cerebellum (A likely reason that the cerebellum has grown so fast in humans, it is a critical part of the substrate for social cognition, most of which is habitual)

# Some Predictions from the Predictive Brain

- Our brains continually interpret information contextually to prepare to act in the world
- We do not perceive as a prelude to considering how to act, but rather perceive in the context of available actions
- Our interpretation of the world is suffused with our prediction of what we expect to see and do next
- An increase in neural activity happens whenever something surprising occurs
- This provides a basis for the old observation that people learn best by being taught global rules and then focussing on exceptions

# Questions and the Predictive Brain

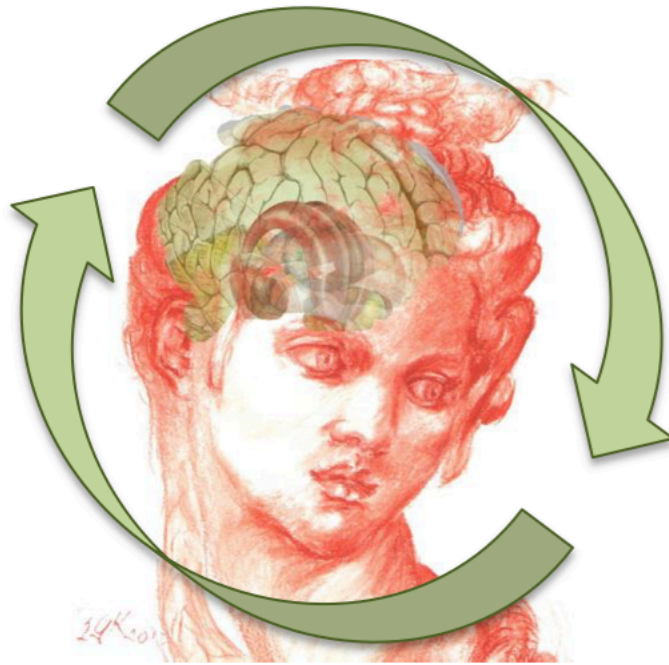
- One reason that asking questions can be an effective teaching tool, is that good questions are unpredictable and unexpected
- A question may trigger “Instinctive elaboration,” a mental reflex that stops predictable, automatic thinking
  - ★ First-level questions are preliminary questions that open up a topic by revealing thoughts, facts, behaviors, and situations
  - ★ Second-level questions, which prompt people to state their opinions, increase neural activity in the areas of the brain associated with reward and pleasure



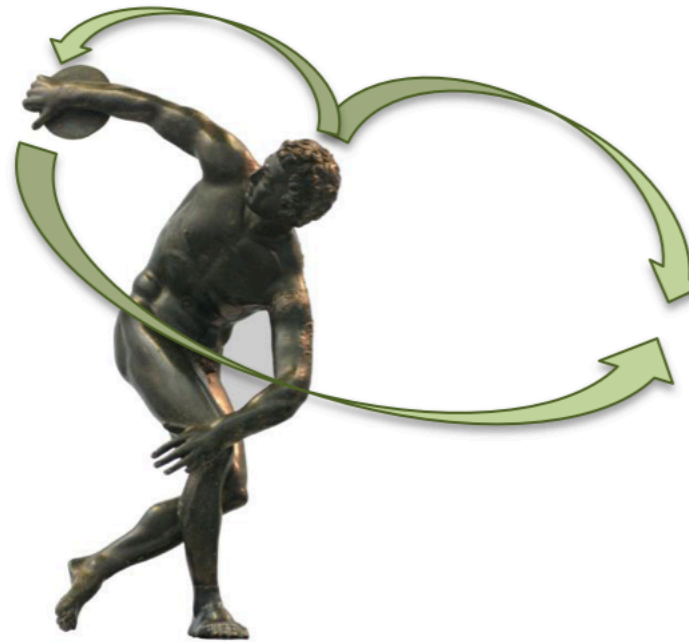
# Interoception

# Interoception and Mental Health

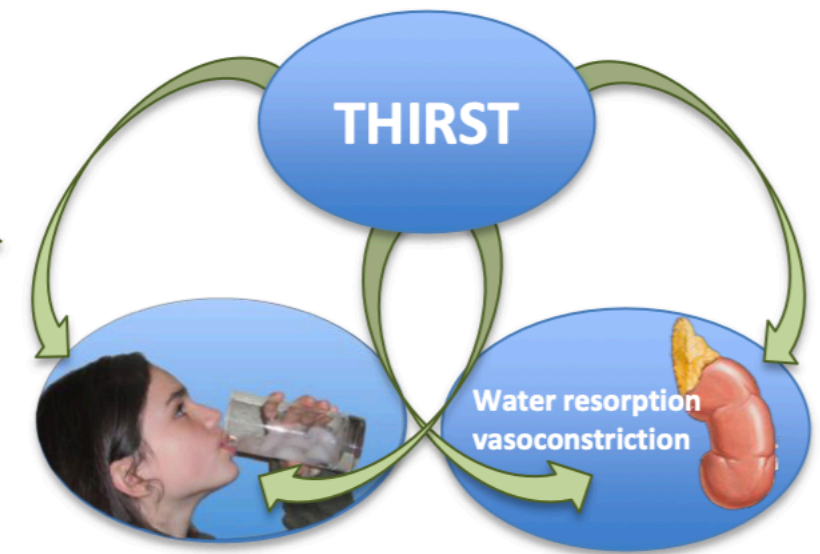
- Interoception refers to the sensing of the internal state of one's body
- It is distinct from the processing of sensory information concerning external (non-self) stimuli (e.g. vision, hearing, touch and smell)
- Interoception is the afferent axis to internal (autonomic and hormonal) physiological control
- The impact of interoception extends beyond homeostatic/allostatic reflexes: it is proposed to be fundamental to:
  - ★ Motivation
  - ★ Emotion (affective feelings and behaviors)
  - ★ Social cognition
  - ★ Self-awareness
- Disturbed interoception is a fundamental component of, for example, autism spectrum, panic disorder, eating disorders and depression



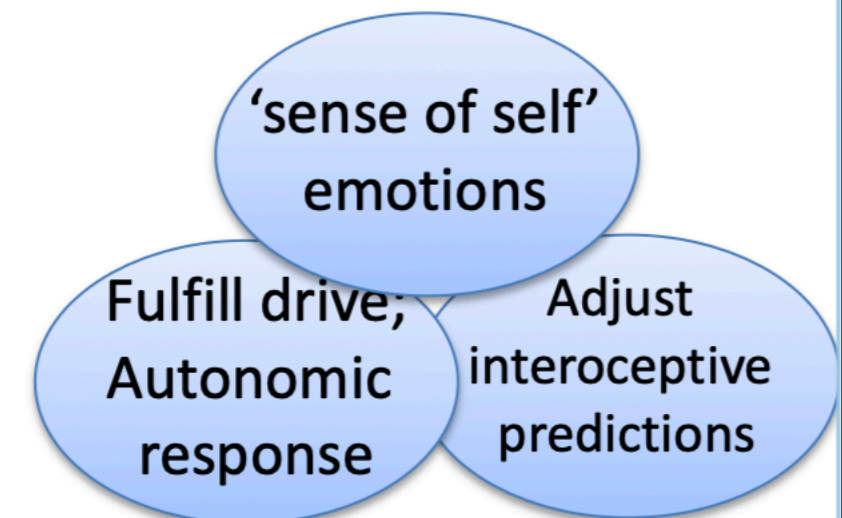
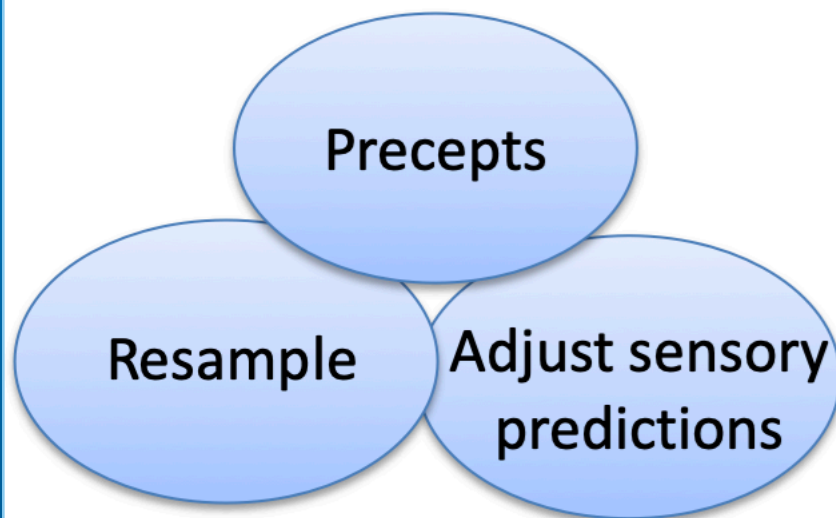
**Exteroception**



**Proprioception**



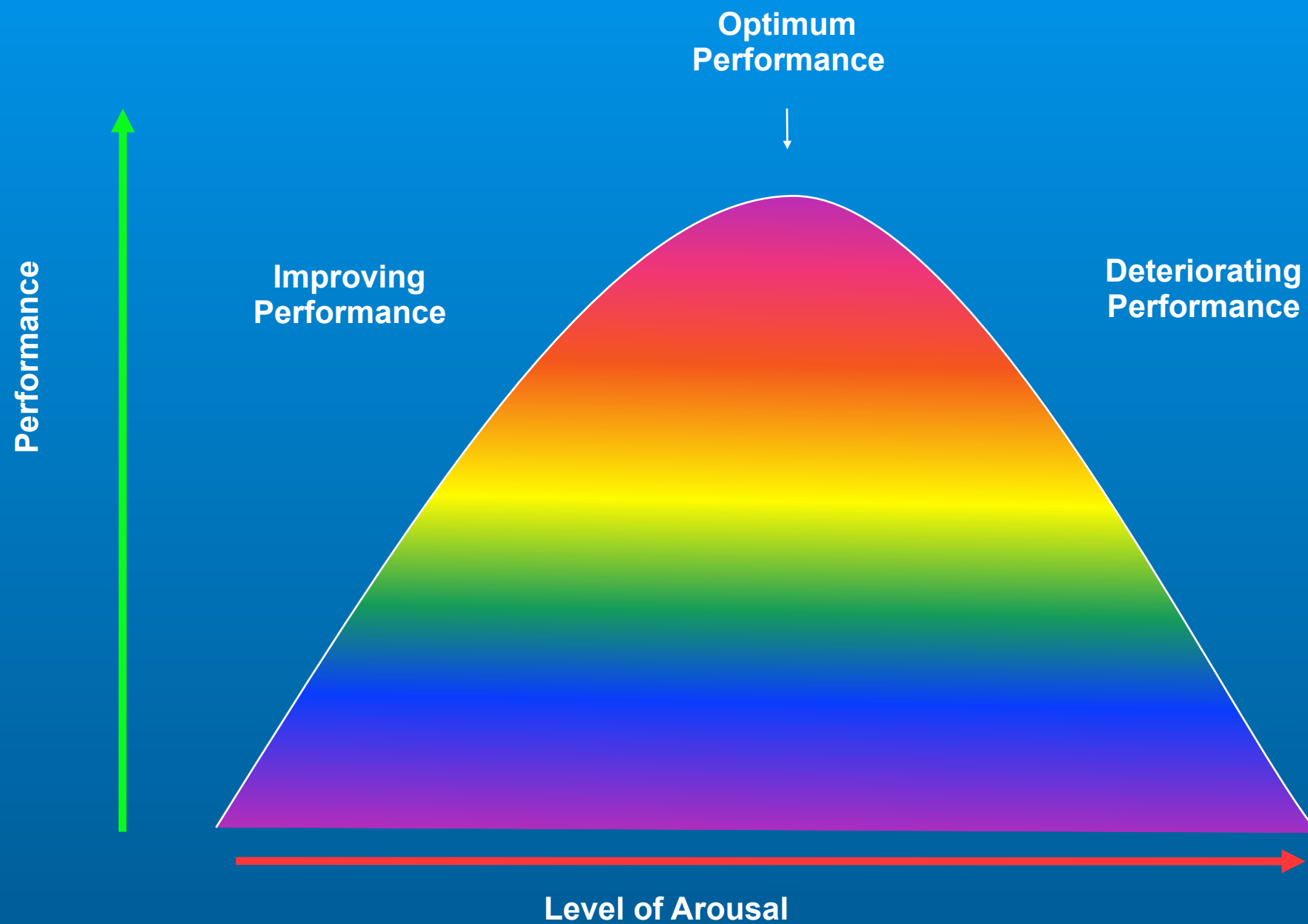
**Interoception**





# Junk Food Reduces Hippocampal and Interoceptive Function

- In animals, a Western style diet—high in saturated fat and added sugar—causes rapid impairments in hippocampal-dependent learning and memory (HDLM) and perception of internal bodily state (interoception)
- Hippocampal lesions can produce impairments in accurately sensing signals of hunger and satiety
- In an experiment, healthy volunteers given Western breakfast or a healthier option
- Test subjects had significant reductions in HDLM and reduced interoceptive sensitivity to hunger and fullness
- Larger changes in blood glucose correlated with greater reductions in learning and memory



*The Yerkes-Dodson Graph, showing how some arousal enhances performance, while too much can cause performance to deteriorate*

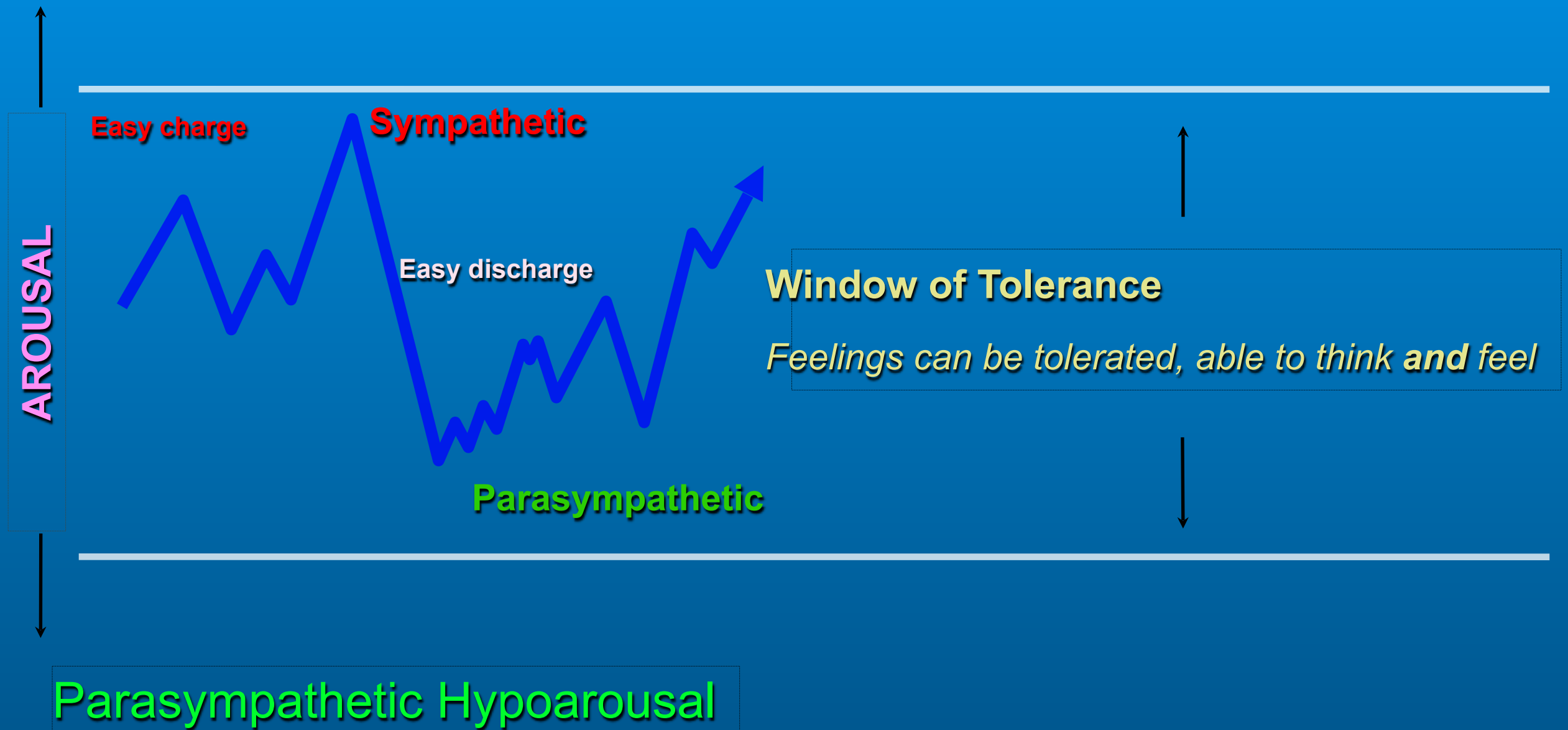
# The Window of Tolerance

- The autonomic arousal model of responses developed from simple fight/flight/freeze models:
  - ★ Useful in assessing whether someone is operating within a state in which:
    - Information can be processed and
    - New learning can occur
  - ★ This is the 'window of tolerance' between hyper-arousal and hypo-arousal

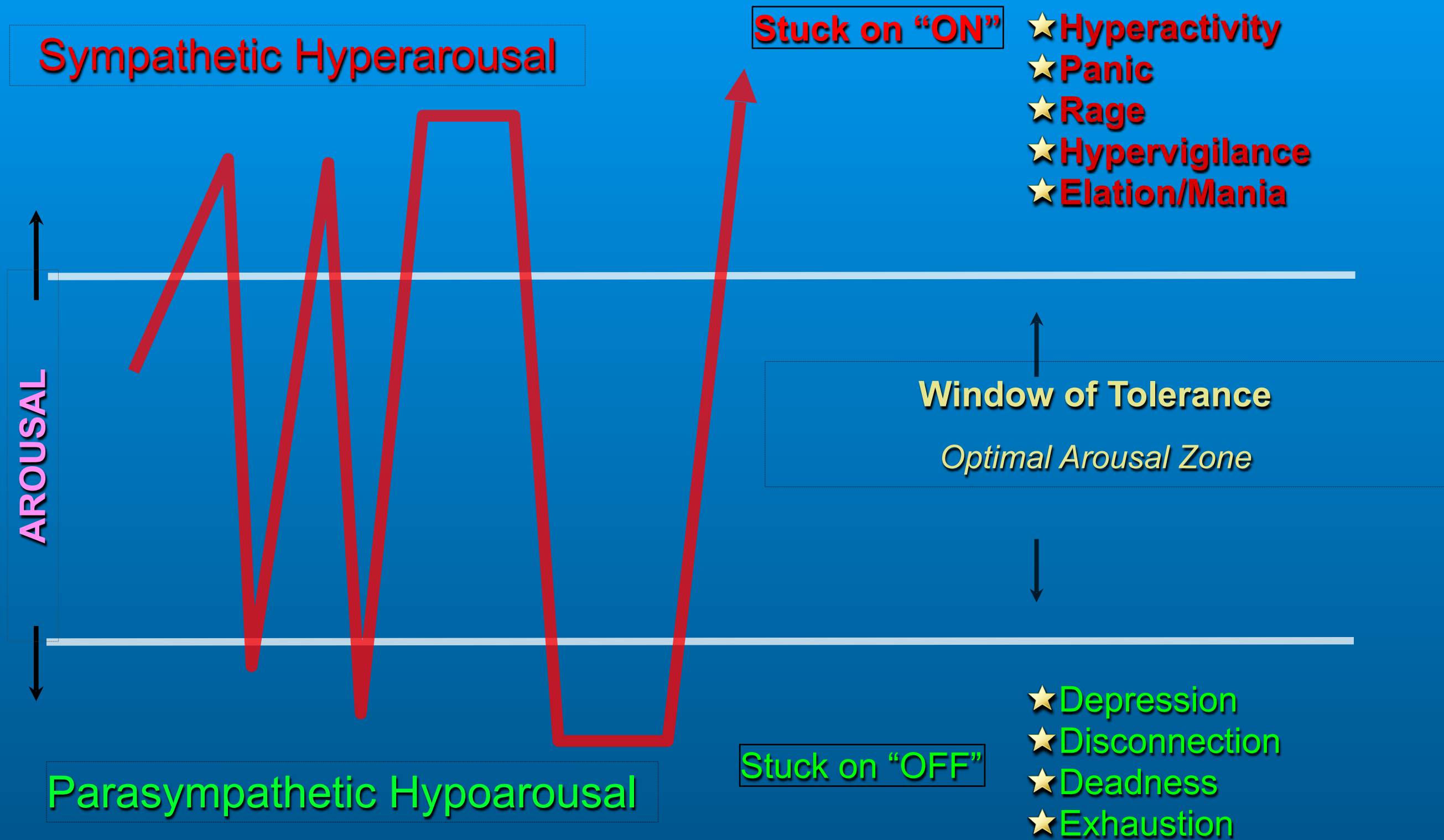


# Autonomic Arousal is Designed to Adapt to Environmental Demands

**Sympathetic Hyperarousal**

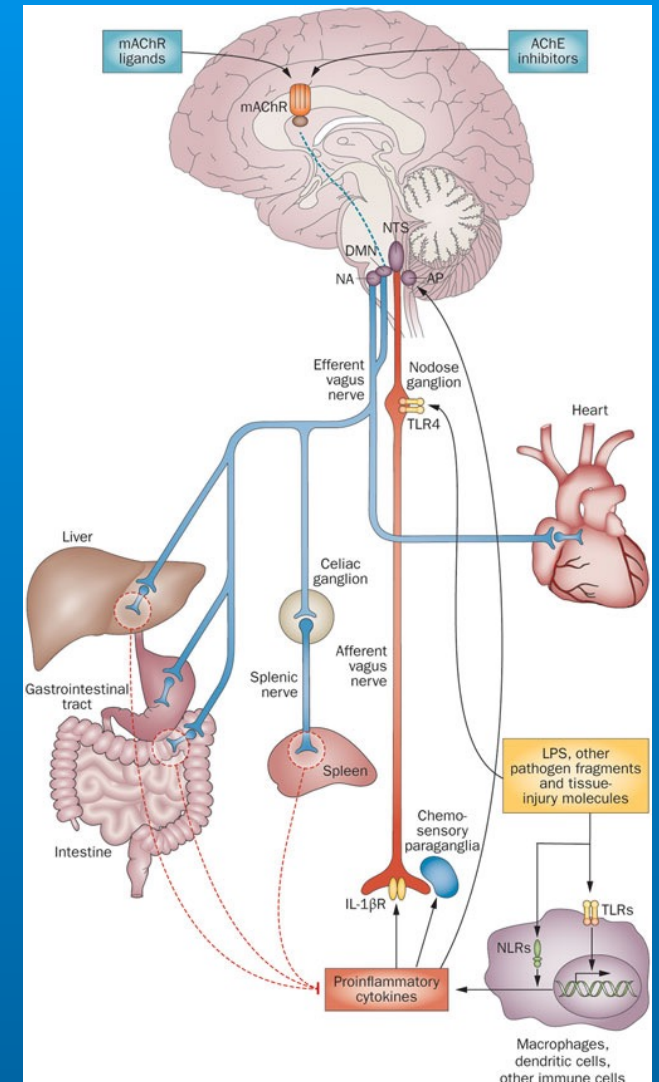


# Autonomic Adaptation to Threat



# Polyvagal Theory

- The vagal complex in the brainstem is the origin of the vagus nerve
- It has enormous influences throughout the body, controlling, for example:
  - Heart
  - Lungs
  - Intestinal motility
  - Metabolism
  - Immune system
- Polyvagal theory is a reconceptualization of the interlinking of autonomic state and behavior, in which the vagus is seen as a complex regulator that is also involved in prosocial activities, including empathy and emotional regulation





# The Autonomic Model Has Explanatory Power

- Why do 50% of people fail to benefit from therapy?
  - ★ They are the ones with higher levels of baseline fear and accompanying activation of associated neural circuits
- Intense negative emotions block neuroplasticity and the ability to adapt and learn
- In those people, work on reducing activation is an essential prerequisite for successful therapy
- The same applies to learning: over activated and under activated people cannot learn

# Polyvagal Theory: Relevance to Learning

- There is bidirectional communication between body and brain, explaining how:
  - Thoughts and emotions affect physiological states
  - How physiological states influence thoughts and emotions
  - How mind-body practices influence both
- The use of positive facial expressions and prosody conveys benevolent feelings of concern and recruits passive neuroceptive pathway
- Mind-body practices recruit active pathways through voluntary behaviors
- Peripheral vagal system provides “portal of intervention” for correcting dysfunctions of central and autonomic nervous systems

## A Final Example: Temperature, Mood and Feelings

- People with depression sweat less than others, an observation first made in 1890
- Outside temperature directly affects mood and feelings: people exposed to warmth, prefer a gift for a friend over a reward for themselves and are more trusting
- People prefer to watch romantic movies when they feel cold
- When people feel socially excluded, they feel physically colder, leading to lower estimates of ambient temperatures
- Exposure to physical and social warmth cues independently activate overlapping regions of the middle insula and ventral striatum



# Conclusions

- Enough new findings have come together to enable us to develop new insights and understandings
- Each that we have discussed has been or is being tested
- While we are always eager to expose “neuromyths,” it is good to know that they have not had a negative impact on teachers: good teachers still teach well!
- Though much remains to be learned, we already have access to a range of new approaches to help students and their teachers cope and learn in revolutionary new ways