

# Concussion 40 years after the Centripetal Theory of Concussion (CTC): what is concussion? Is there a unifiable theory?

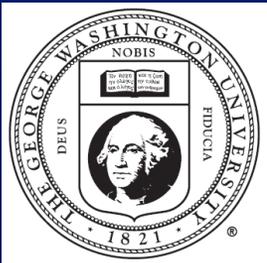
IRCOBI

September 9, 2015, Lyon

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**Clinical Professor of Neurosurgery**, George Washington University

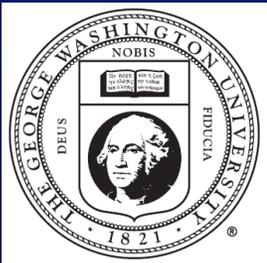
[tgennarelli@att.net](mailto:tgennarelli@att.net)



# What's Happened in TBI in the last 40 years?

In the 1970's, **there were no**

- **CT scans**
- **MRI**
- **PET**
- **Neuroradiologists**
- **Neuro ICU's**
- **Neuro-intensivists**
- **Trauma Centers or specialists**



# What's Happened in TBI in the last 40 years?

**The best Lab Computer c. 1970, the PDP12**



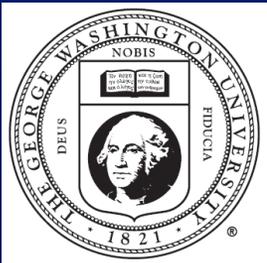
**12 bit processor;  
4kb expanded to 16kb**



**MEDICAL  
COLLEGE  
OF WISCONSIN**

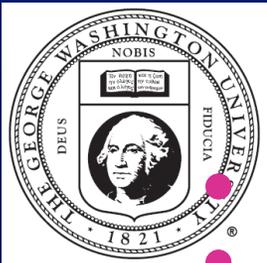
# PHENOTYPES OF TRAUMATIC HEAD INJURY - 1980

- **SCALP LACERATIONS**
- **SKULL FRACTURES**
- **CONTUSION, LACERATION**
- **HEMORRHAGE: EDH, SAH, SDH, ICH**
- **CONCUSSION SYNDROMES**
- **DIFFUSE BRAIN INJURY**



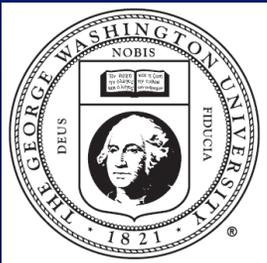
# PHENOTYPES OF TRAUMATIC HEAD INJURY

- SCALP LACERATIONS
- SKULL FRACTURES
- TRAUMATIC BRAIN INJURY
  - FOCAL BRAIN INJURIES
    - CONTUSION, LACERATION
    - HEMORRHAGE: EDH, SAH, SDH, ICH
  - DIFFUSE BRAIN INJURIES
    - CONCUSSION SYNDROMES
      - Civilian non-sport related
      - Civilian sport related
      - Military/blast related
    - DIFFUSE AXONAL INJURY
      - Brain Swelling: unilateral or bilateral
  - PENETRATING INJURIES
- BLAST-EXPLOSIVE INJURIES and PTSD
- CTE



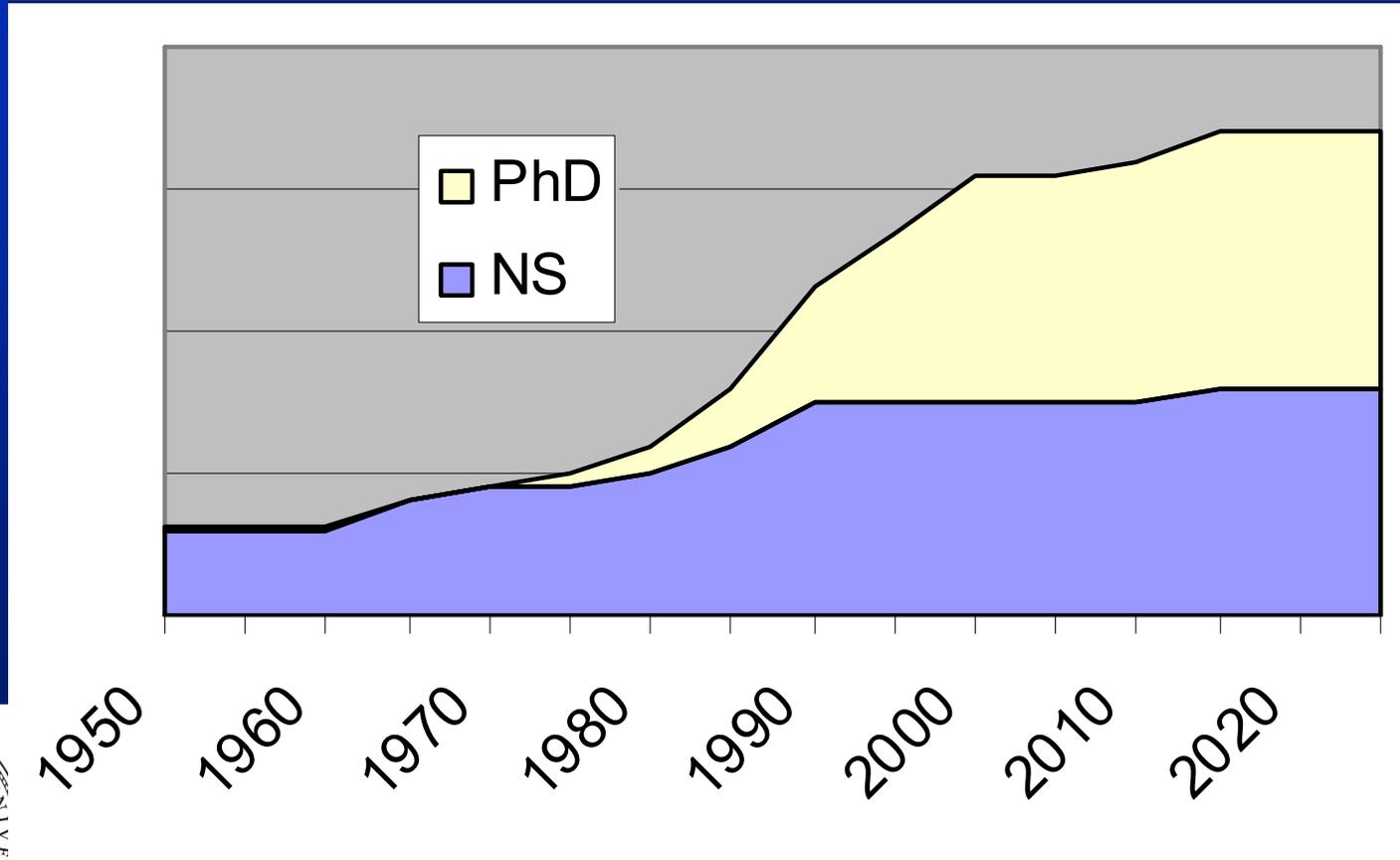
# The Ultimate Plan to solve TBI

Neurosurgeons

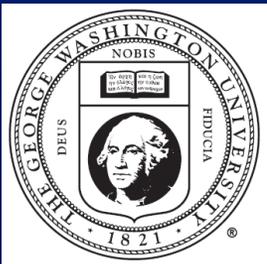
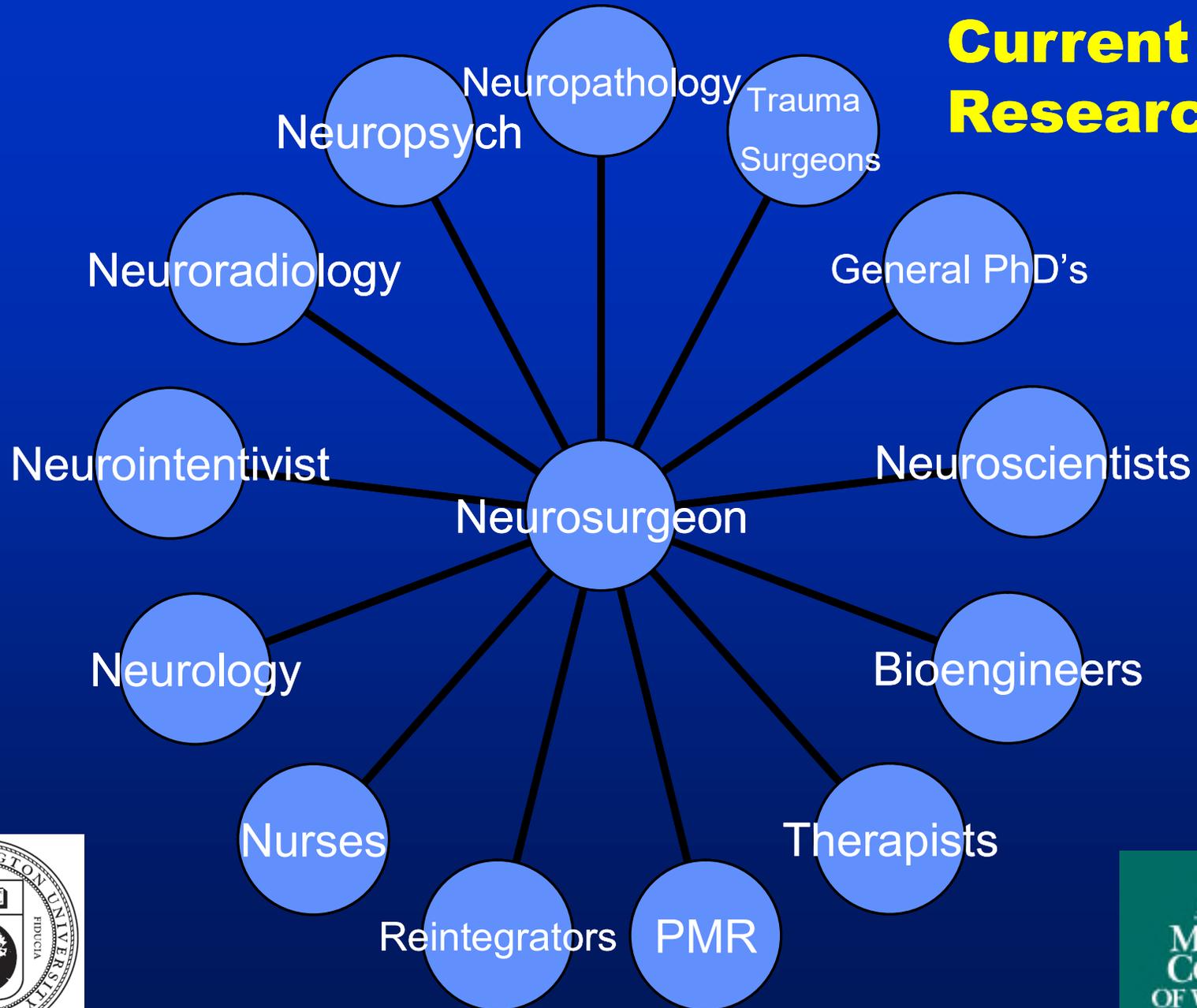


# Neuroscientists

Bring a new dimension to TBI

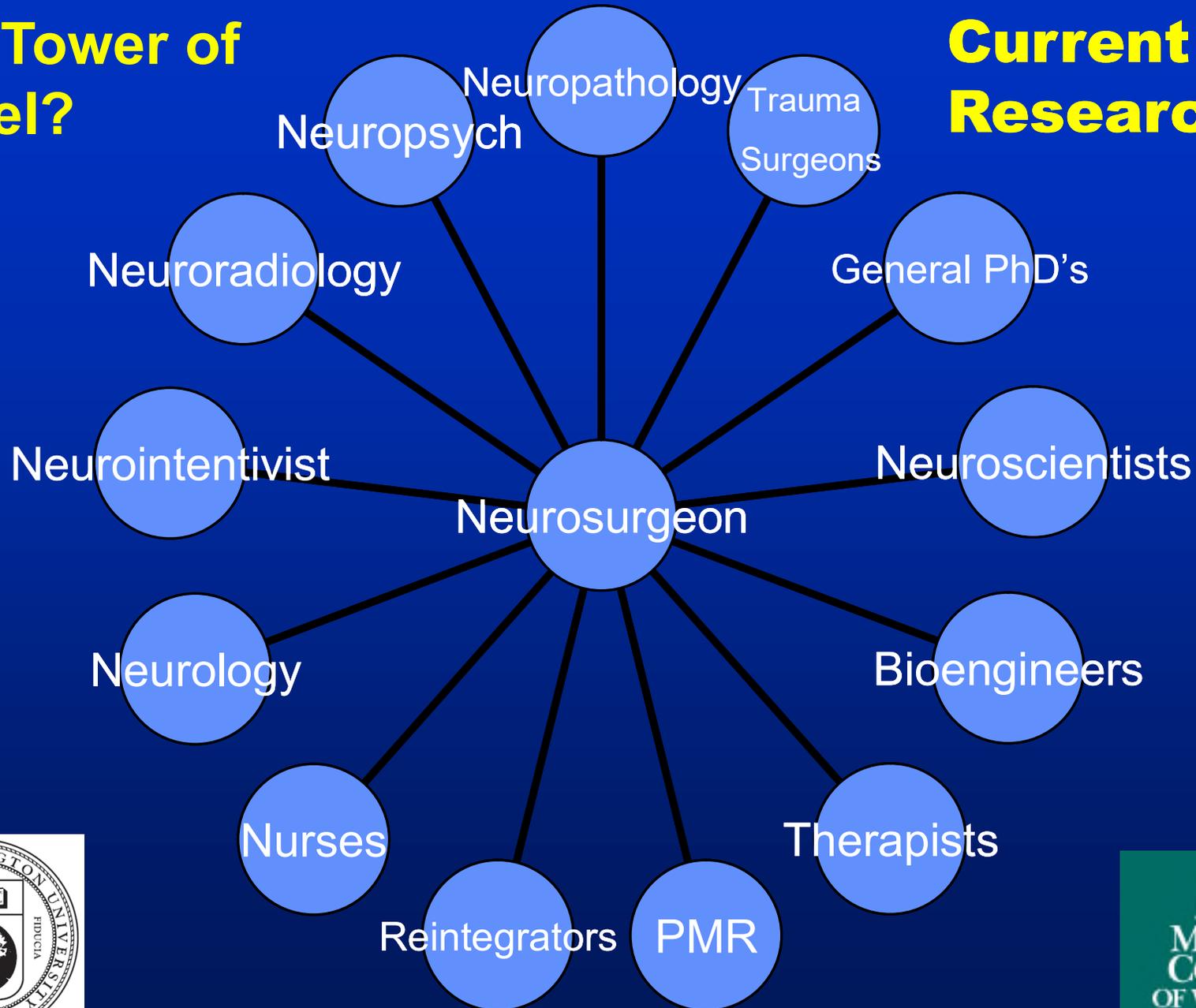


# Current TBI Research



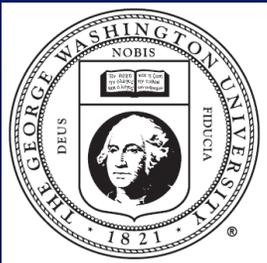
# The Tower of Babel?

# Current TBI Research



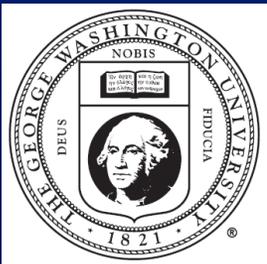
# Research Question regarding CTC:

- is the centripetal theory of concussion still valid today?
- **Hypothesis:** yes it is



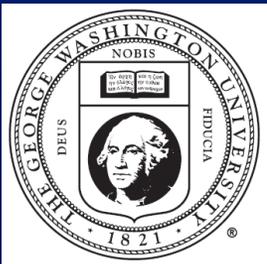
# Methods:

- **Review the concept of CTC**
- **Review the literature**
- **Apply to current biomechanics**
- **Apply to current pathophysiology**



# Theories of Concussion

- **Vascular:** brief ischemia, decreased CBF
- **Reticular:** brainstem site ARAS produces LOC
- **Centripetal:** a complex variation of reticular
- **Pontine Cholinergic System:** activation of inhibitory system in dorsal pons
- **Convulsive:** Sx like those of sz: eg. excitatory



After Shaw 2006 in Foundations of Sport related Brain Injuries, (Slobounov and Sebastianelli) Springer



Presented, in  
part, 1<sup>st</sup> IRCOBI ,  
1973

CEREBRAL CONCUSSION AND TRAUMATIC UNCONSCIOUSNESS

CORRELATION OF EXPERIMENTAL AND CLINICAL OBSERVATIONS  
ON BLUNT HEAD INJURIES

*Brain* (1974) 97, 633–654

BY

AYUB K. OMMAYA AND T. A. GENNARELLI

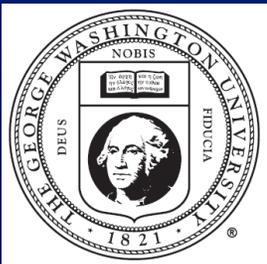
Our hypothesis for cerebral concussion would then be defined as *a graded set of clinical syndromes following head injury wherein increasing severity of disturbance in level and content of consciousness is caused by mechanically induced strains affecting the brain in a centripetal sequence of disruptive effect on function and structure. The effects of this sequence always begin at the surfaces of the brain in the mild cases and extend inwards to affect the diencephalic-mesencephalic core at the most severe levels of trauma.*

**“It is suggested that rotational components of accelerative trauma to the head produce a graded centripetal progression of diffuse cortical-subcortical disconnection phenomena which is always maximal at the periphery and enhanced at sites of structural inhomogeneity.”**

**Subsequently, this has become known as the  
centripetal theory of concussion (CTC)**

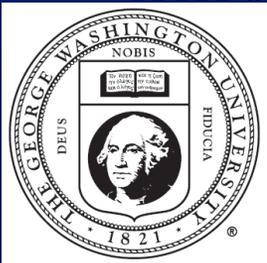
# The CTC hypothesis consisted of several parts:

- **concussion has a series of gradations of injury severity (caused by mechanical energy),**
- **the severity of the clinical alterations is related to the severity of the mechanical input to the brain that produced mechanical strains in the brain in different regions and in different amounts,**

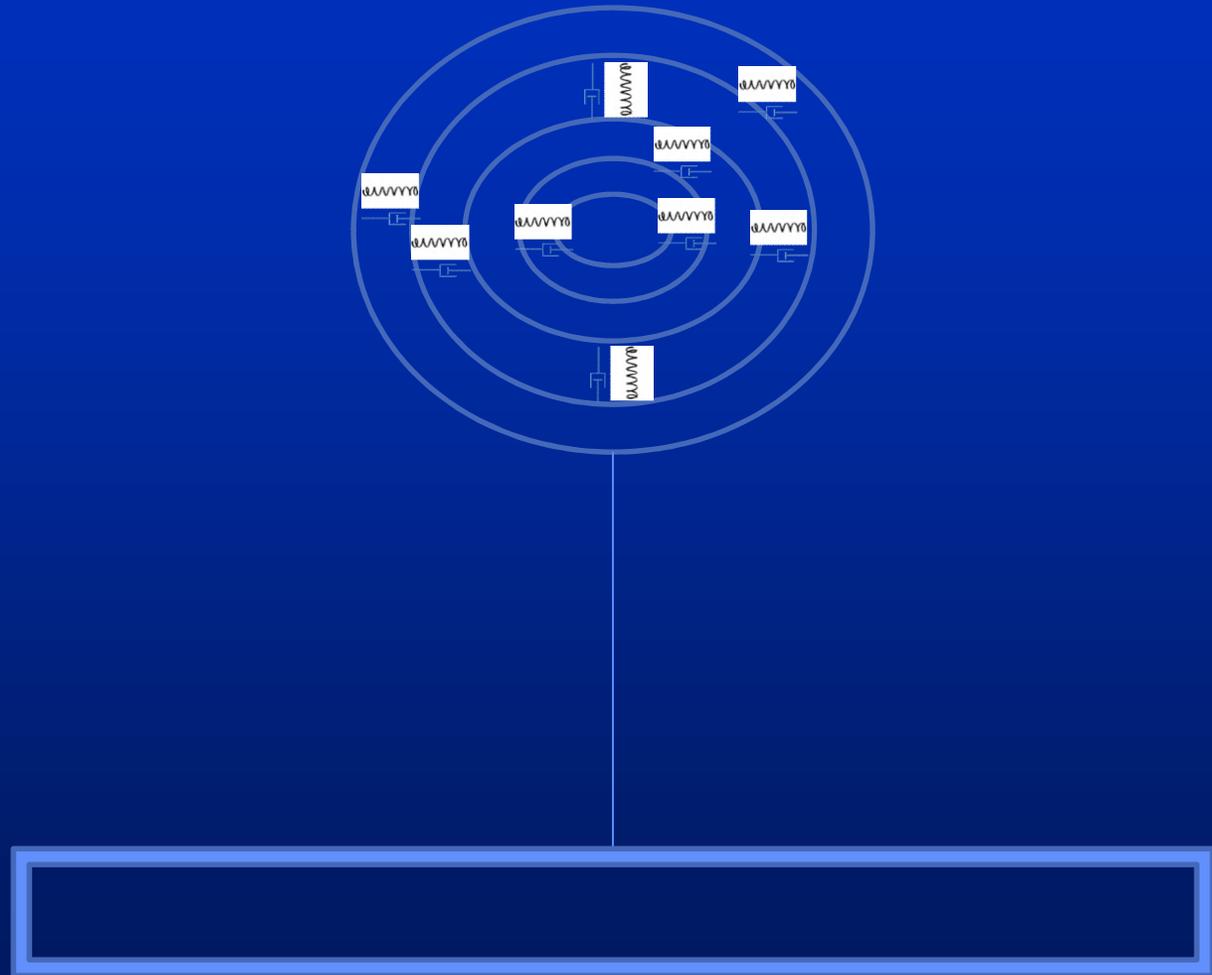


# **The CTC hypothesis consisted of several parts:**

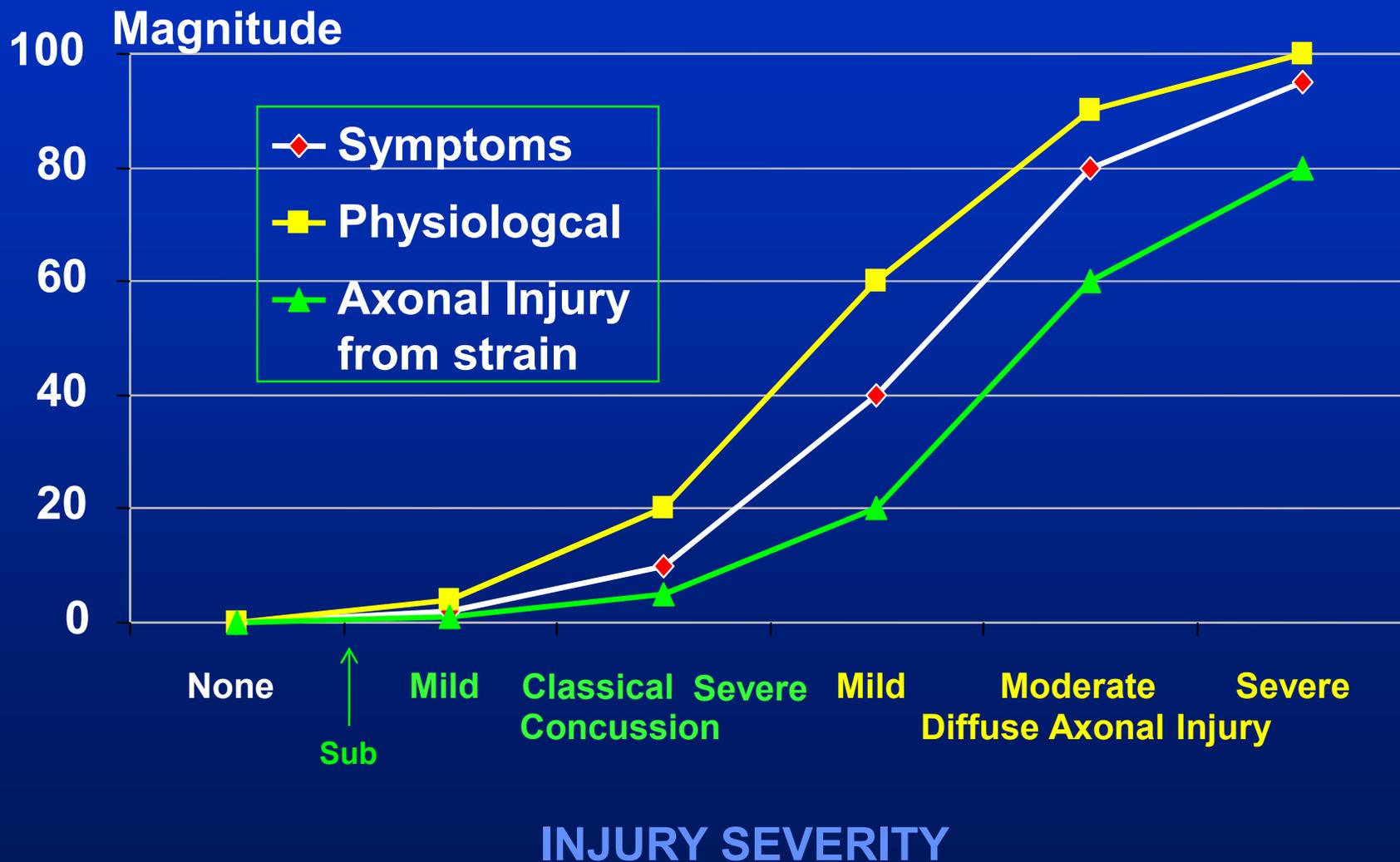
- **the sequence of concussion severity results from a centripetal sequence of disruptive effects on brain function and structure, and**
- **that rotational components of accelerative trauma to the head produce a graded centripetal progression of diffuse cortical-subcortical disconnection phenomena which is always maximal at the periphery and enhanced at sites of structural inhomogeneity.**



# Current Concept of Concussion and the CTC

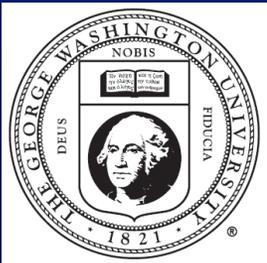


# THE CONTINUUM OF DIFFUSE BRAIN INJURY

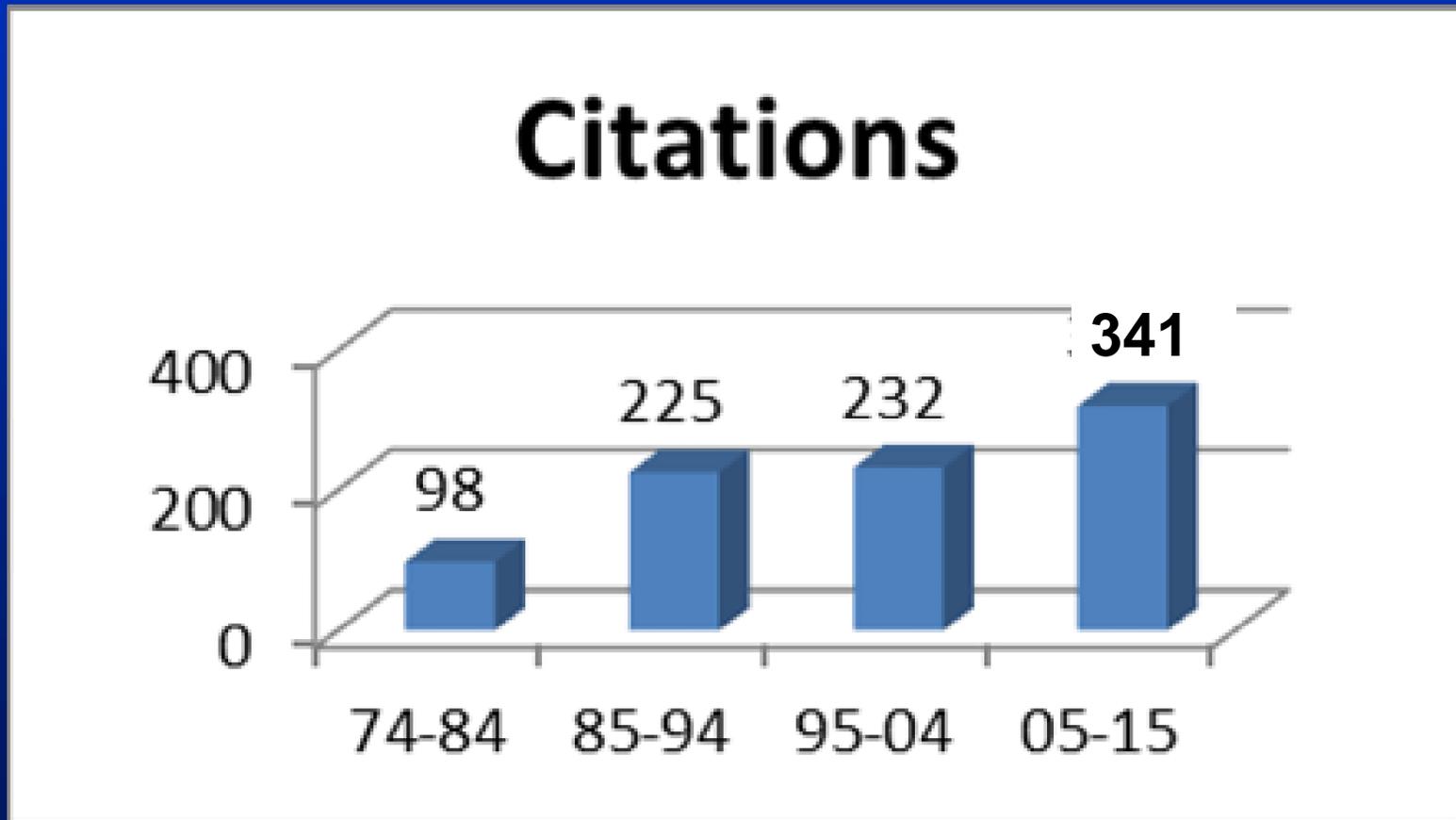


# Centripetal Theory

- Cited by 896 papers as of 1 September 2015
- 3<sup>rd</sup> most cited paper on concussion since 1974
- 27% of concussion papers have <10 citations

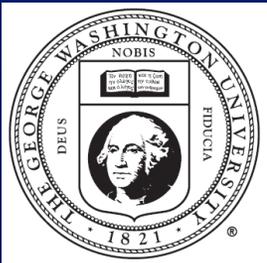


# Citations of Centripetal Theory over time



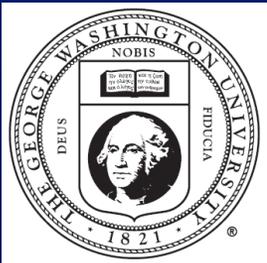
# Detractors from the Centripetal Theory

- **McCrorry 2001:** no structural cortical pathology demonstrated speaks against; prefer brainstem disturbance and some cortical path (Br J Sp Med)
- **Shaw 2006:** “ambitious, ingenious but ultimately flawed”



# Factors influencing Strain patterns

- **Anatomy:** soma, axons, synapses, dendrites
- **Anatomy:** instantaneous centers of rotation
- **Homogeneity of axon directions**
- **Tissue density gradients**
- **Physics:** amplitude and duration of stress



# Why cortex shows little damage

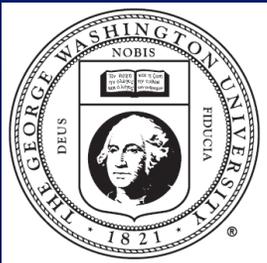
- **Mostly soma & dendrites not axons**
- **Multi-directional**
- **Ultra microscopic structural changes, difficult to demonstrate**
- **More resistant to strain**



# Conclusion

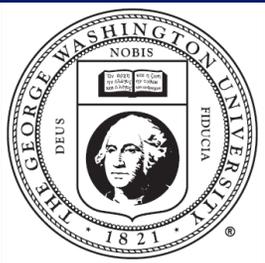
- **Despite 40 years of scrutiny,**
- **Despite a few detractors,**
- **Despite 40 years of newly developed TBI knowledge,**

**the Centripetal Theory of Diffuse Brain Injury remains viable and soundly based in contemporary biomechanics and pathophysiology**



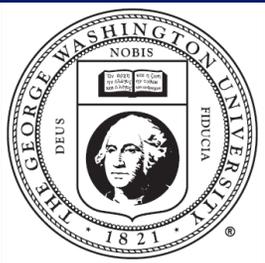
# OR

- **the CTC has survived because there's nothing better out there!**



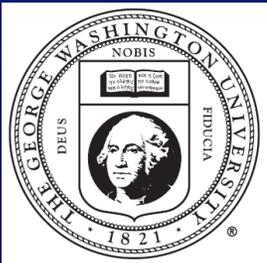
# OR

- **the CTC has survived because there's nothing better out there!**
- **So, are there more options?**

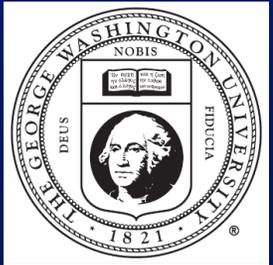
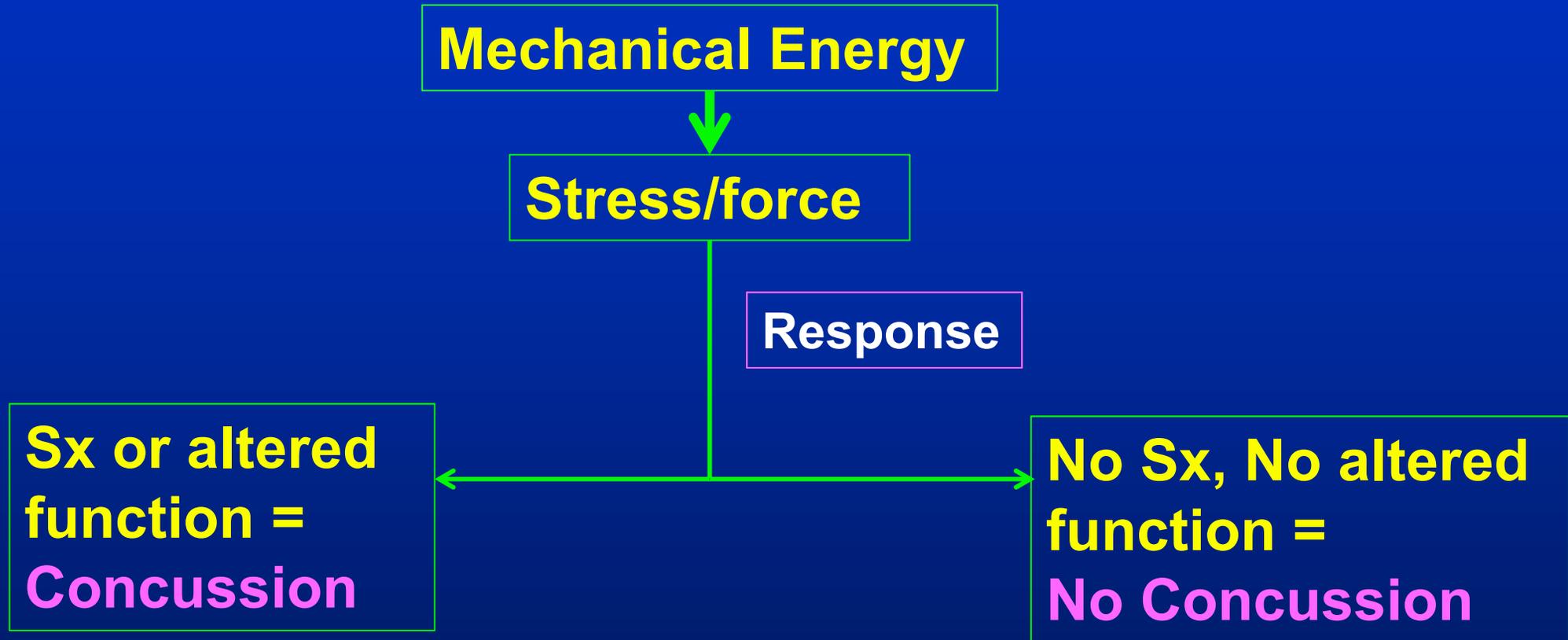


## Corollary Question:

- **The Diffuse Brain Injuries were/are a useful concept**
- **But,**
- **Did this result in too much focus on the axon?**

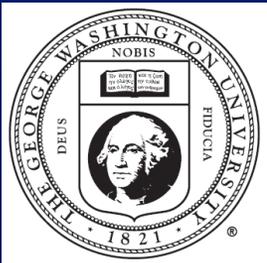


# What is concussion today?



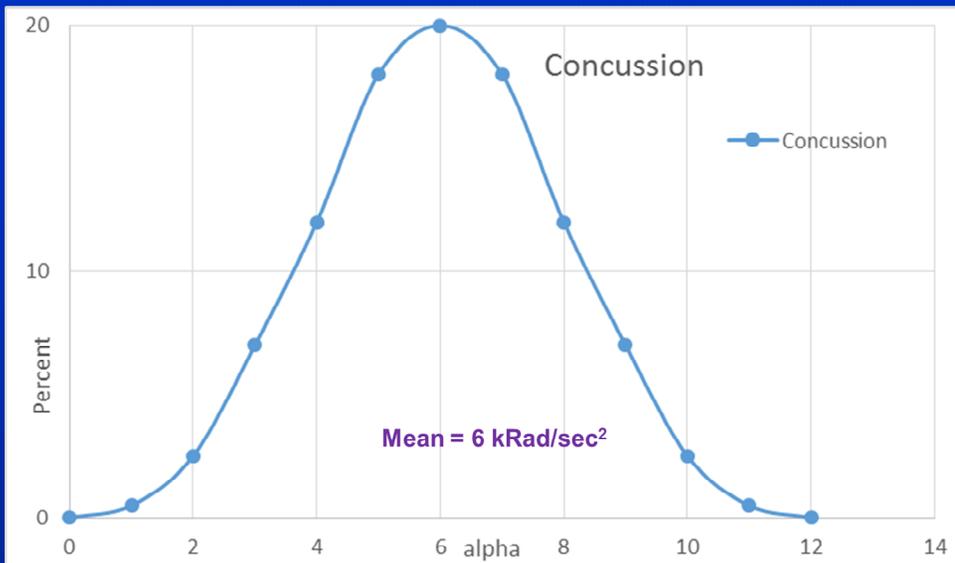
# Historical Definitions of concussion

- **before 1974: LOC**
- **1980's - ~2000: altered brain function**
- **Currently: any symptom**

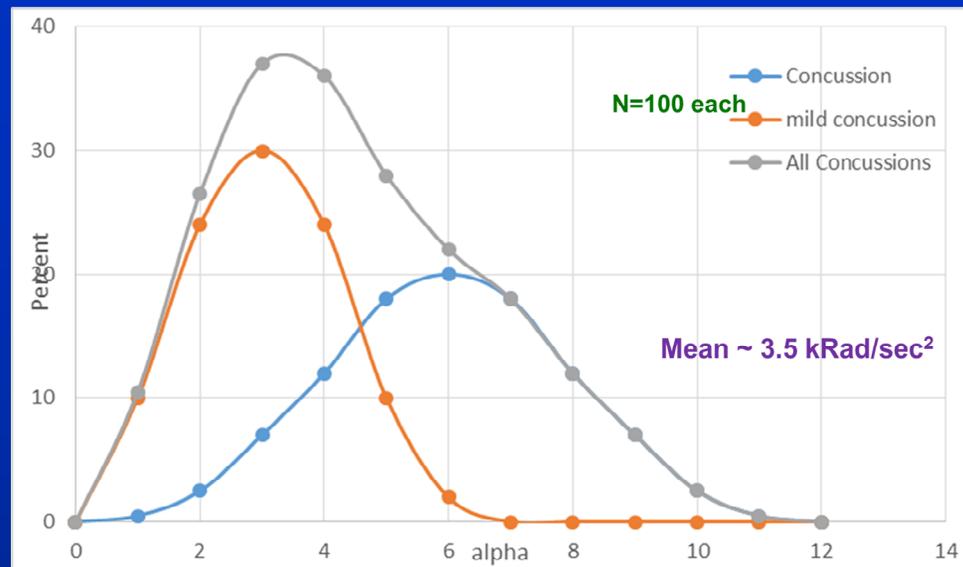


## Concussion before 1970:

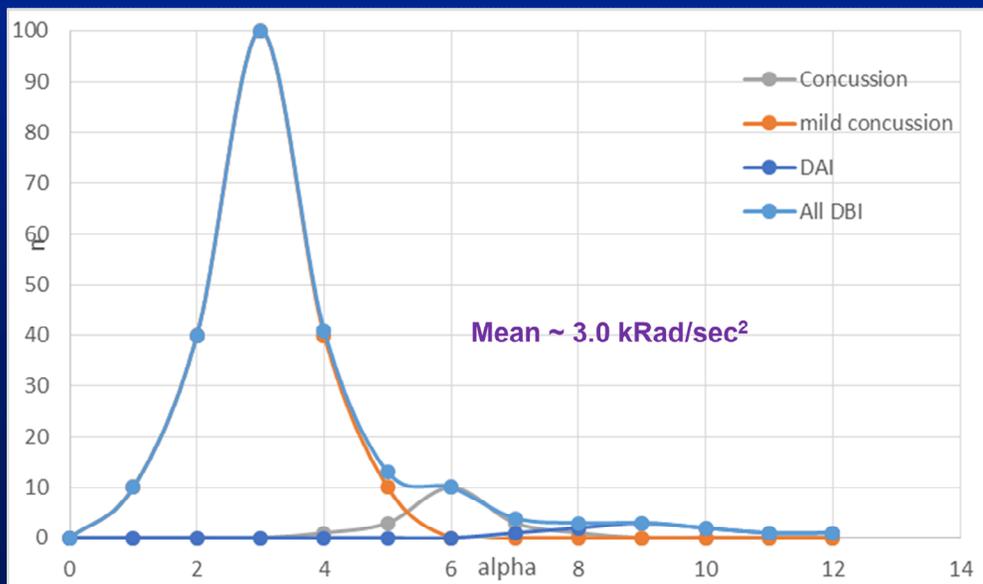
Concussion = loss of consciousness = LOC



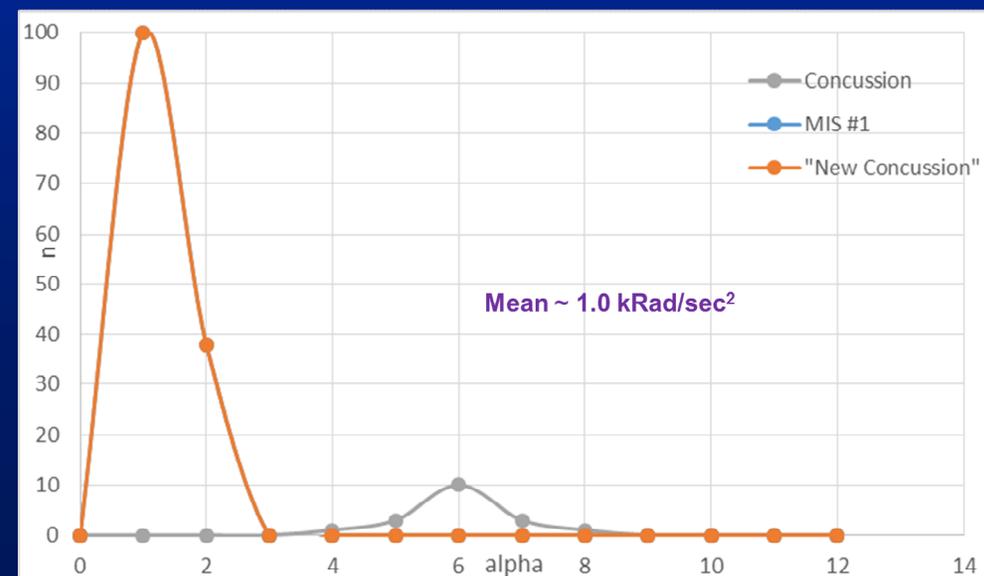
## Mid-1970's: Not all concussions have LOC



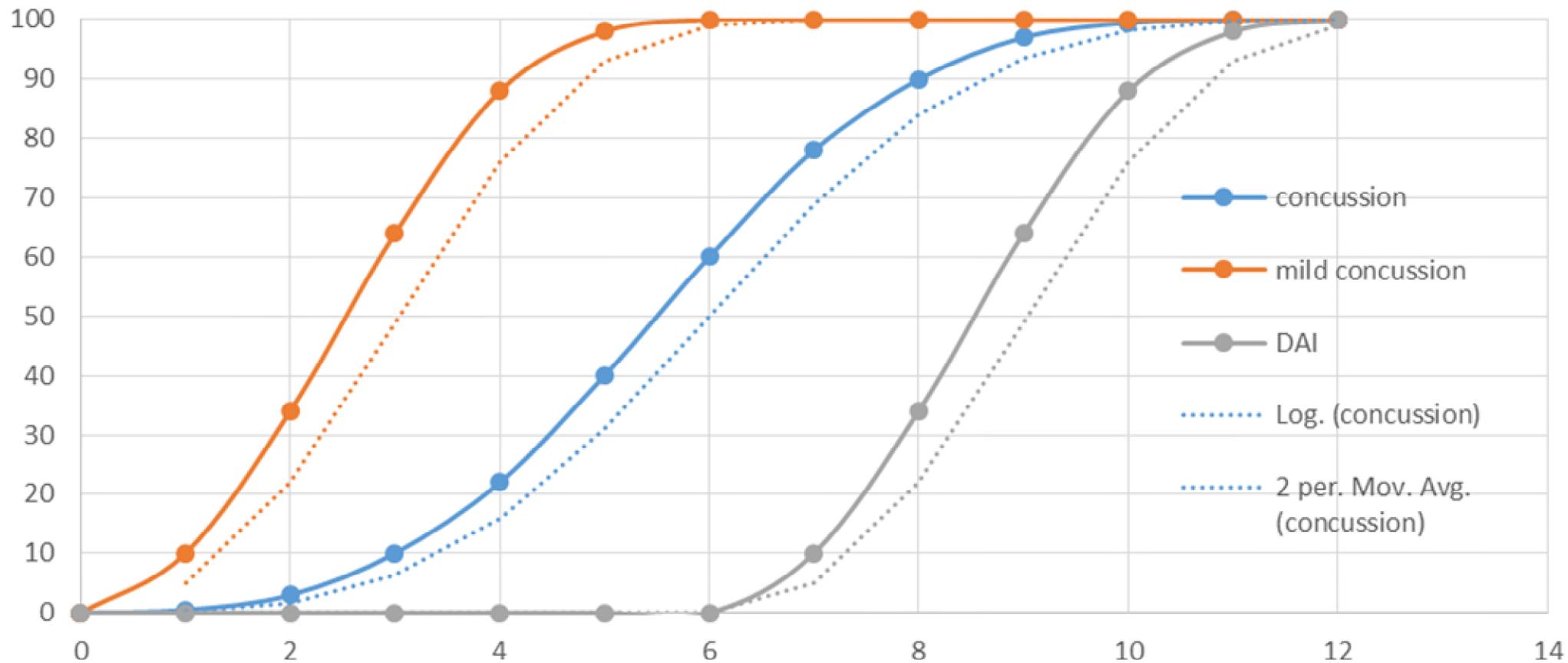
## More realistic distributions



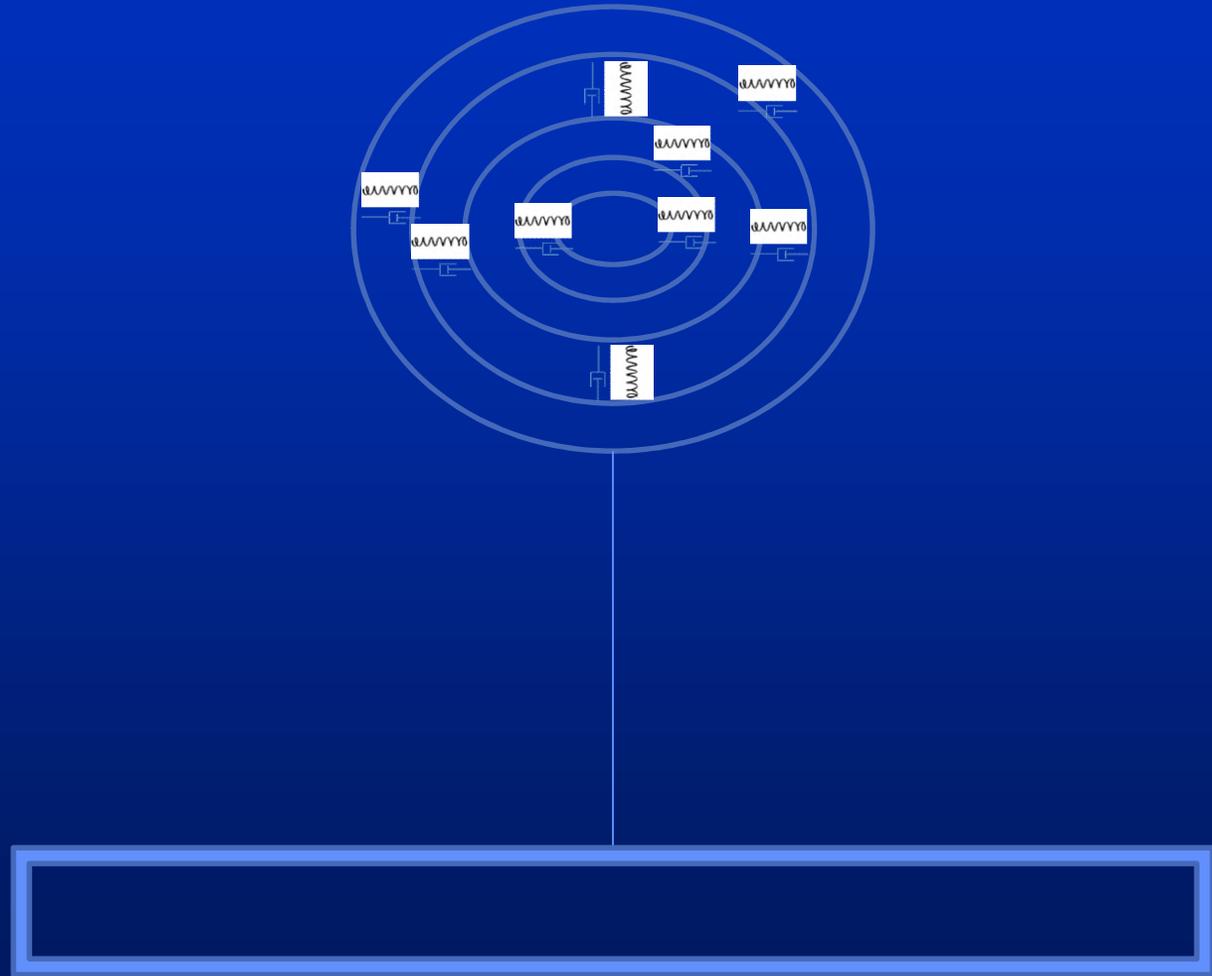
## 2010's: Concussion (mTBI) = any MIS MIS = Mechanically Induced Symptom



# Cumulative Distribution of DBI



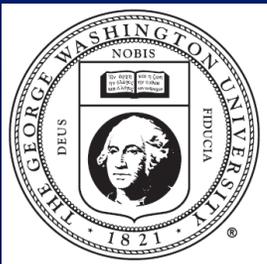
# Current Concept of Concussion and the CTC



# The new concussion:

any symptom after a head hit

(or not hit)

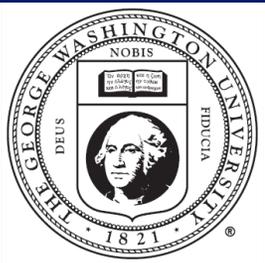


# The new concussion:

any symptom after a head hit

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The theories of concussion  
have lagged far behind the  
publications



# Today's new “concussion”

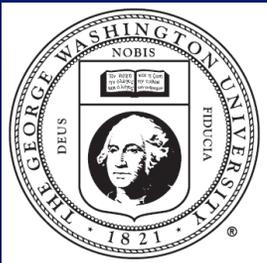
- No longer is “concussion” the same as “cerebral concussion” or “commotio cerebri” because many symptoms currently ascribed to “concussion” or its (more) confusing moniker mild traumatic brain injury (mTBI) are arguably not of cerebral or even of brain origin.
- These include headache, dizziness, seeing “stars”, tinnitus, fuzzy or blurred vision, fatigue, neck pain, photophobia, taste or smell disorders, sensitivity to noise, etc.
- Currently, the term “cerebral” concussion is being replaced by virtually any symptom arising after head motion whether it arises from the cerebrum or not..
- Thus, a Symptomcentric Concept of the Concussions is proposed whereby symptoms from various sites arise in response to a mechanical stimulation of the brain or other individual anatomic



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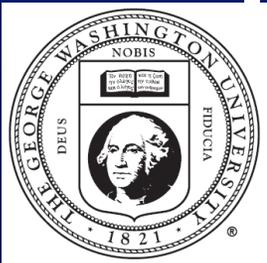


# What other brain structures can respond to mechanical Stimuli?



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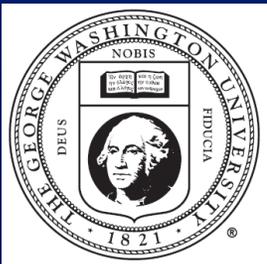
- **Neurons:** axons, soma, dendrites, synapses, networks
- **Blood vessels:** arterial, venous, capillary
- **Oligodendrocytes**
- **Astrocytes**
- **Microglia**

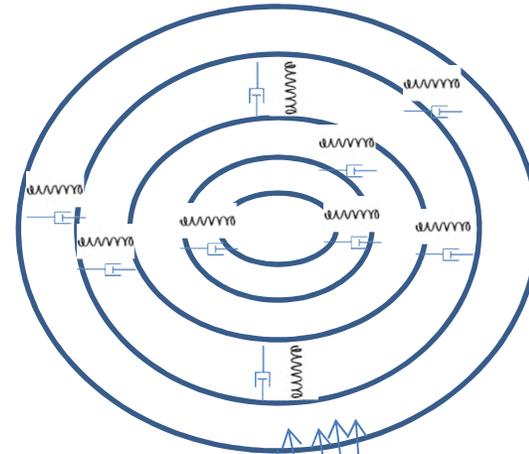


# Brain Mechanical Responses

## Mechanically Induced Symptoms = MIS

- **Neurons:** axons, soma, dendrites, synapses, networks
- **Blood vessels:** arterial, venous, capillary vasoconstriction or vasodilatation
- **Oligodendrocytes:** demyelination, altered electrical transmission
- **Astrocytes:** gliosis
- **Microglia:** inflammation



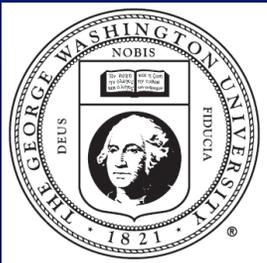


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# What else can be concussed besides the brain?

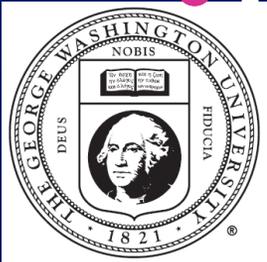
Are there other structures that respond to mechanical stimulation? What is concussible?



# What else can be concussed besides the brain?

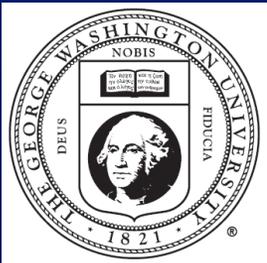
Are there other structures that respond to mechanical stimulation? What is concussible?

- **Olfactory nerves, tract**
- **Retina, optic nerves**
- **Trigeminal: Face, scalp, skin**
- **Vestibular apparatus: semicircular canals**
- **Auditory apparatus: cochlea**
- **The neck: muscles, ligaments, joints, vessels**
- **Cervical spinal cord**



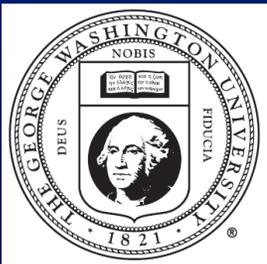
# Mechanically Induced Symptoms = MIS

- **Olfactory concussion:** posttraumatic symptoms arising from the olfactory nerves, bulbs or tracts such as diminished or exaggerated smell.
- **Retinal concussion:** posttraumatic symptoms arising from retinal motions or from traumatic alterations of the electroretinogram such as diminished, dim or “fuzzy” vision, photophobia or visual aberrations.
- **Trigeminal concussion:** posttraumatic symptoms arising from stimulation or depression of the branches of the trigeminal nerve such as headache, facial pain or numbness.
- **Vestibular concussion:** posttraumatic symptoms arising from semicircular canal dysfunction such as dizziness, balance problems, lightheadedness.
- **Auditory Concussion:** posttraumatic symptoms arising from cochlear dysfunction such as hyper or hypoacusis, sensitivity to noise.



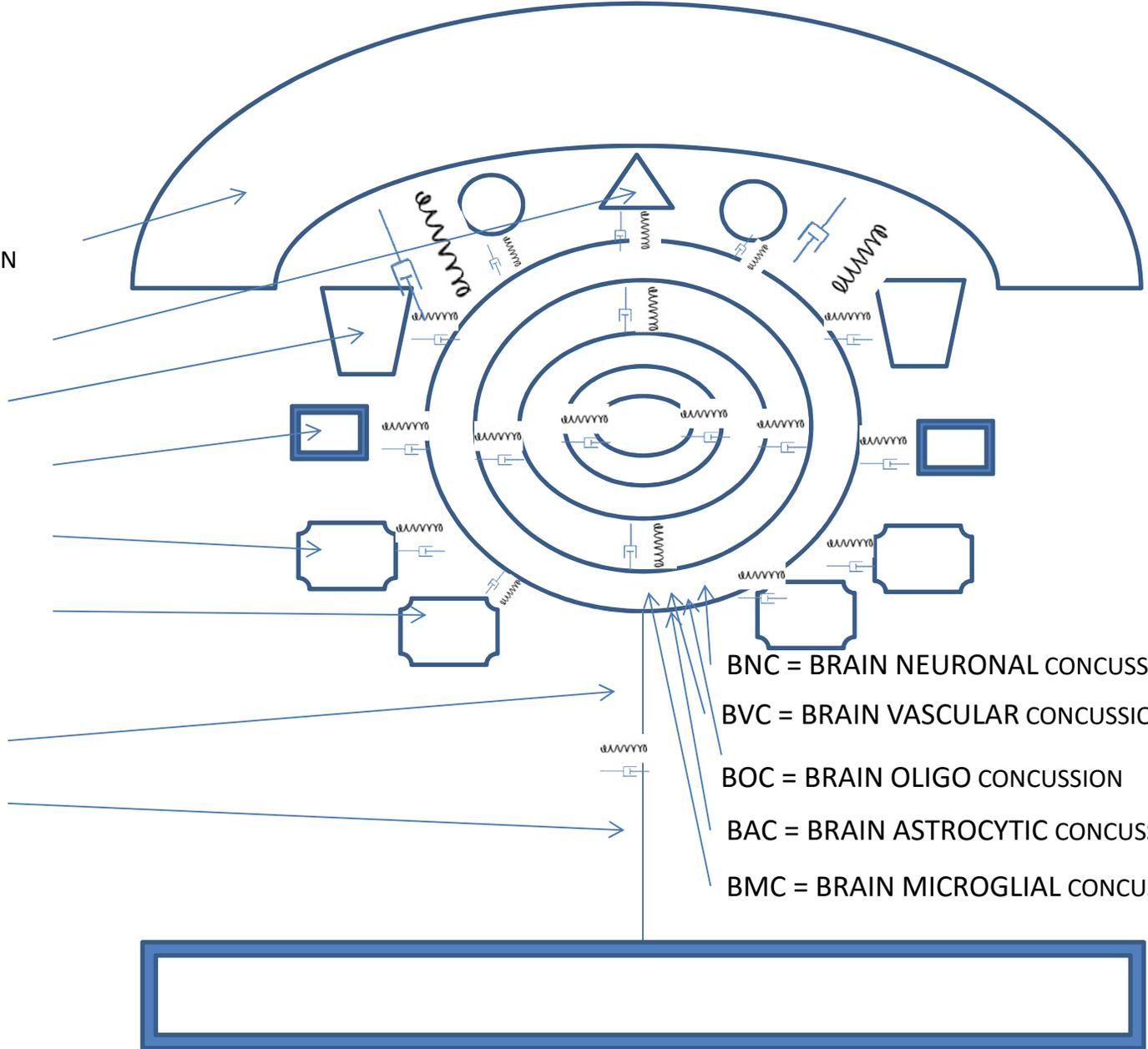
# Mechanically Induced Symptoms = MIS

- **Cervical concussion:** posttraumatic symptoms arising from the nerves, muscles, joints, ligaments or blood vessels in the neck such as neck pain, numbness/pain in posterior portion of head, lightheadedness.
- **Spinal concussion:** posttraumatic symptoms arising from the cervical spinal cord such as tingling, numbness, weakness.
- **Psychological Concussion:** posttraumatic symptoms arising from the influence of mechanical energy on one's overall psychological state. This is a more abstract "injury", the magnitude and expression (symptoms) of which depend on not only the magnitude of the mechanical input but also on the pre-existing personality "strength".



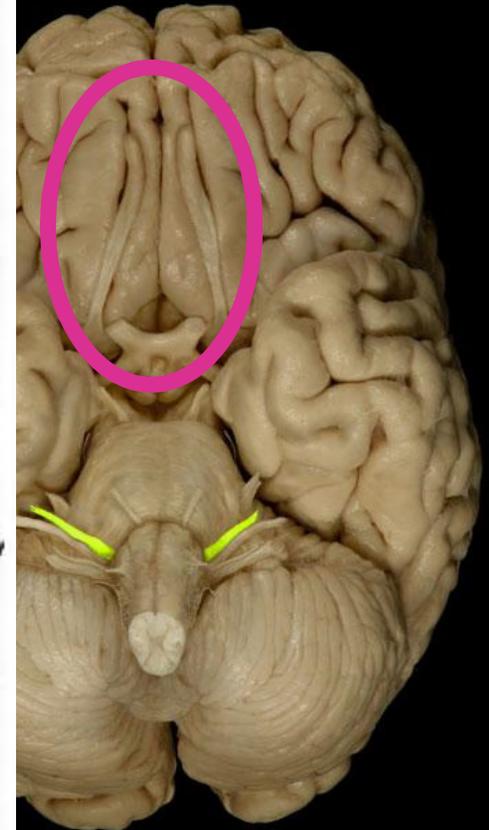
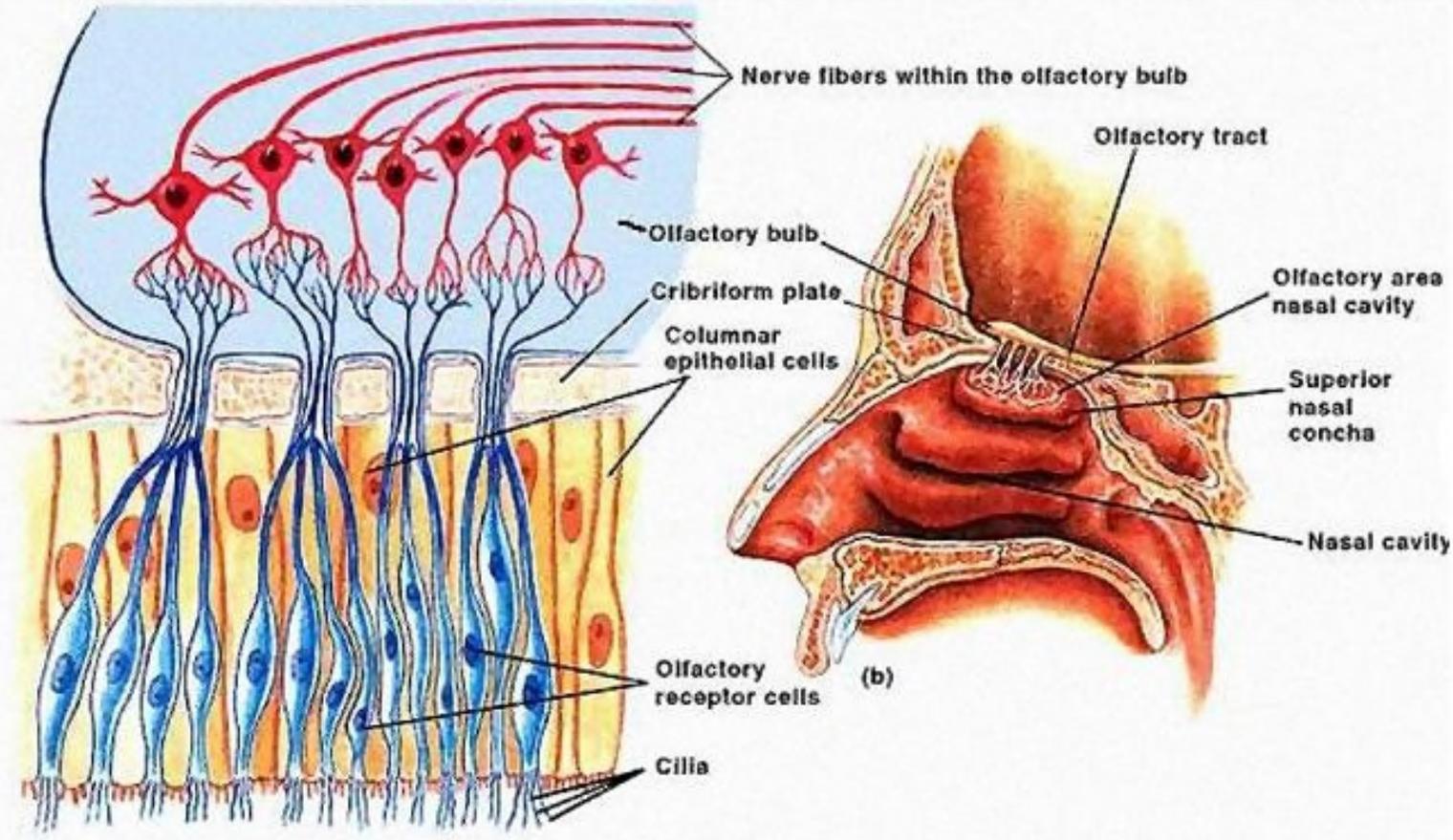
# Symptomcentric Concept of the Concussions

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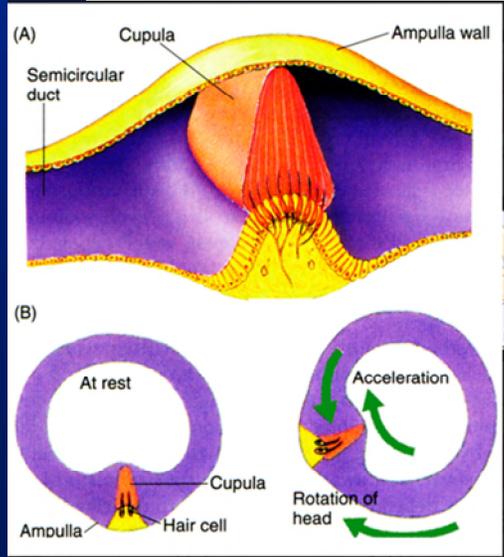
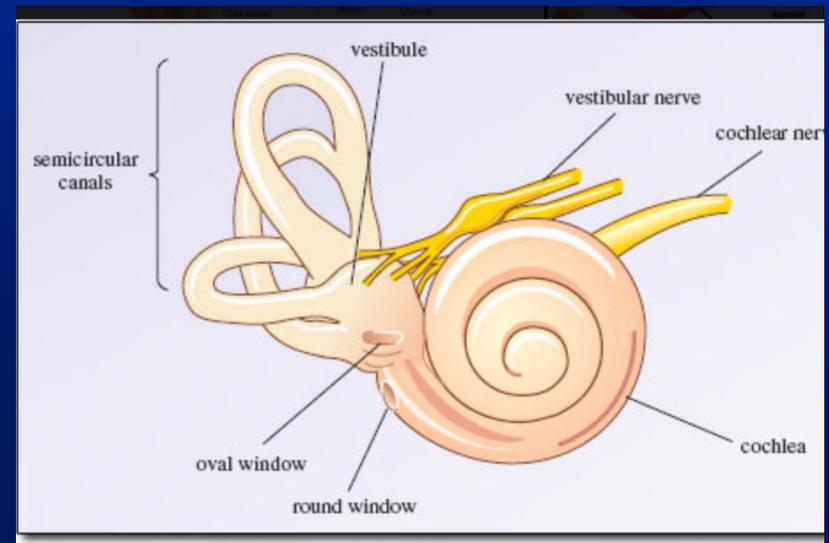
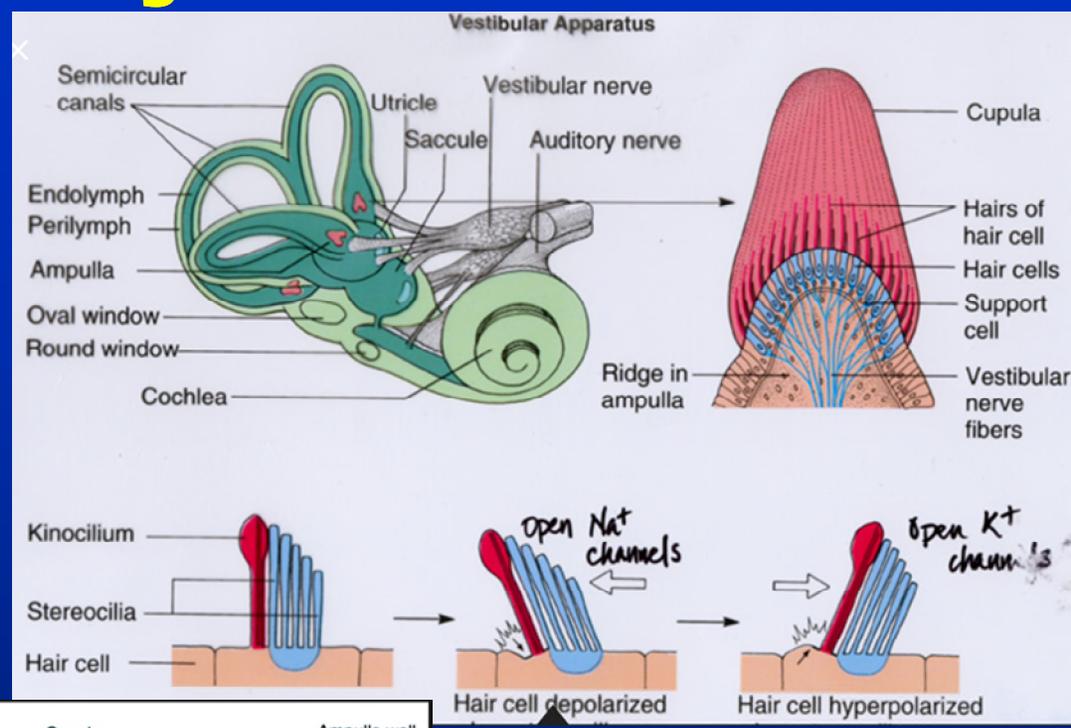
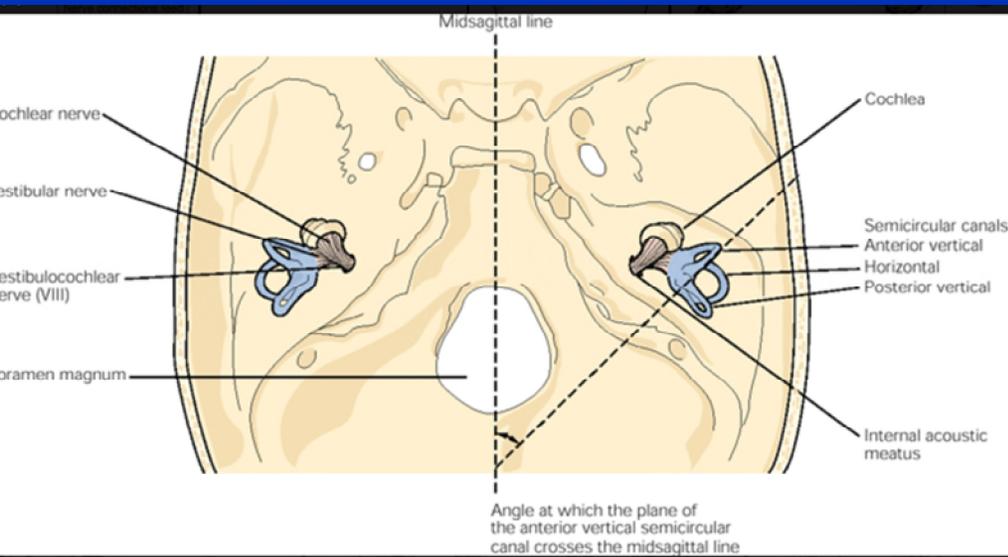


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# Olfactory Concussion

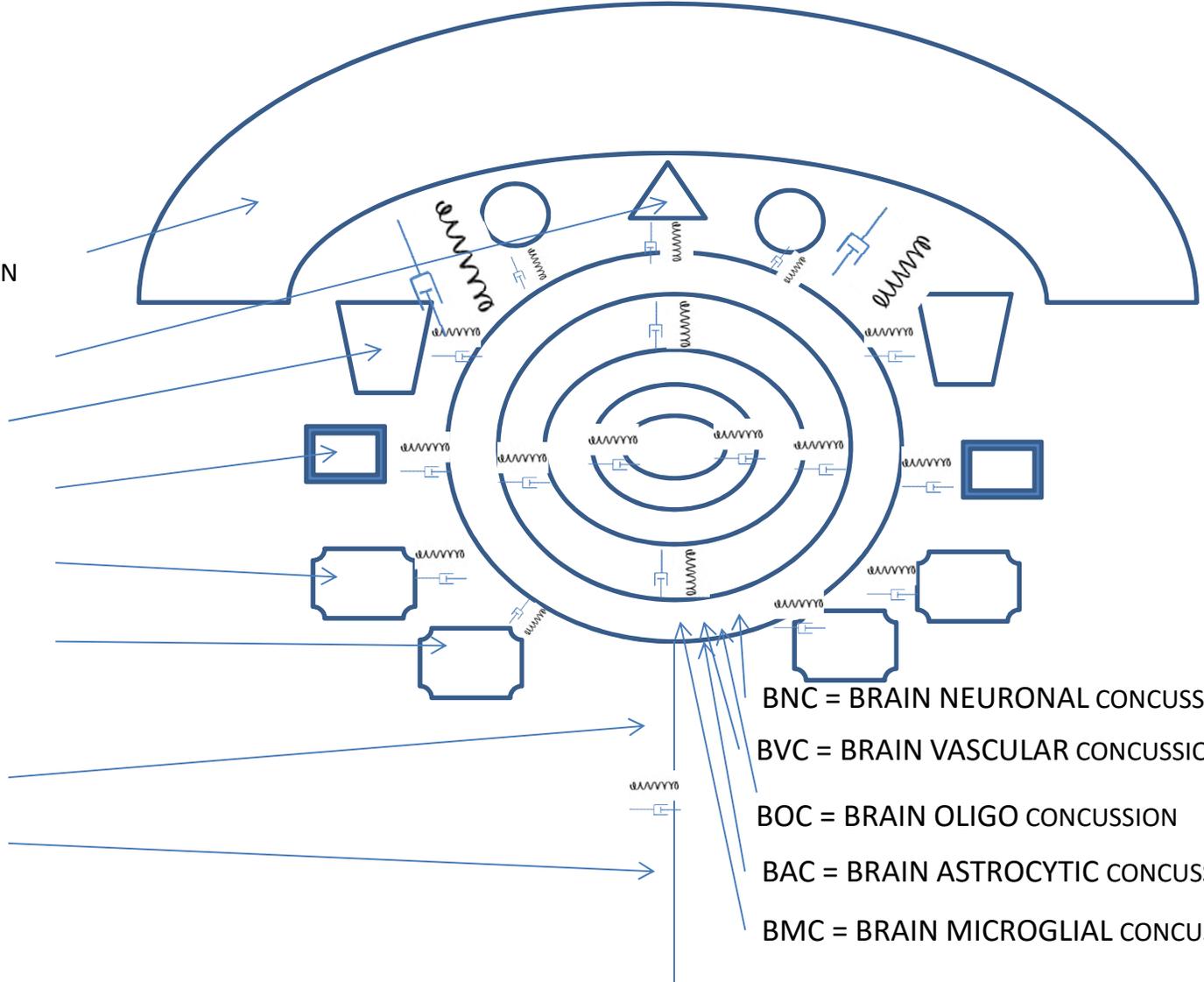


# Vestibular-Auditory Concussion



# Symptomcentric Concept of the Concussions

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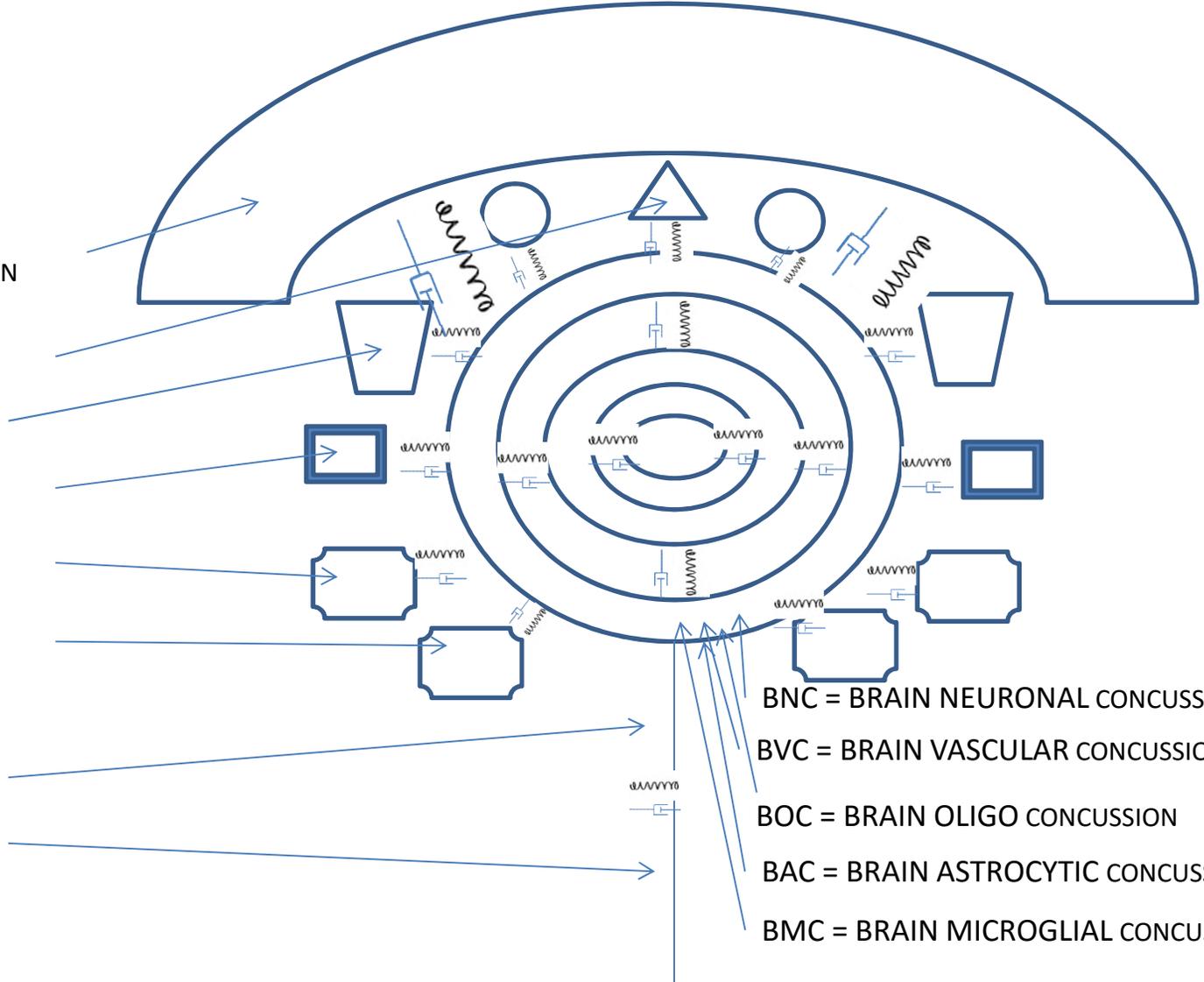


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**These can occur singly or in any combination**

# Symptomcentric Concept of the Concussions

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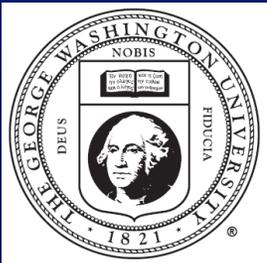
Some can occur by angular OR translational motions

# Thanks to my many collaborators over the years

- **Medical School:** 1968 Tony Raimondi, Don Matson
- **NIH:** 1970-72 Ayub Ommaya
- **Univ Pennsylvania:** 1976-1995
  - Larry Thibault
  - Tom Langfitt, Walter Obrist many residents and students
- **Glasgow University:** 1976-2006
  - Hume Adams, David Graham
- **MCW:** 1999-2011
  - Narayan Yoganandan, Frank Pintar, Jianrong Li, Jiangyue Zhang

**Thanks for your attention...And  
now, the rest is in your hands!**





Gennarelli

