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Non-visual Spatial Orientation Mechanisms

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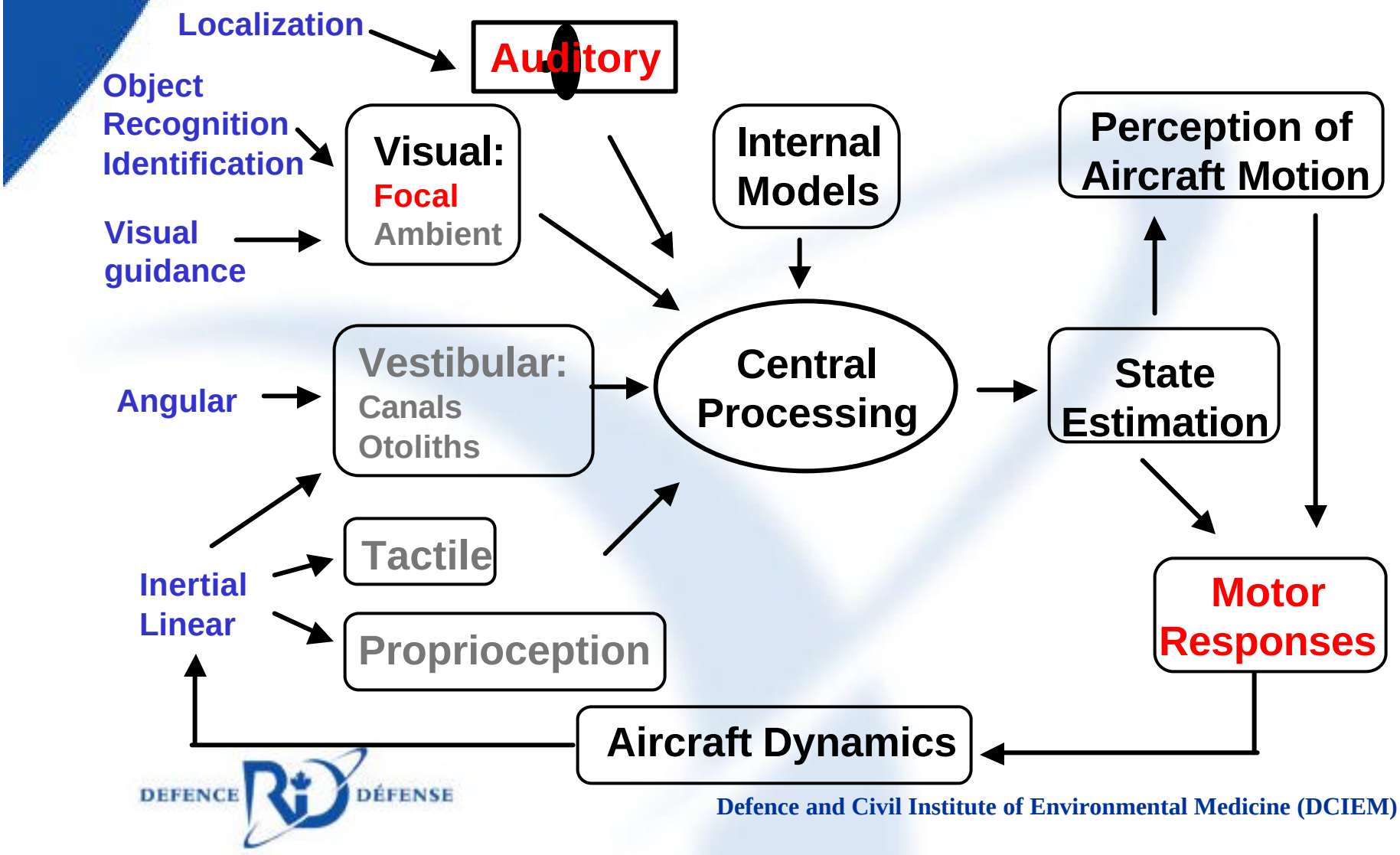
Canada

Spatial Orientation in Flight



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Auditory Input to Orientation

- Binaural sound localization is of limited use.
  - High ambient noise.
  - Internal sound reflection.

- Aircraft position and flight trajectory - over R/T.

- Noise generated from boundary layer and engine.

  - Perception of velocity - frequencies and intensities of airspeed.
  - Perception of pitch attitude - angle of attack.

Acoustic Orientation Research

- Stereophonic acoustic orientation cues (auditory lateralization)
  - control of aircraft bank angles (Lyons et al. 1990, Tea 1993)

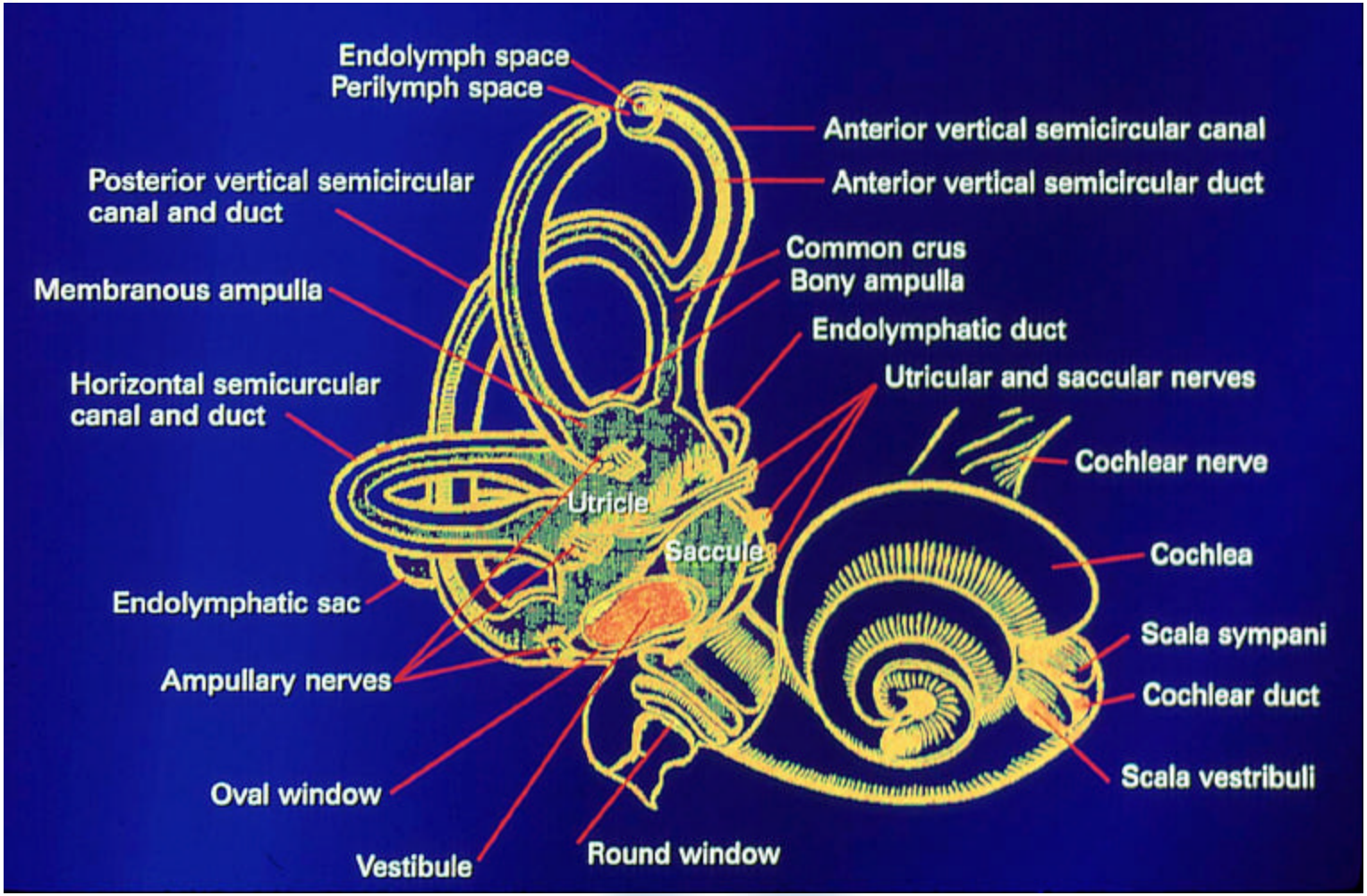
- 3-dimensional auditory displays as acoustic attitude indicator.

  - effective as a radar display when paired with 2D visual display (Bronkhorst et al. 1997; Veltman et al. 1996)

  - enhancement in target acquisition and spatial awareness (McKinley 1997)

  - degraded accuracy in the F/B and U/D dimensions in applied settings (Gilkey et al. 1996)

  - no effects on spatial SA (Oving et al. 1998)



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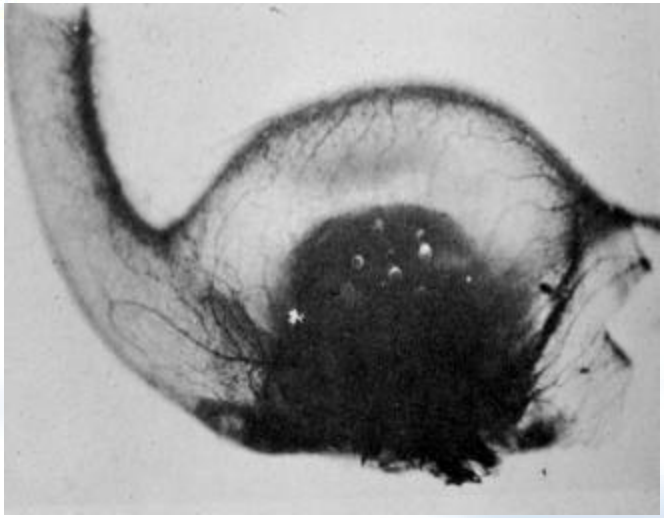
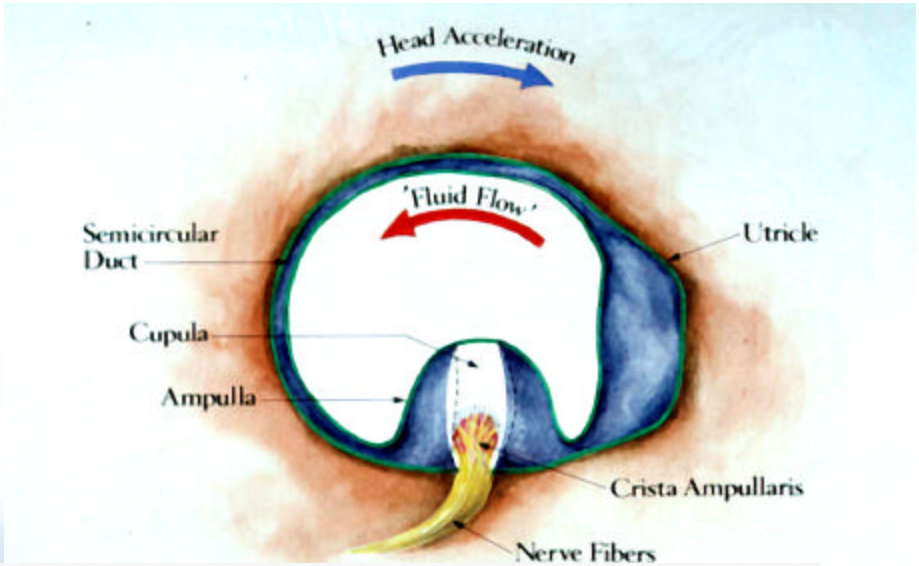
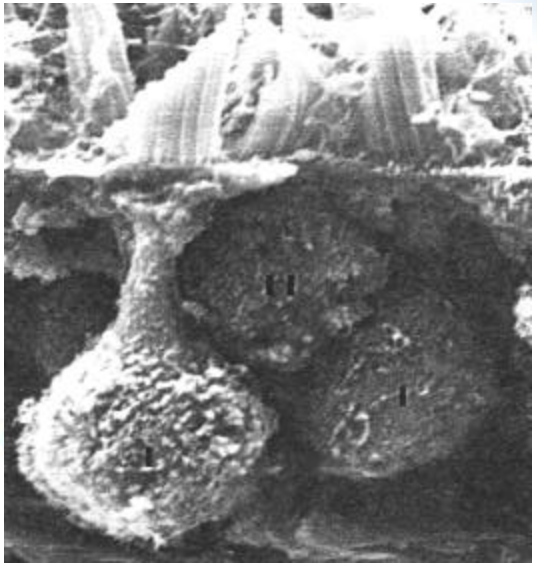
Force acting on cupula is ? ?

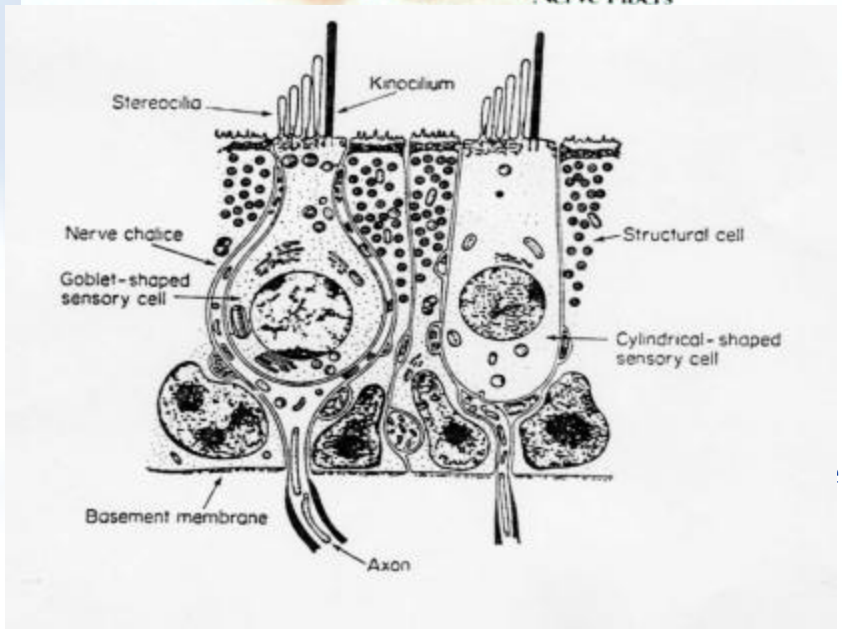
? ? ? ? ? + ? (d?/dt) + ? ($d^2?/dt^2$)

During normal head rotation, canals are integrating accelerometers.



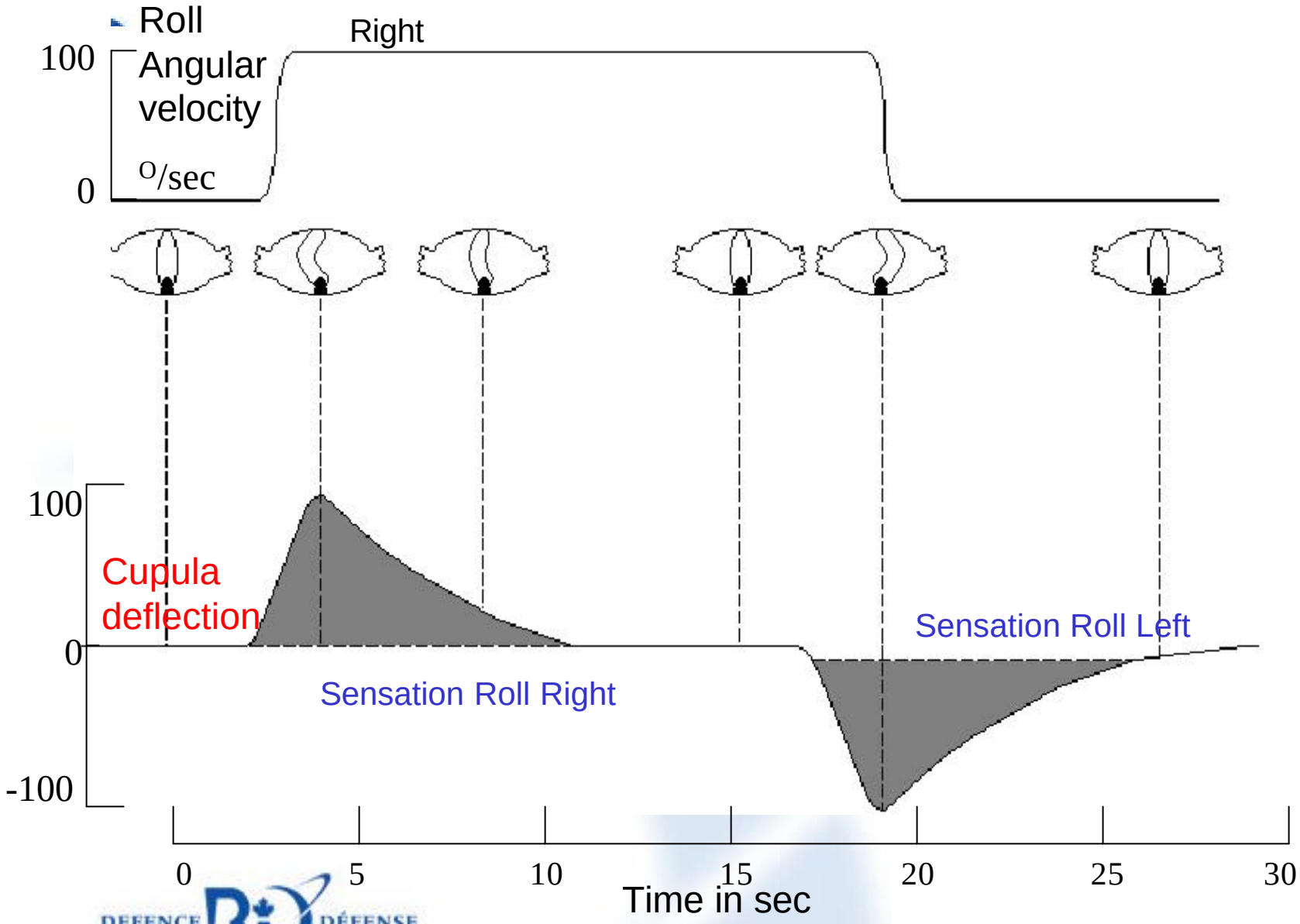






(DCIEM)

Hydrodynamic Properties of Canal-Cupula-Endolymph System



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Post-Rotational Decay

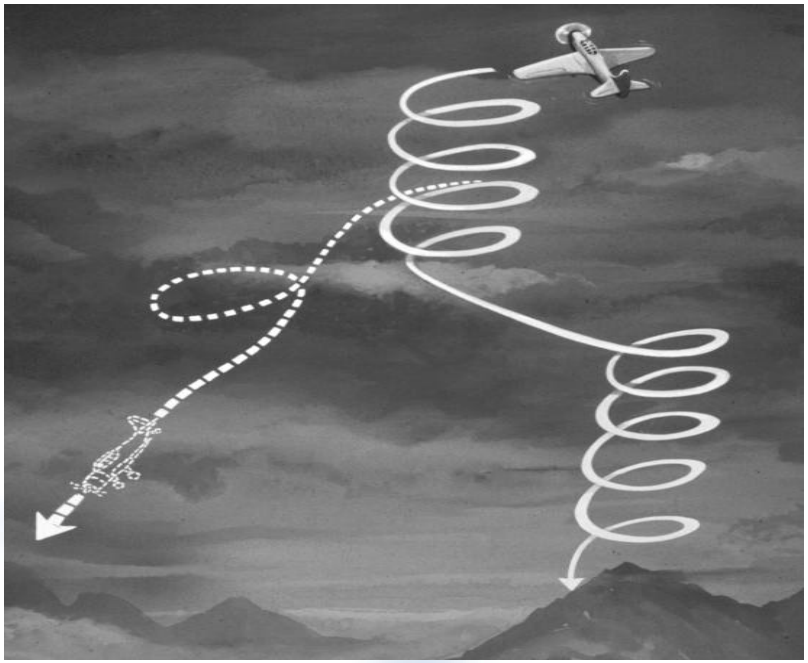
- Post-rotational decay in Roll (4s) < Pitch (7s) < Yaw (16s), measured from:
  - Duration of post-rotational decay of the resulting illusory sensation of rotation (Melville Jones et al. 1964, Guedry et al. 1971)
  - Time course of slow phase velocity of compensatory nystagmus (Melvill Jones et al. 1964)
- Greater rate of error development in roll than in pitch and yaw.

Semicircular Canal Inadequacies

- Limited threshold of vestibular perception 0.14, 0.5 and 0.5°/s^2 for yaw, roll and pitch respectively.
- Perceived angular velocity is less than the actual angular velocity.
- Absence of sensation of rotation during constant velocity rotation.
- Apparent sensation of rotation in the opposite direction during deceleration.
- Persistent apparent sensation of rotation in the opposite direction, after physical rotation has actually stopped.
- Greater rate of error development in roll > pitch > yaw.

Somatogyral Illusions

False sensation of rotation or absence of rotation results from misperceiving the magnitude or direction of an actual rotation.



Graveyard Spin

Gillingham Illusion - Post roll effect on attitude perception (Ercoline et al. 2000)

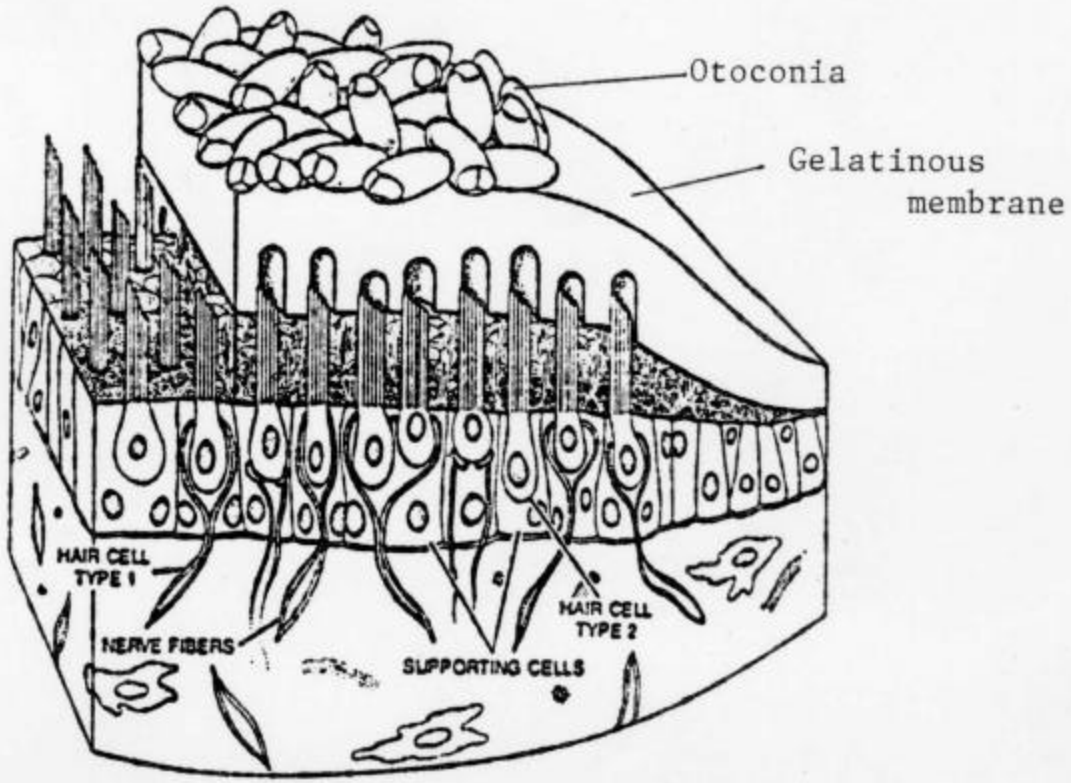
Coriolis Cross Coupling Effect

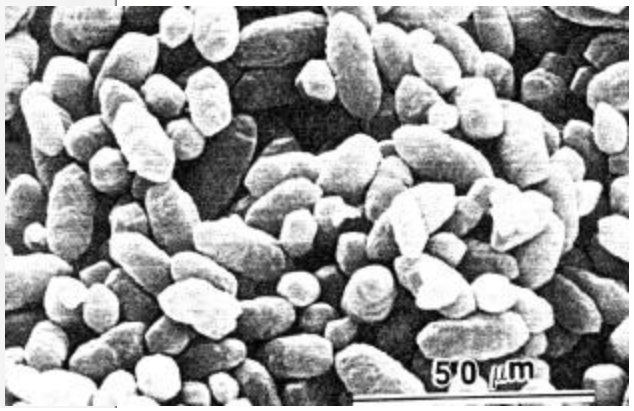
- Interaction between the inertia, viscosity of the endolymph, and the elasticity of the cupula of the orthogonal semicircular canals.

- Disorientation produced by head movements in flight may be a combination of cross-coupled and G-excess illusion (Benson 1999)
  - can be induced in high agility flights without head movements (Pancratz et al. 1994)

- Coriolis induced forearm and calf blood flow increase.
  - peripheral pooling of blood (Sunahara et al. 1965; Sinha 1974; Cheung et al. 2000)
  - potential cause of reduced tolerance to subsequent G forces.

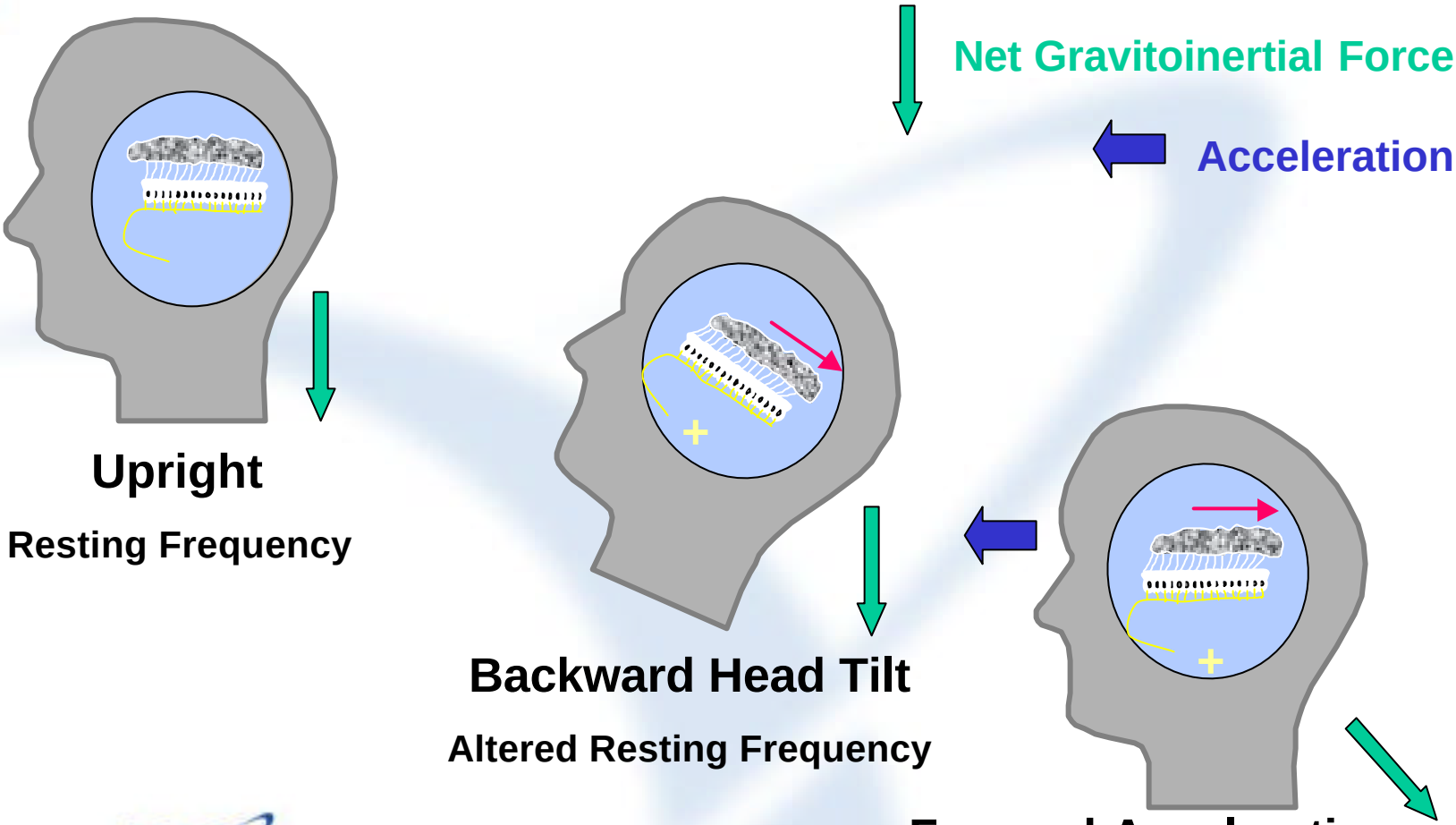
Utricular Macular Epithelium





? ? ? ? ? ? ?? ?d? ?dt) + m ?d^2? ?dt^2)

Otolith Ambiguity In Sustained Acceleration



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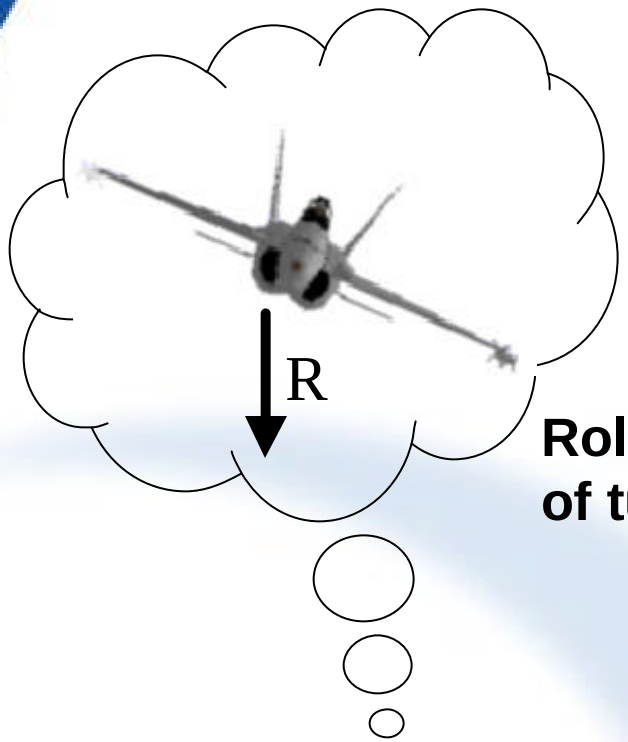
Otolith Deficiencies

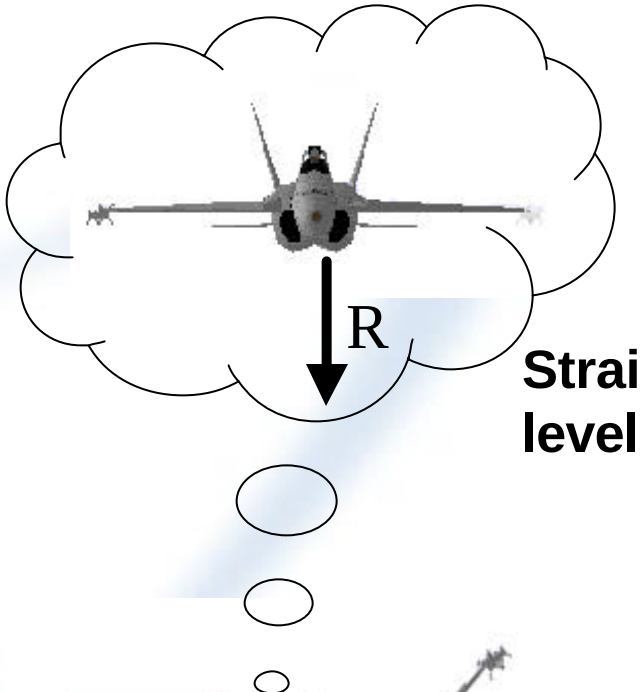
- Inherent inability to distinguish between gravity and linear acceleration.
- Interpretation of otolith signals rely almost entirely on the direction and not the magnitude of the applied GIF.
- Otolith organs are only accurate for determining the direction of the vertical with the head upright pitched forward 25°.
- Limited threshold (Y and X = 0.005-0.01G; Z = 0.01-0.1G)
- Higher threshold and greater error in detecting vertical motion.

False Perception of Attitude During Turns

Interprets sustained resultant with earth vertical



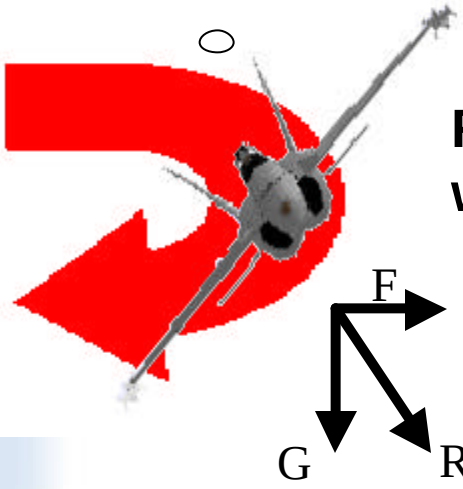
Rolled out of turn



Straight and level

Flat turn

Coordinated bank turn



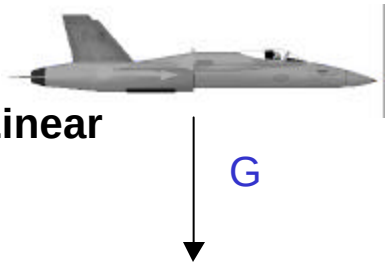
R aligns with Z

False Sensation of Pitch during Forward Acceleration

Aircraft Motion and Attitude

Perception of attitude, relative to true vertical

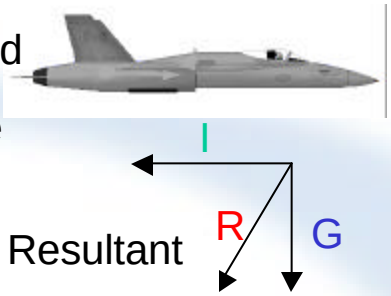
Constant Linear Speed



Acceleration

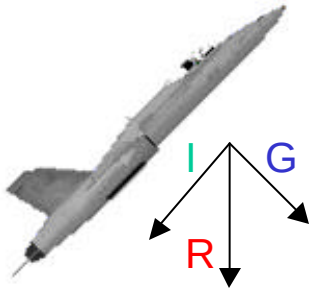
Increase in speed

Inertial force due to acceleration



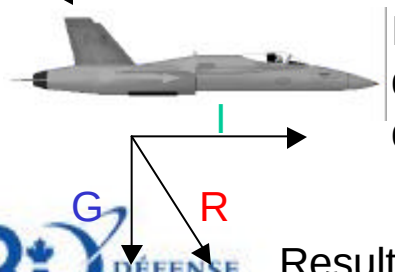
Resultant

Perceiving a non-vertical resultant force as vertical



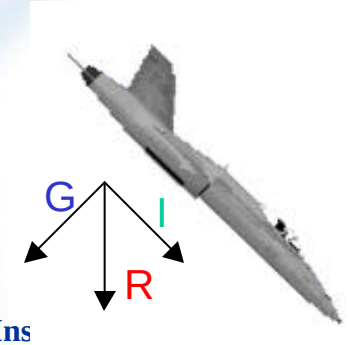
Deceleration

Decrease in speed



Inertial force due to deceleration

Resultant



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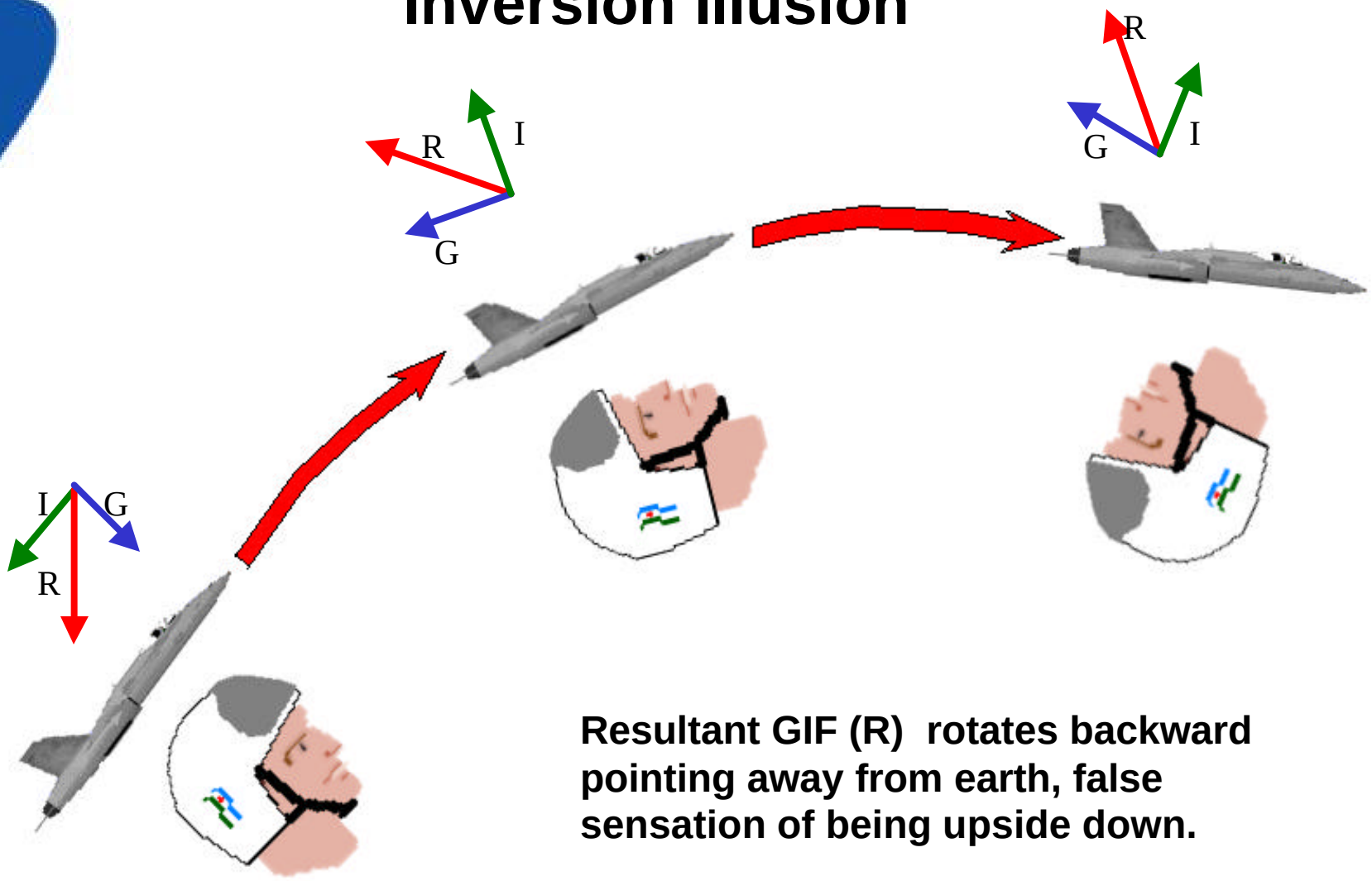
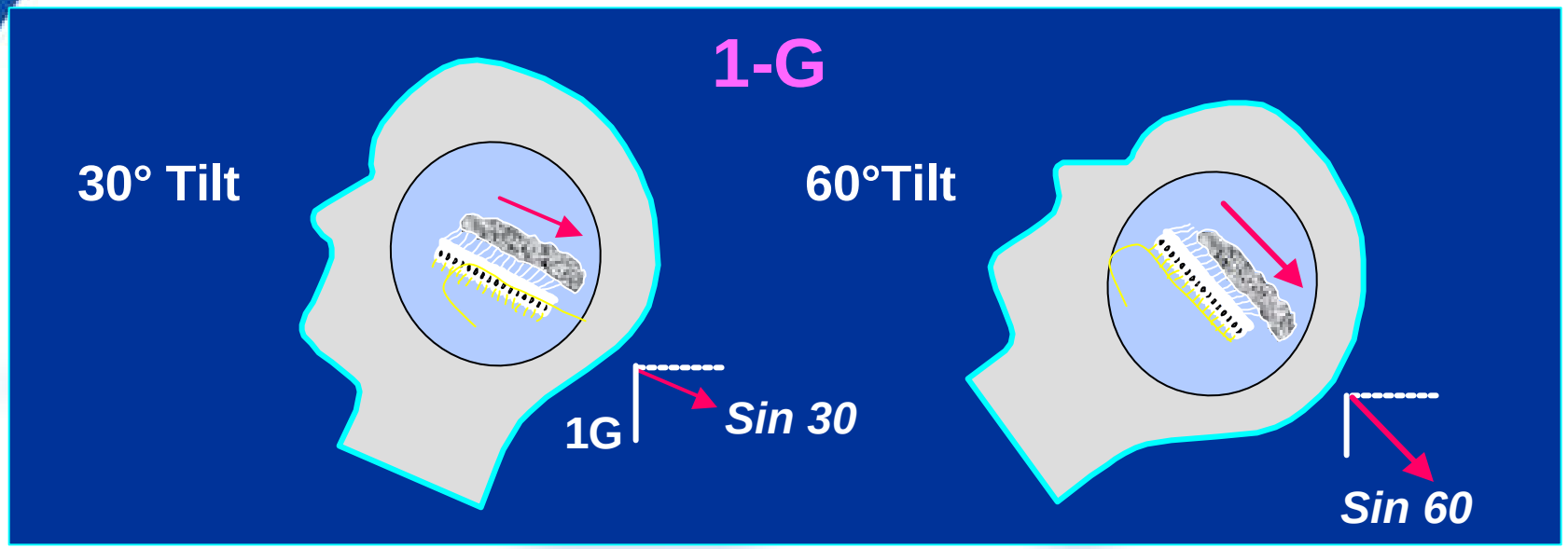
Inversion Illusion

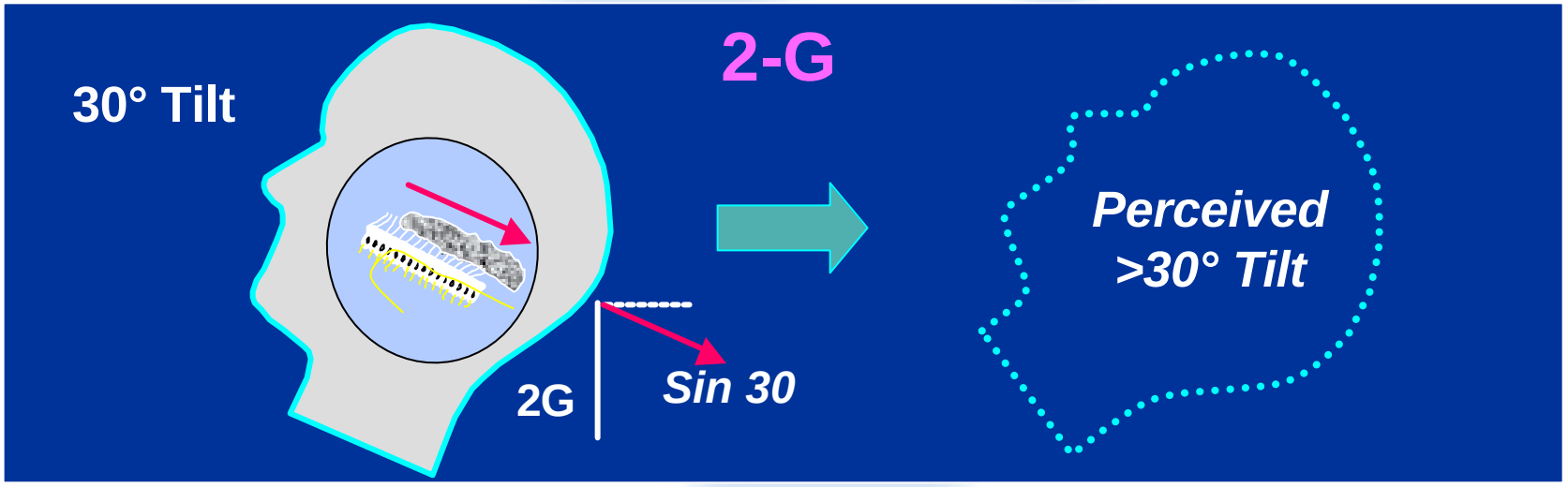


Resultant GIF (R) rotates backward pointing away from earth, false sensation of being upside down.

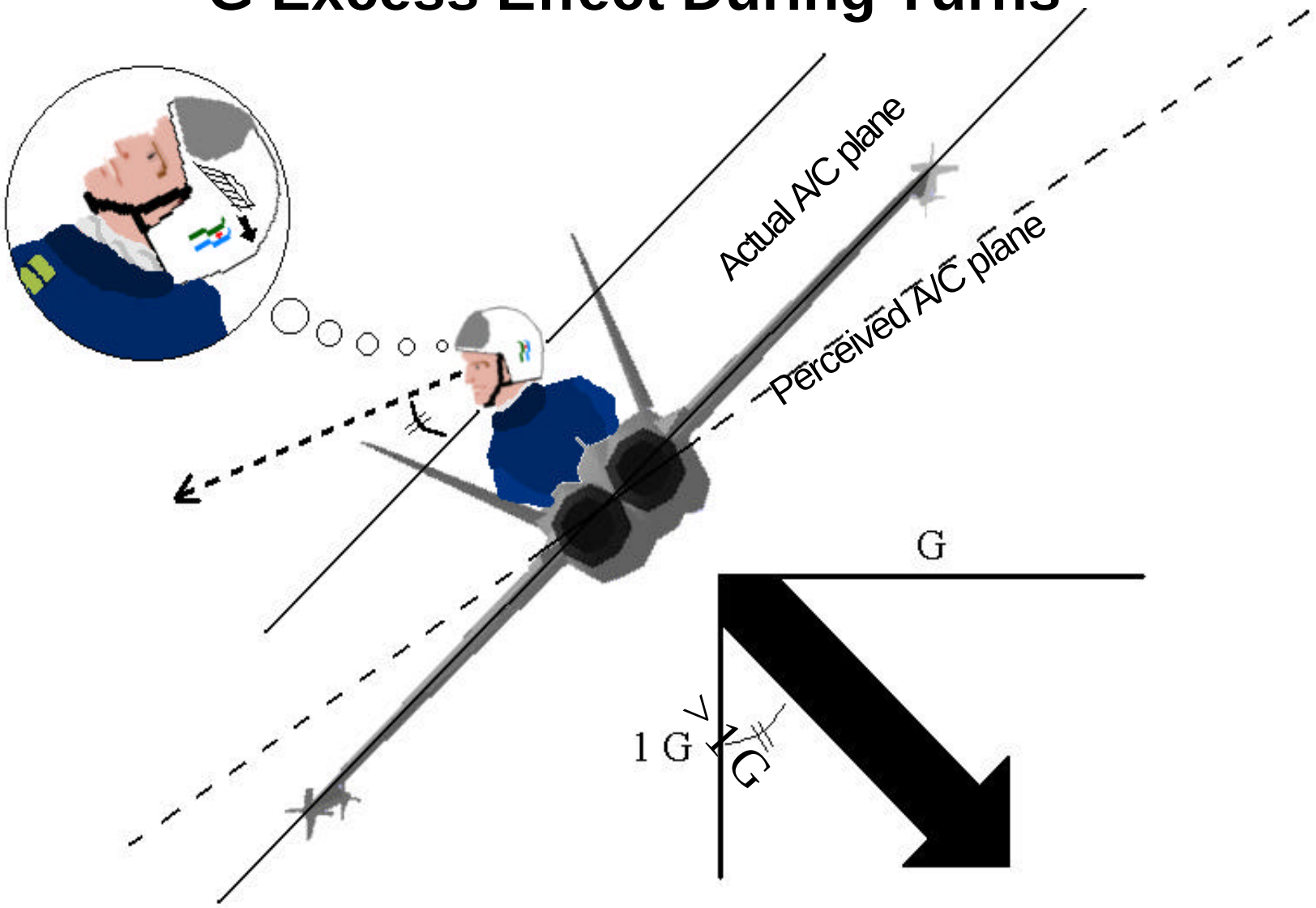
G-Excess Tilt Illusion

An exaggerated sense of body tilt that occurs when G > 1.





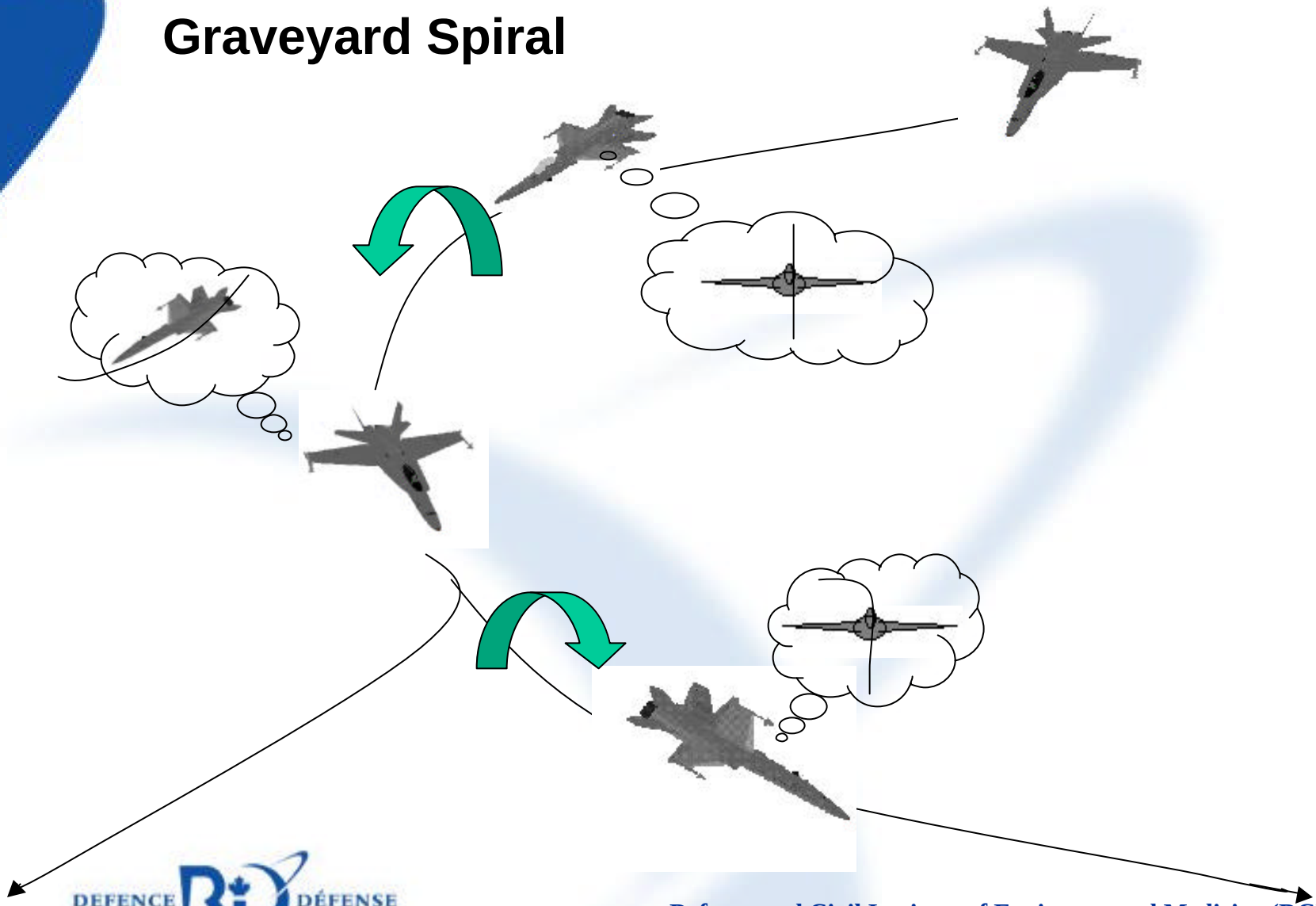
G Excess Effect During Turns

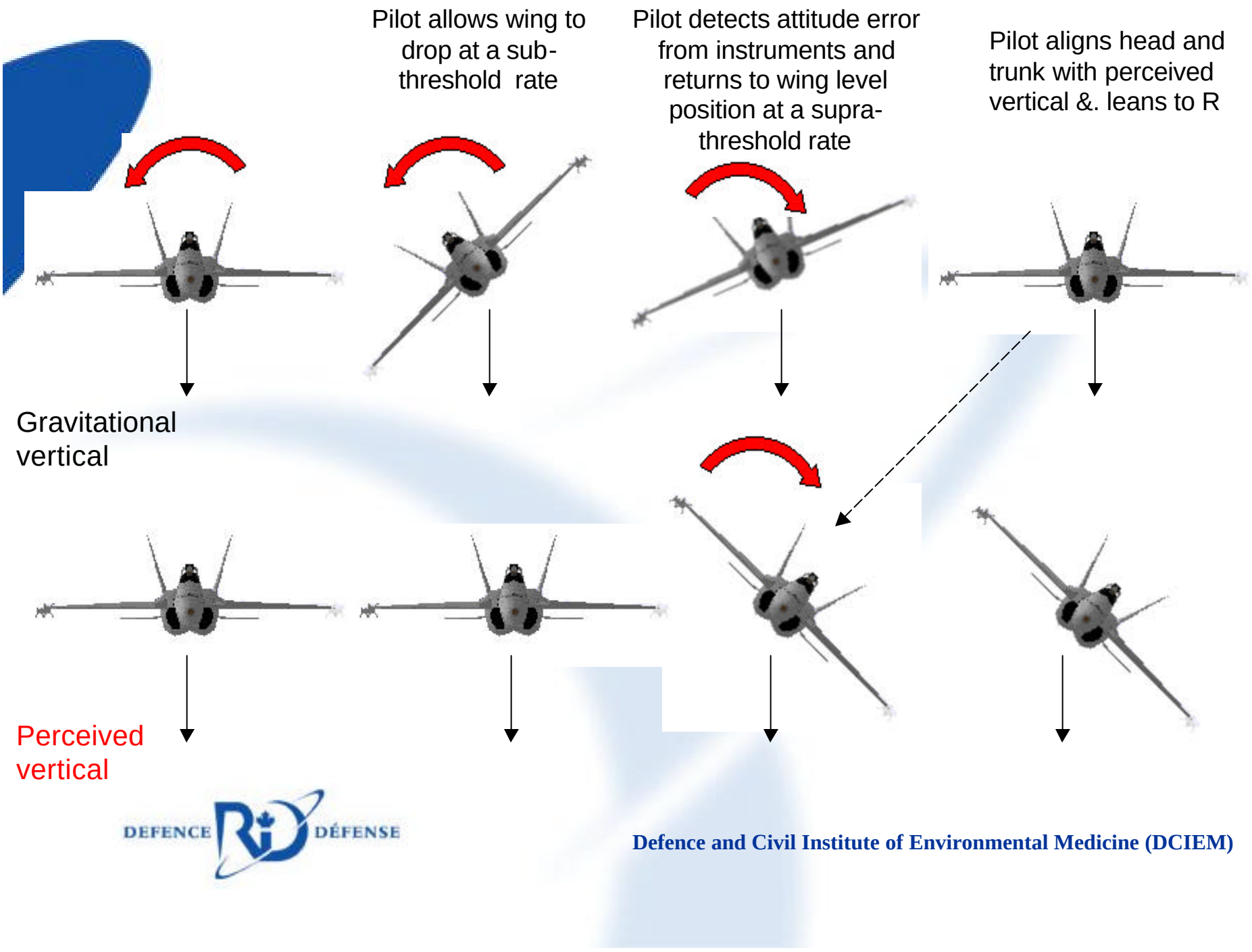


Under-bank illusion when facing inside of turn and head elevated,

Pitch up illusion when facing forward during turn (Gillingham and Previc 1993)

Graveyard Spiral





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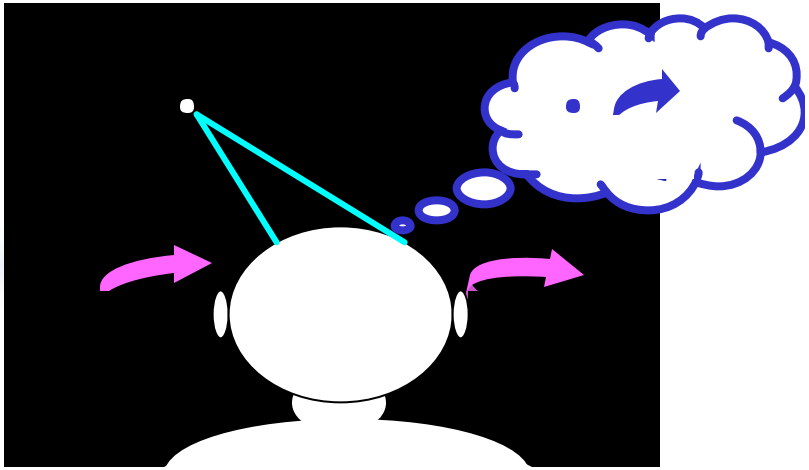
Visual Localization Errors

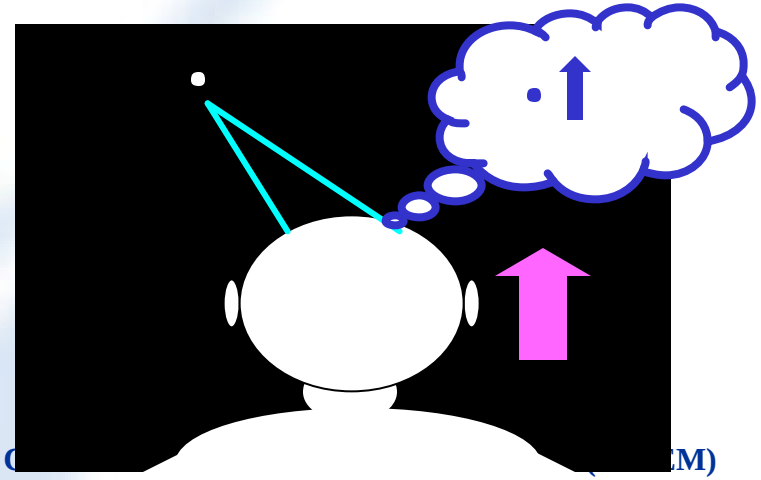
• When external visual cues are ill defined:

• Oculogyral Illusion Is the apparent displacement of body-fixed objects in the direction of perceived bodily rotation.



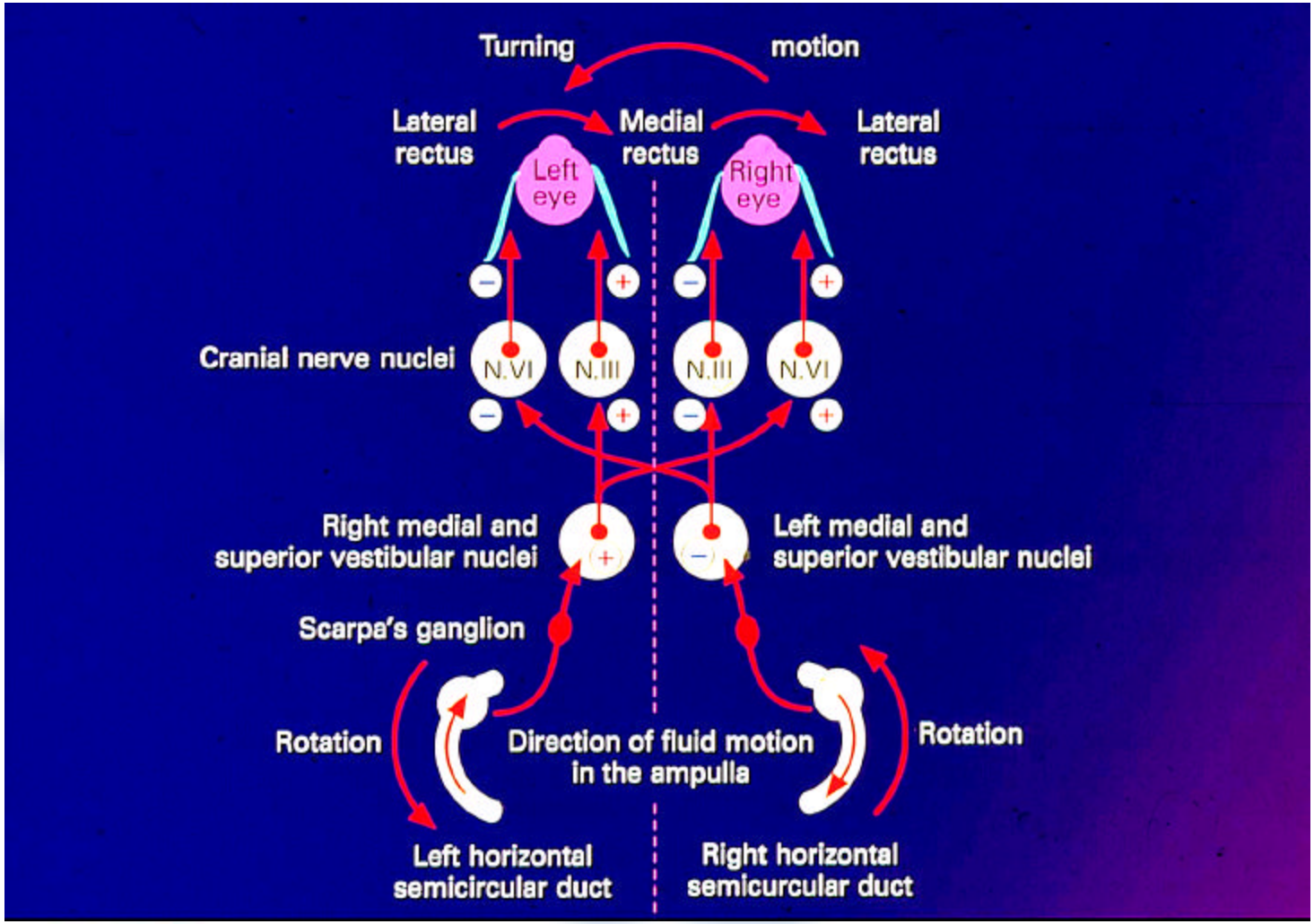
Oculogyral Illusion

• Oculogravic Illusion Is the apparent tilt of the visual field experienced during exposure to altered GIF.

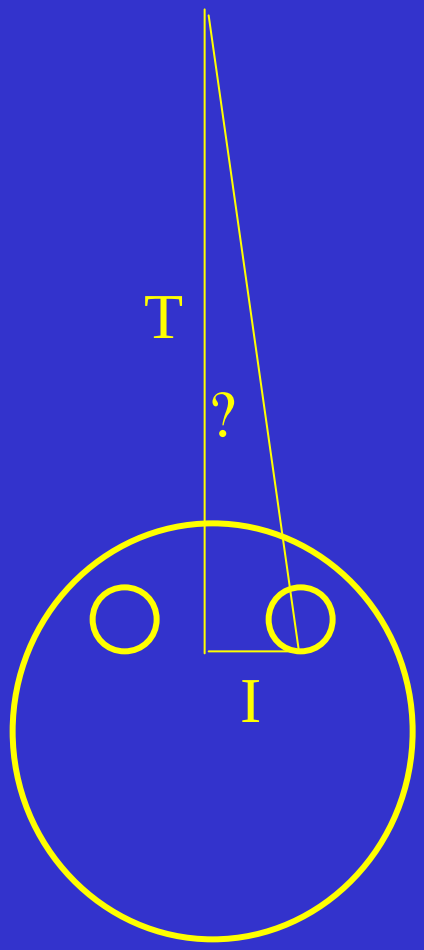


Oculogravic Ilusion

Angular Vestibulo-Ocular Reflex (aVOR)



Geometric Requirements of Target Distance on the translational VOR (tVOR)



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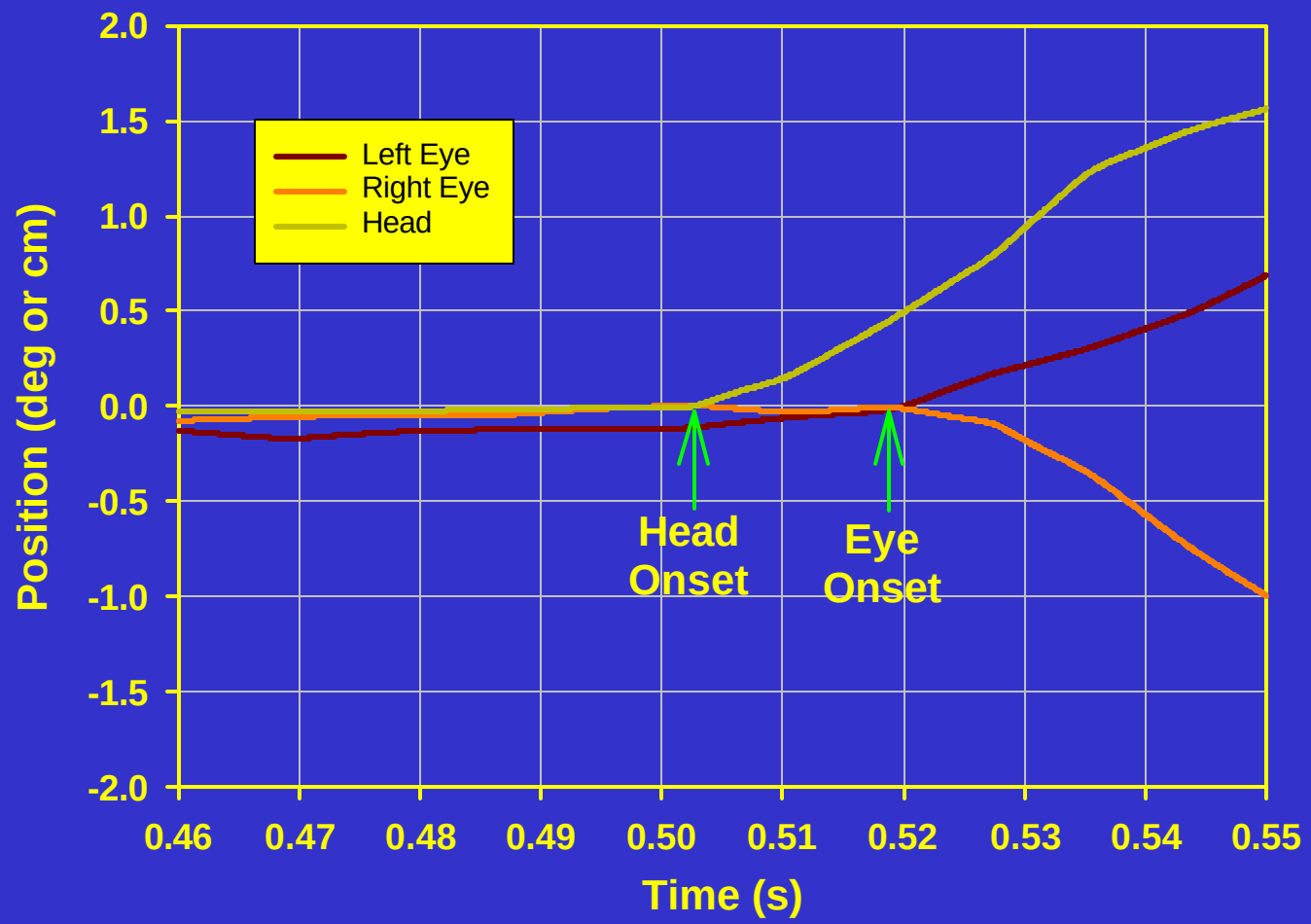
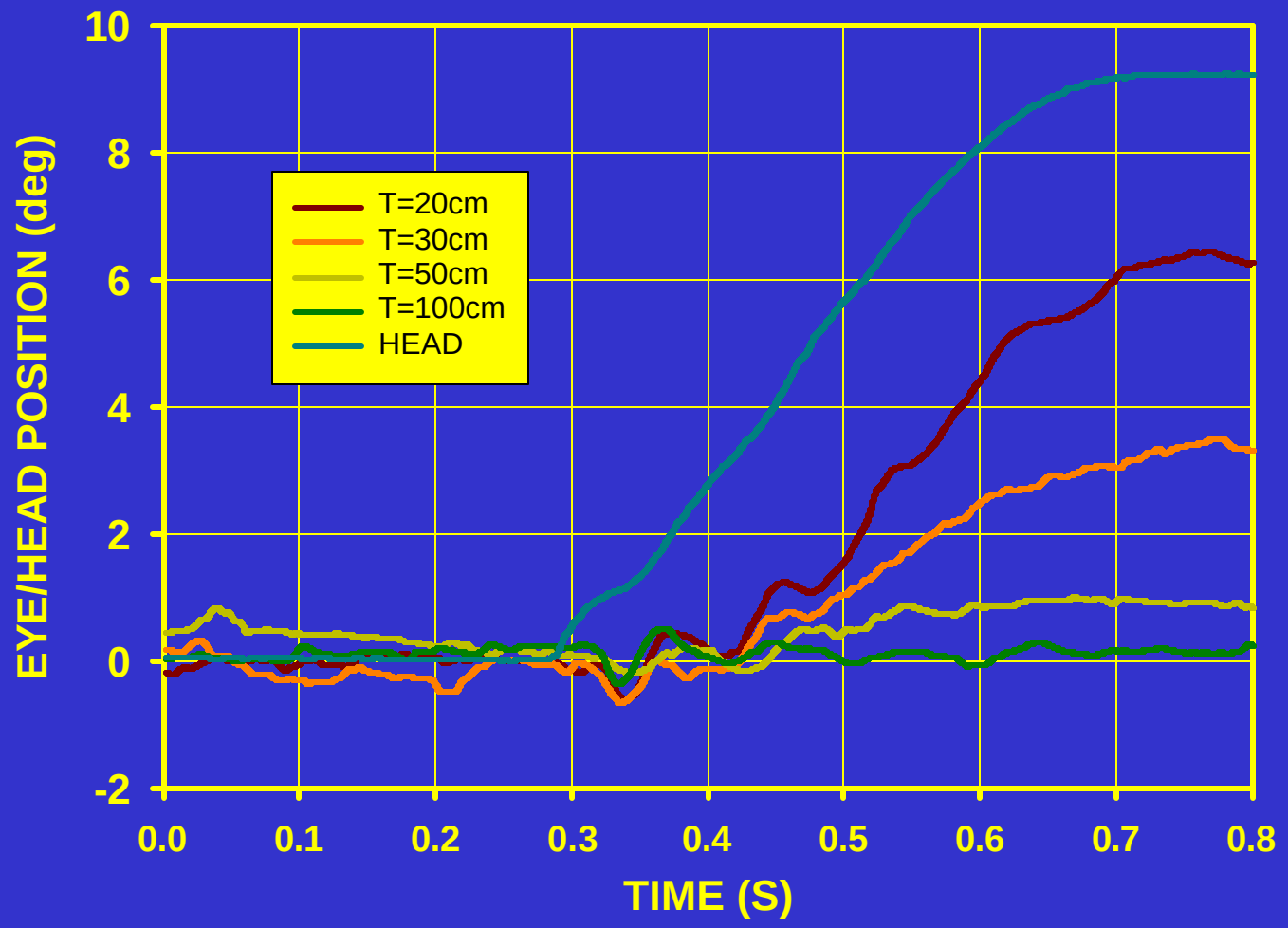
Thus, the closer the target, the larger the required eye movement.

Latency of the tVOR



Target Distance Effects on Evoked Eye Movements



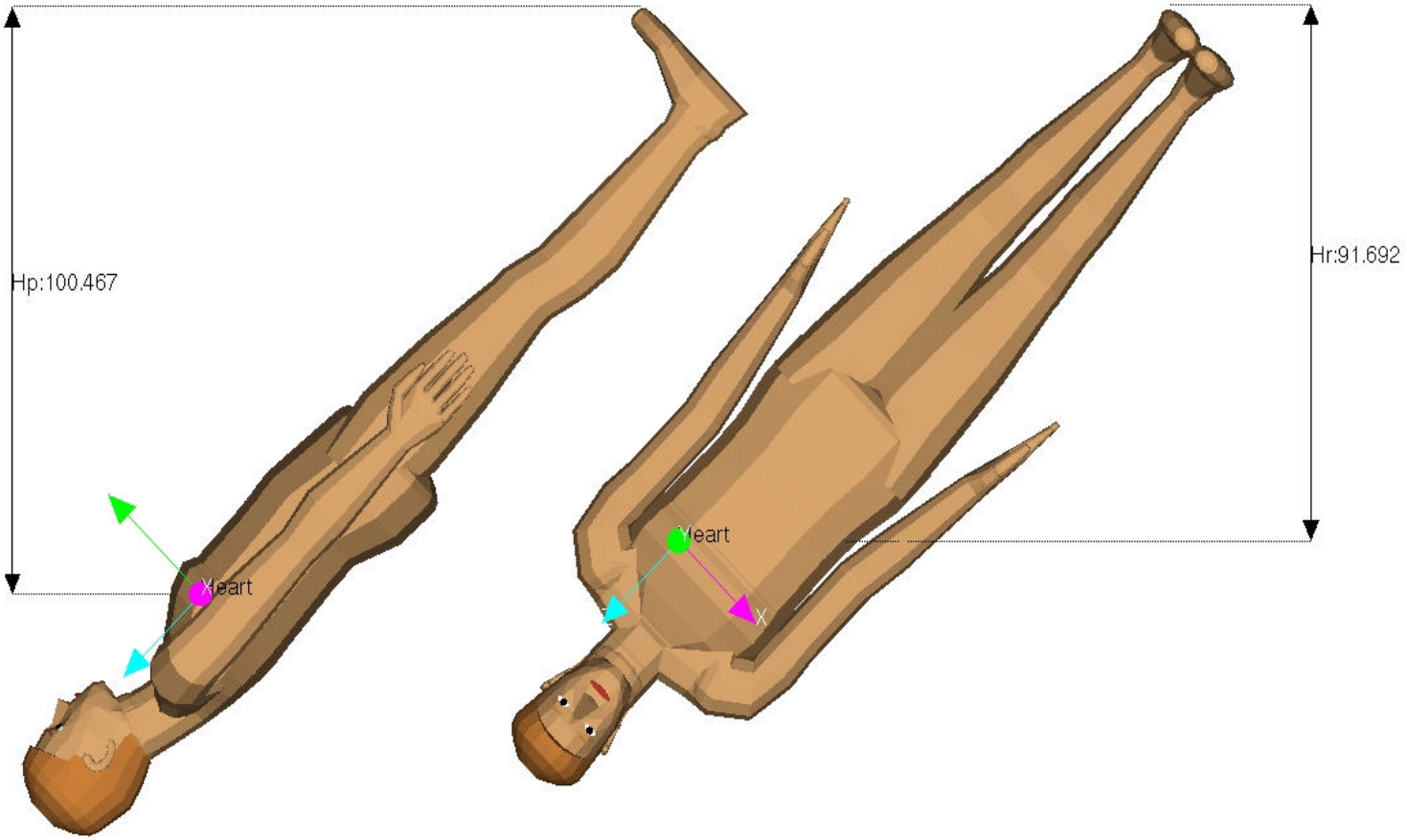
Vestibulo-Sympathetic Reflex

- In cats, pitch up produces an increase in sympathetic activity. No activity during roll or yaw. Response characteristics are similar to those of otolith afferents (Yates and Miller 1994; Yates 1996)

- Bilateral transection of the vestibular nerves caused larger drops in blood pressure during nose-up pitch than cats with intact vestibular inputs (Woodring et al. 1997)

- Increasing evidence to support the hypothesis that the vestibular system contributes to maintaining blood pressure during movement and changes in posture (Shortt and Ray 1997; Hume and Ray 1999; Radtke et al. 2000)

- In humans, better cardiovascular compensation in pitch-induced OH than roll-induced OH (Cheung et al. 1999)



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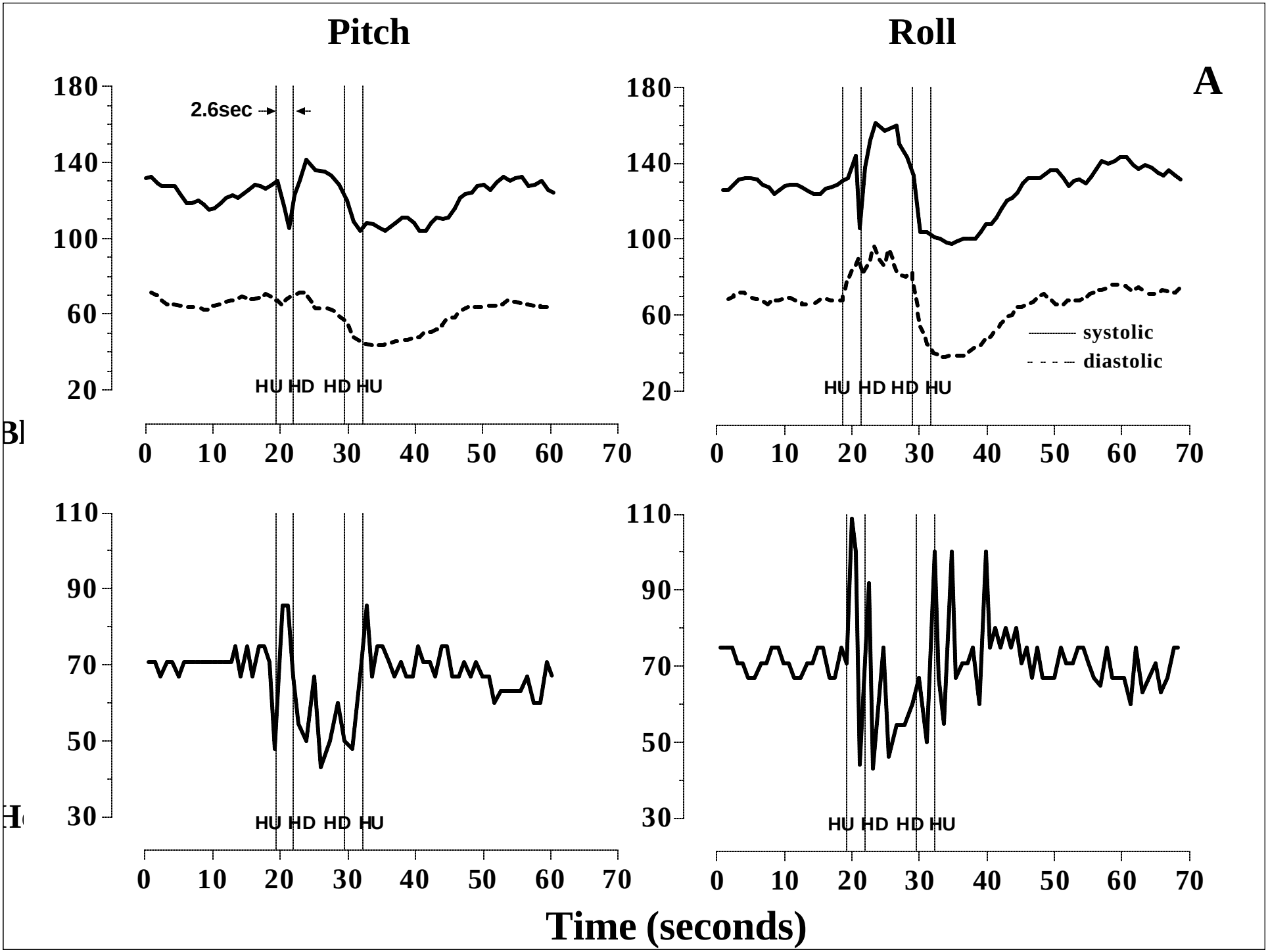
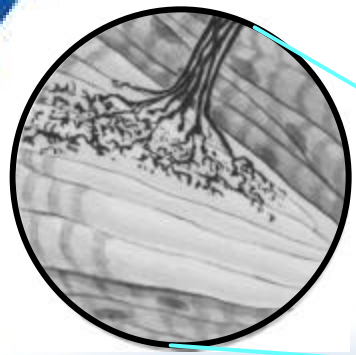

Pitch
Roll
A
180
140
100
60
20
2.6sec
HU HD HD HU
systolic
diastolic
110
90
70
50
30
0 10 20 30 40 50 60 70
Time (seconds)

Other Reflexes

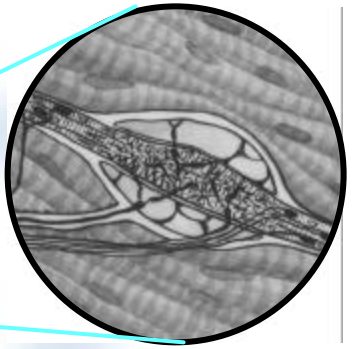
- Vestibulo-Collic Reflex - influences neck musculature to stabilize the head and visual field.
- Optokinetic Cervical Reflex - natural head tilt during bank, an apparent attempt to align the eyes with the visible horizon.
- Vestibulo-Spinal Reflex - acting on limb muscle control in conjunction with limb reflexes to stabilize the body.
- Different after-effects of active vs. passive rotation.

Other Proprioceptors and Tactile Sensors

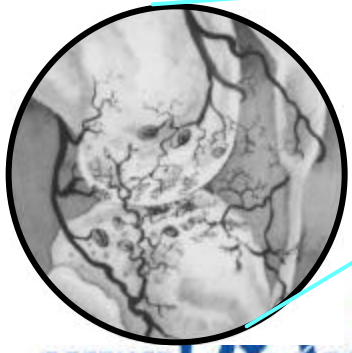
- Complement the dynamic component of the otolith.
- Influence the interpretation of other sensory signals through expectation.



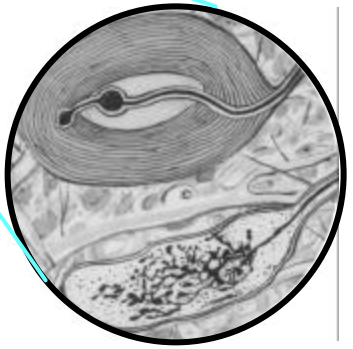
Golgi Tendon Organ



Muscle Spindle Organ



Joint Receptor



Pacinian Corpuscle

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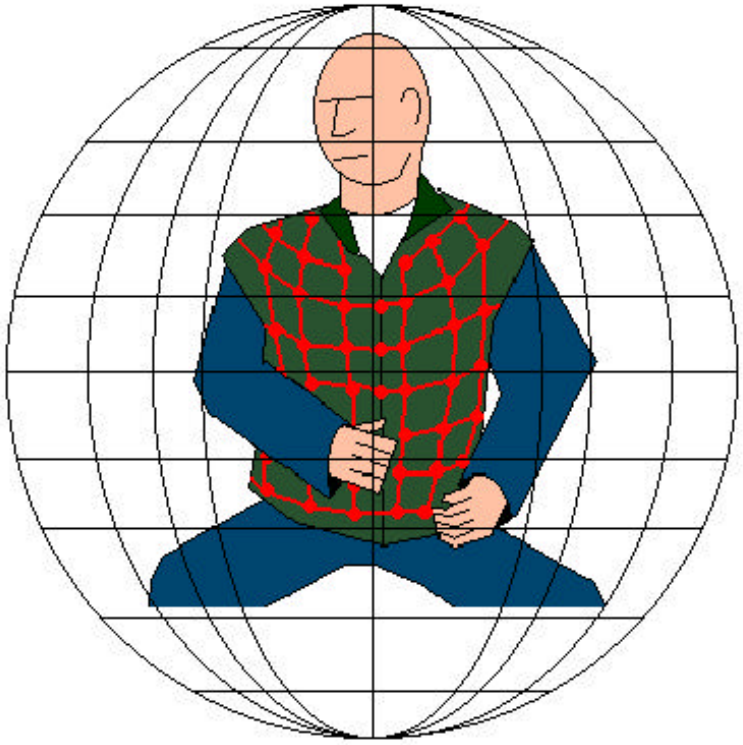
Tactile Situation Awareness System™

- Torso harness fitted with multiple electromechanical stimulators to continuously update pilot's awareness of position (Rupert 2000).

- Resolution?

- Rate at which tactile data can be utilized?

- Conflict resolution between tactile and other sensory cues?



- Performance under G?

- GIF influence on somatosensory midline localization (Lackner and Dizio 2000)

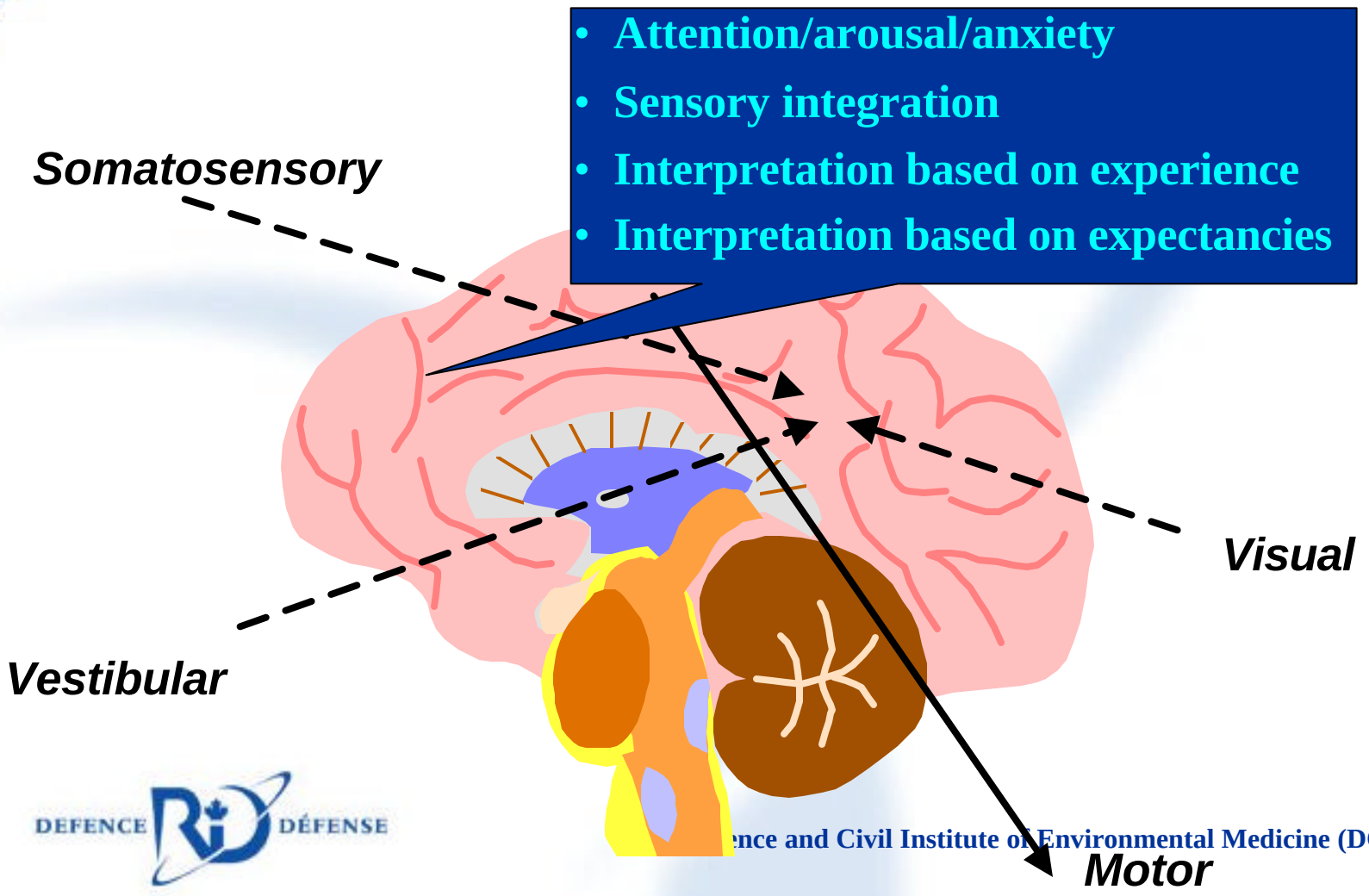
Altered Sensory Motor Control

- Unusual GIF impose altered sensory motor control demands on the coordination of body postures and movements.

- Non 1G force levels lead to alterations in the effective weight of the head and body (Lackner & Dizio 1989) which in turn may alter:

  – visual localization (Dizio & Lackner 1990)
  – manual-control bias (Previc & Donnely 1993)

Cognitive Factors



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