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Sensorimotor transformation: lessons from the neurophysiological study of visually-guided eye movements

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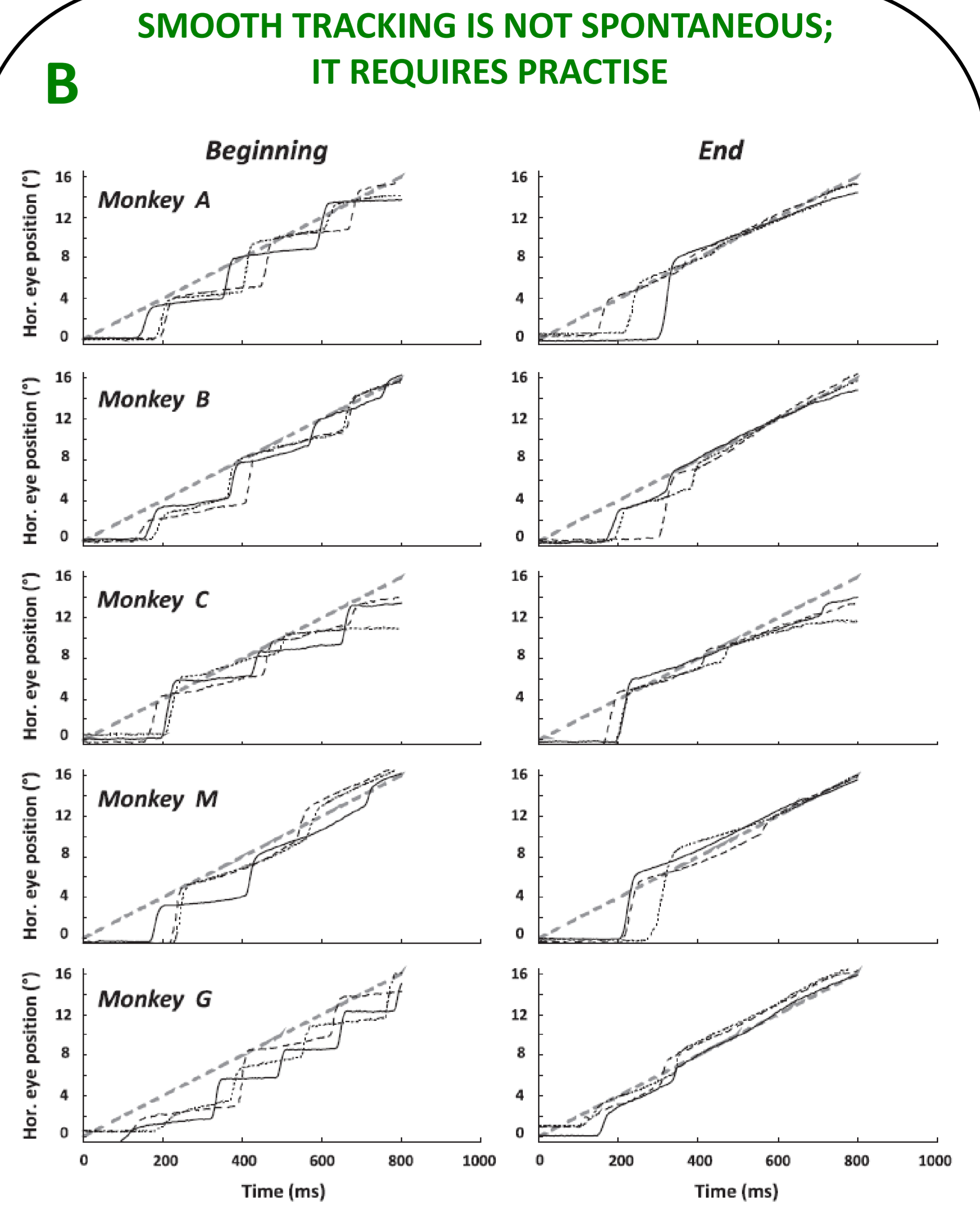
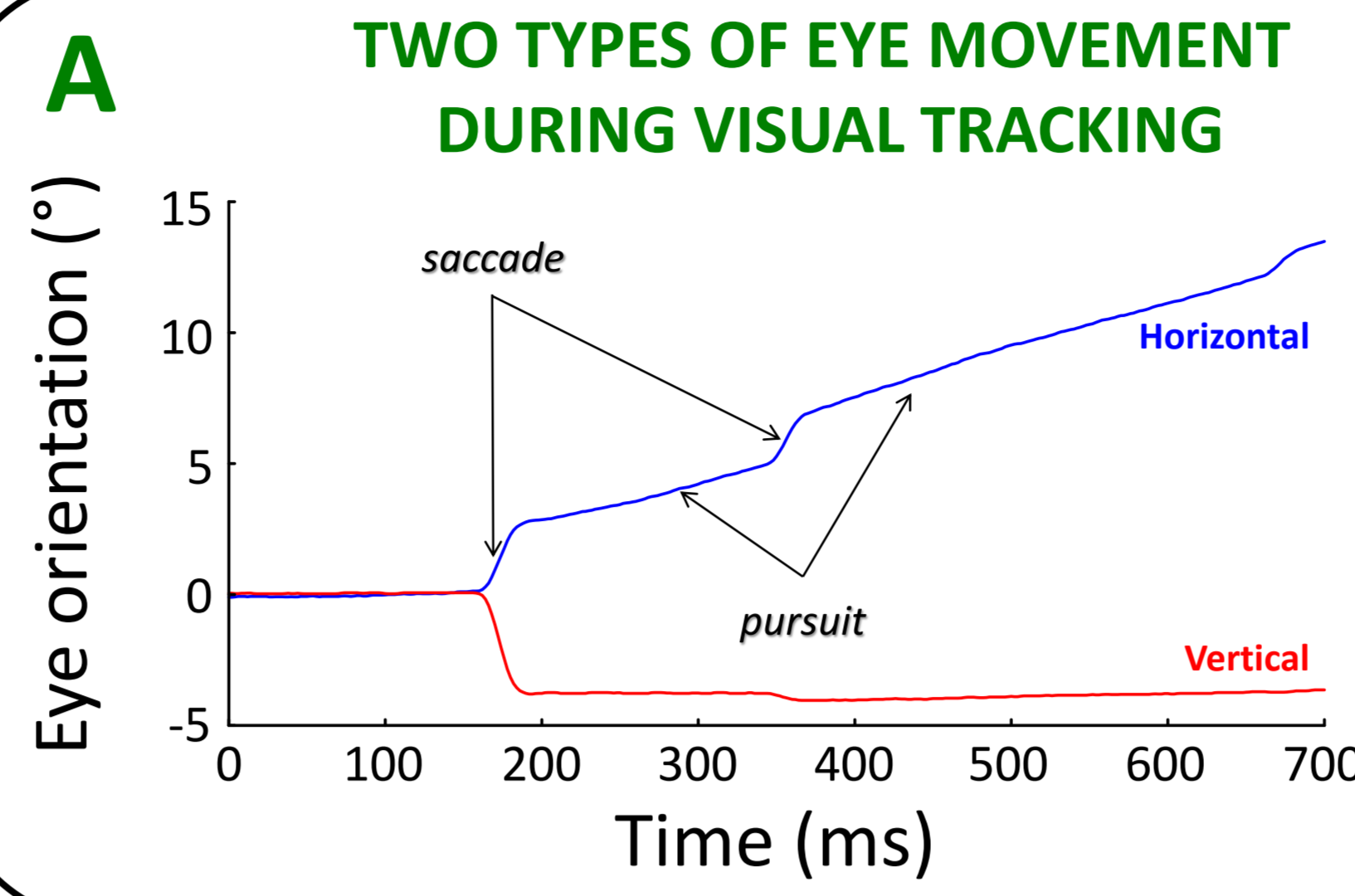
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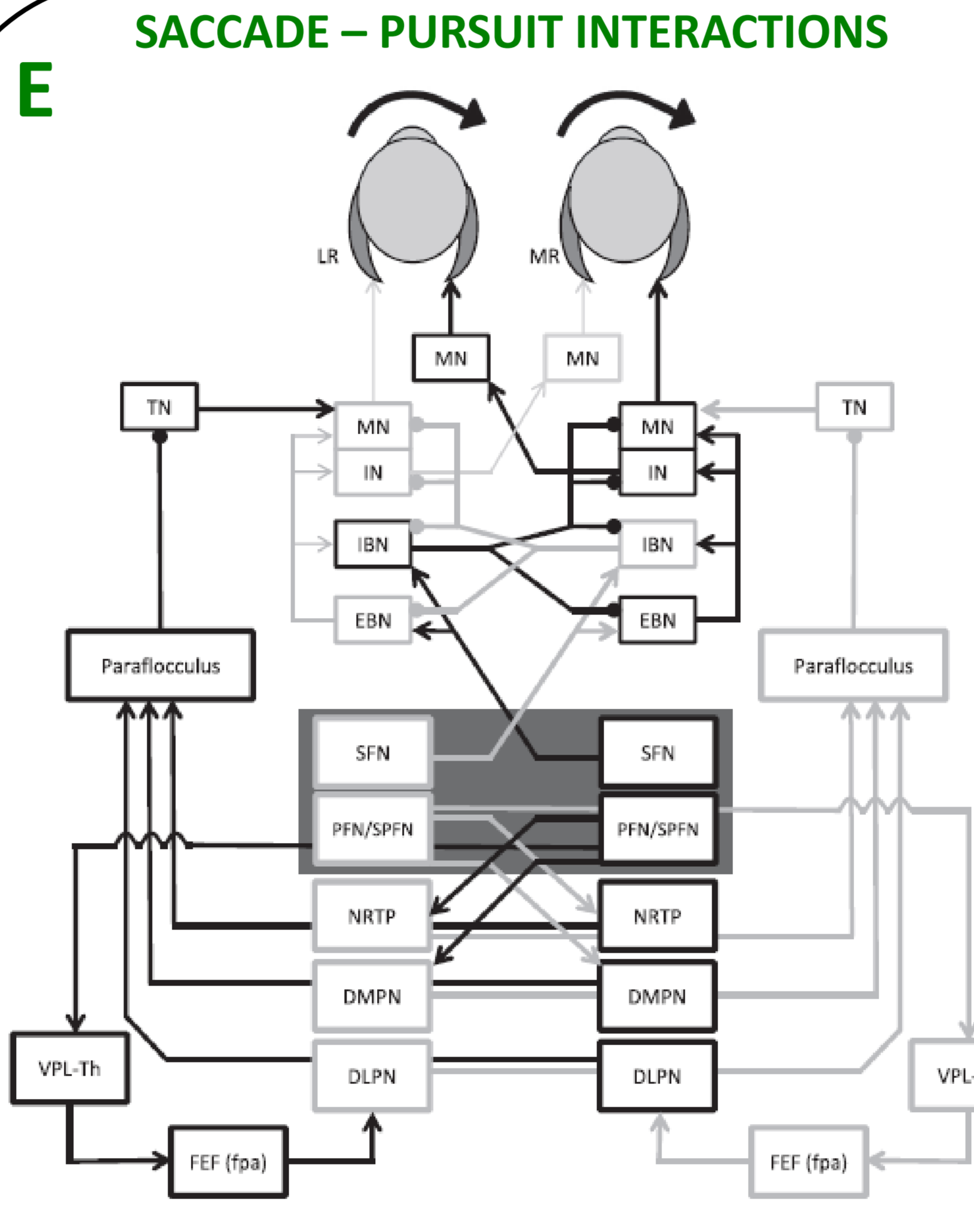
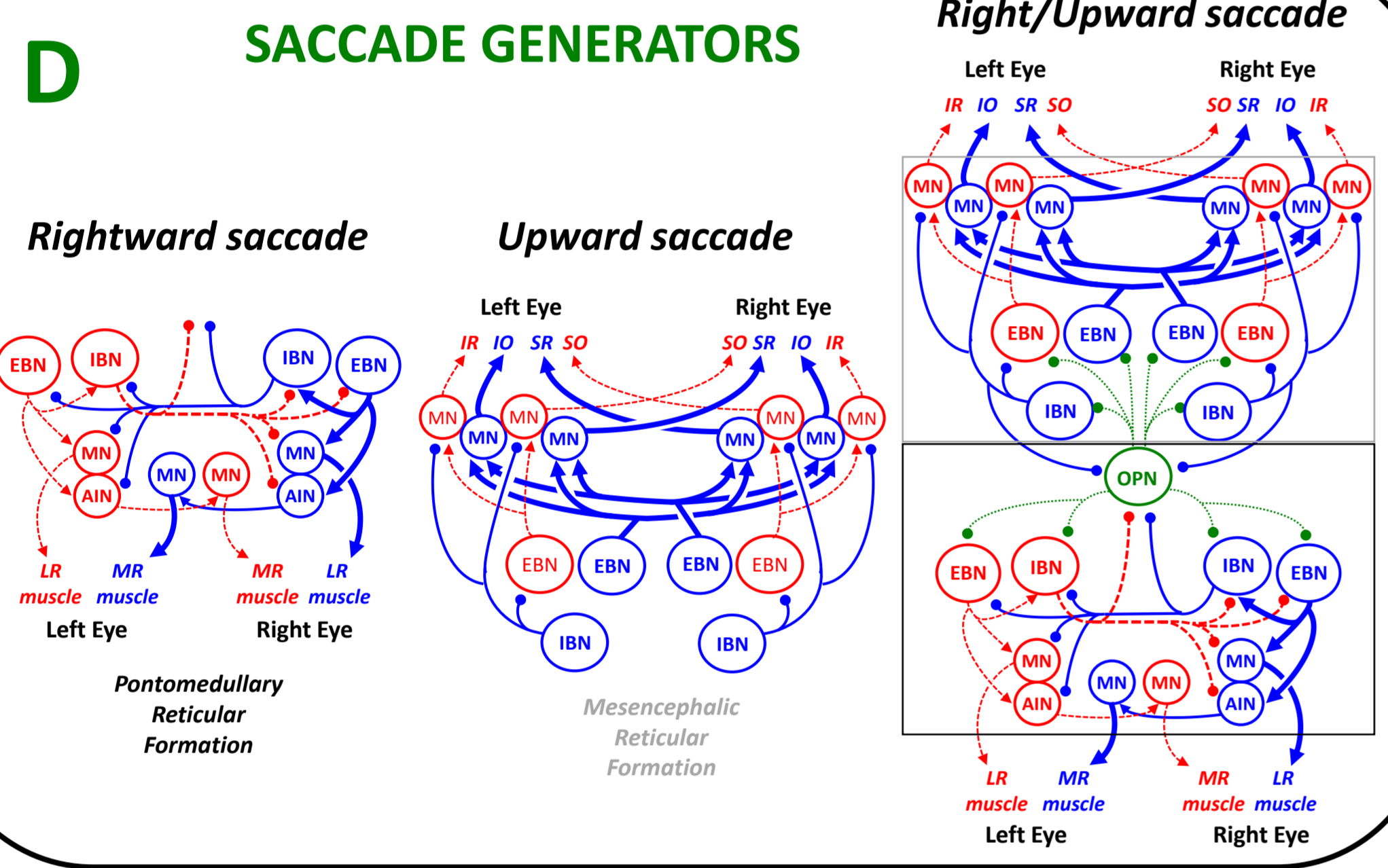
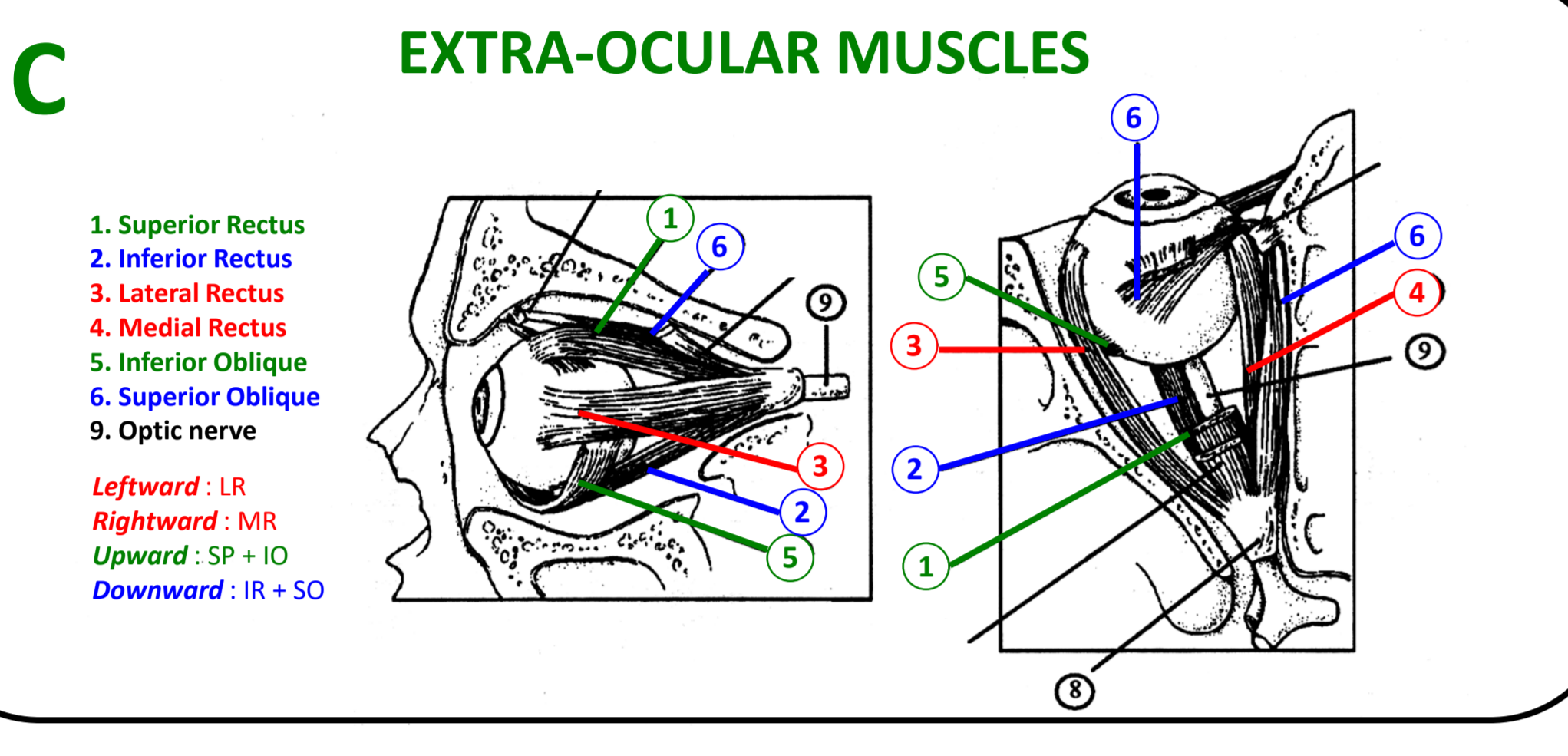
Tracking visually a target that moves in the physical world involves two types of eye movement which recruit parallel and largely distinct neuronal streams. The first movement is a very rapid movement (called saccade) which brings the target image within the central visual field, whereas the second movement, much slower, maintains the visual centering (A). Most of the time, the eyes do not rotate as fast as the moving visual target. The target image slips on the retina and the tracking is punctuated by catch-up saccades. The performance during which gaze moves as if it were attached to the target is not a spontaneous oculomotor behavior; it is the outcome of a repeated training (B). This artifact is important to consider when eye movements are used as a probe for detecting neurological or even psychiatric disorders.

Saccadic and slow (pursuit) eye movements involve the same extraocular muscles (C) and the same motor nuclei (motor neurons MN and internuclei neurons in D) but different premotor circuits. The premotor neuronal network generating saccades involves complex symmetries between multiple pools of excitatory and inhibitory neurons (D). Its interactions with the premotor network generating slow eye movements is still under investigation (E).

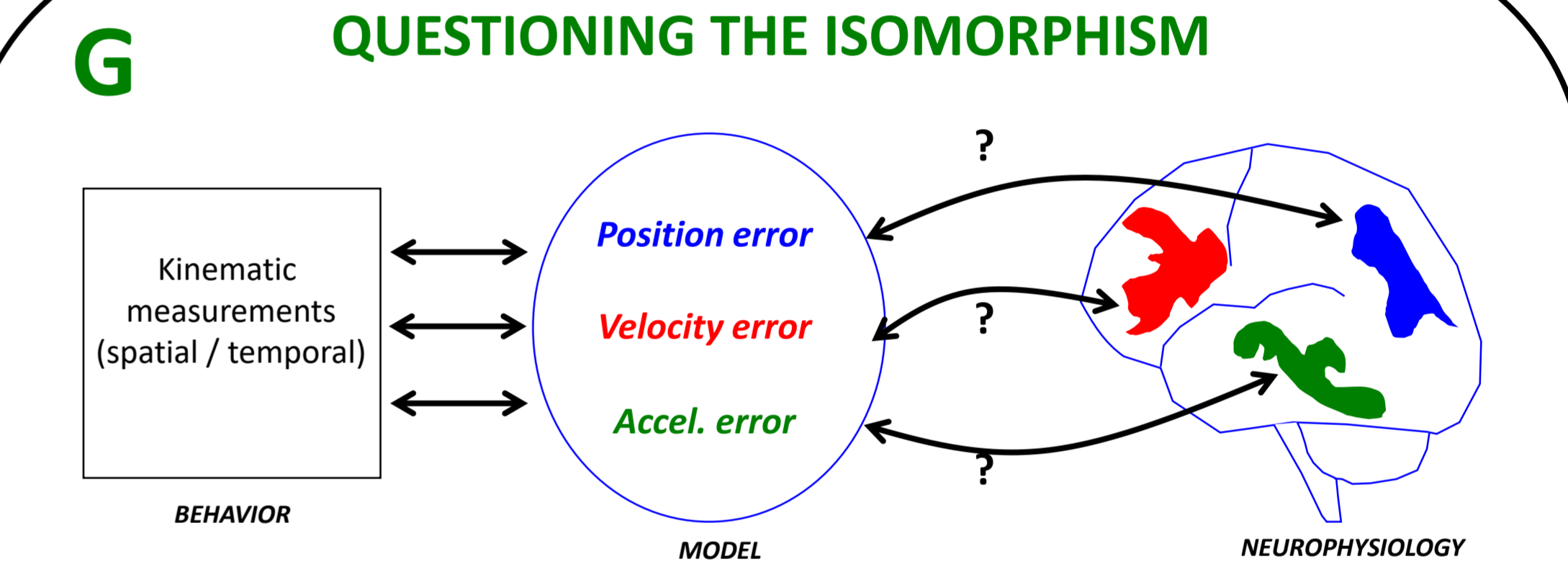


Typical oculomotor behavior of a monkey tracking a visual target moving horizontally with a constant speed. The horizontal eye position is plotted as a function of time after target motion onset for 3 trials recorded during the first (Beginning, left) and last (End, right) training sessions. The time course of horizontal target position is illustrated by the dashed line. The selected trials were recorded in 5 monkeys (from top to bottom, monkeys A, B, C, M, and G) when the target moved in the upper right quadrant with a constant speed (20°/s). During the other randomly interleaved trials, the target moved similarly, horizontally and away from the vertical meridian, but in the lower right, the lower left, or the upper left quadrant.

from Goffart, Bourrelly & Quinton *J Neurophysiol* (2018)
see also Bourrelly, Quinet, Cavanagh & Goffart *J Neurophysiol* (2016)



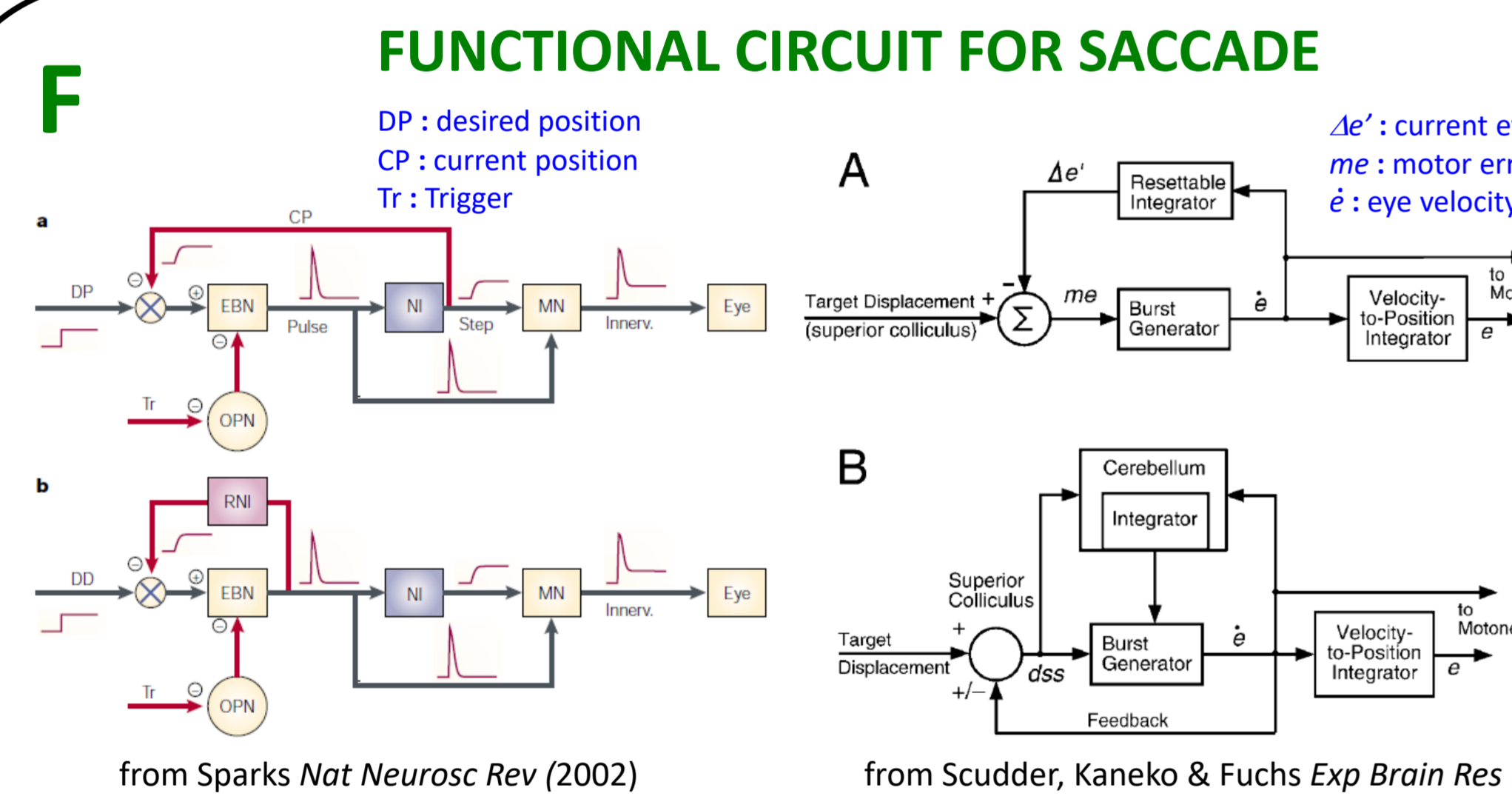
from Bourrelly, Quinet & Goffart *J Neurophysiol* (2018b)



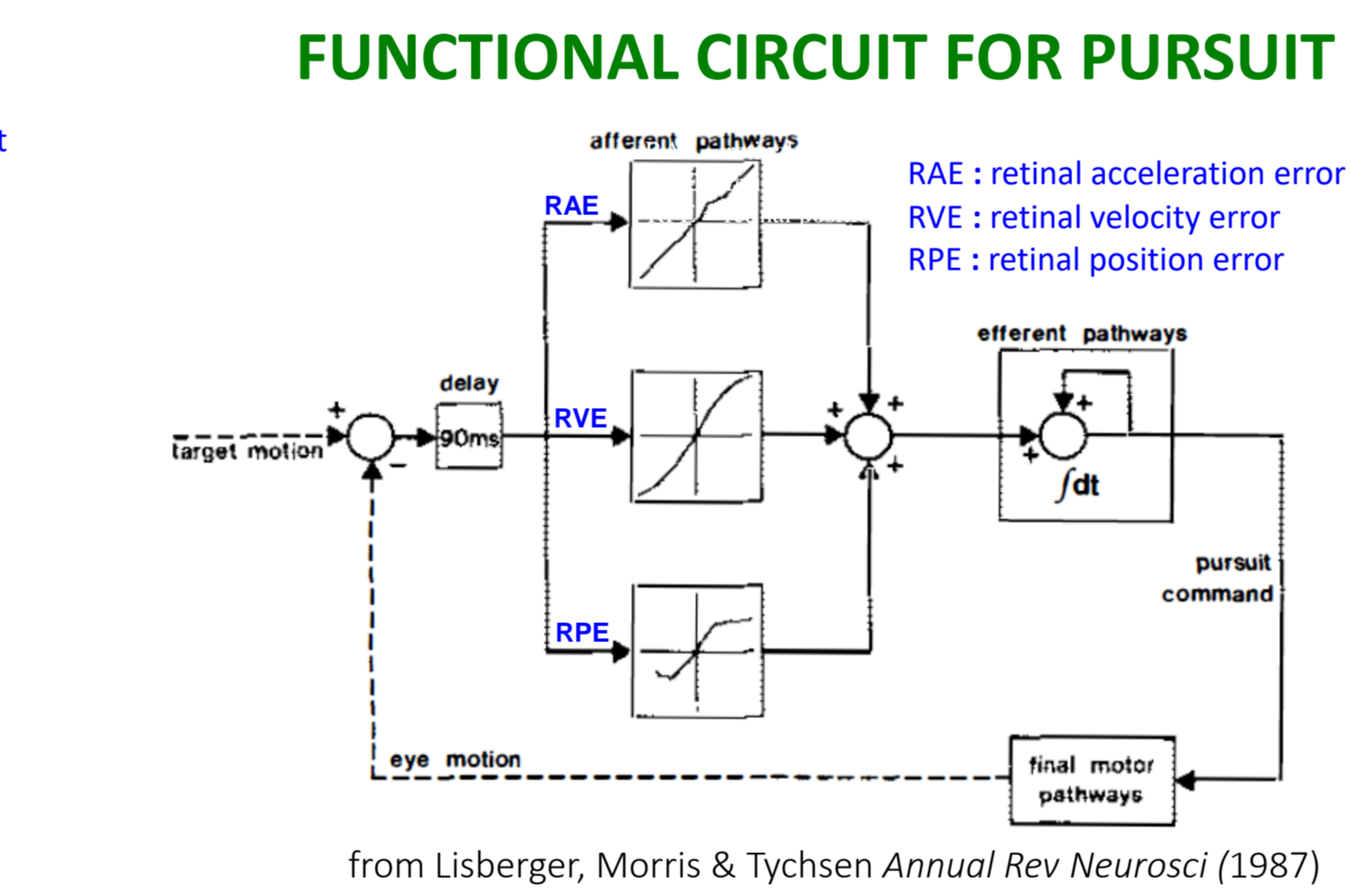
The fact that we measure and model the movement of the eyeball (a rigid body) with kinematic notions does not imply an equivalence in the brain, and notably that the firing of neurons ought to “encode” (i.e., emit spikes related to) amplitude, velocity or acceleration of the eye movement.

“Understanding of brain function is often limited by the tacit acceptance of concepts known to be basically inappropriate. An example is the tenet that the brain, in its internal workings, utilizes space-time reference frames similar to those used in classical mechanics. The fundamental problem may be briefly stated. The process of locating and intercepting moving objects by an animal (a coincidence of the interceptor and a target) is generally described as a coordinated sensorimotor act. While both sensory and motor functions relate to events taking place in external space-time, a concise description of the manner in which space and time information are inter-related in the CNS has not been clearly formulated. One of the reasons for this deficiency appears to be the usage of separate frames of reference for ‘space’ and ‘time’... However, the utilization of separate systems of coordinates for space and time hinges upon the concept of simultaneity. Since within the brain there is no ‘instantaneous’ simultaneity agent comparable to the light, the classical usage of separate space and time coordinates is inapplicable in the case of describing the inner workings of the CNS”

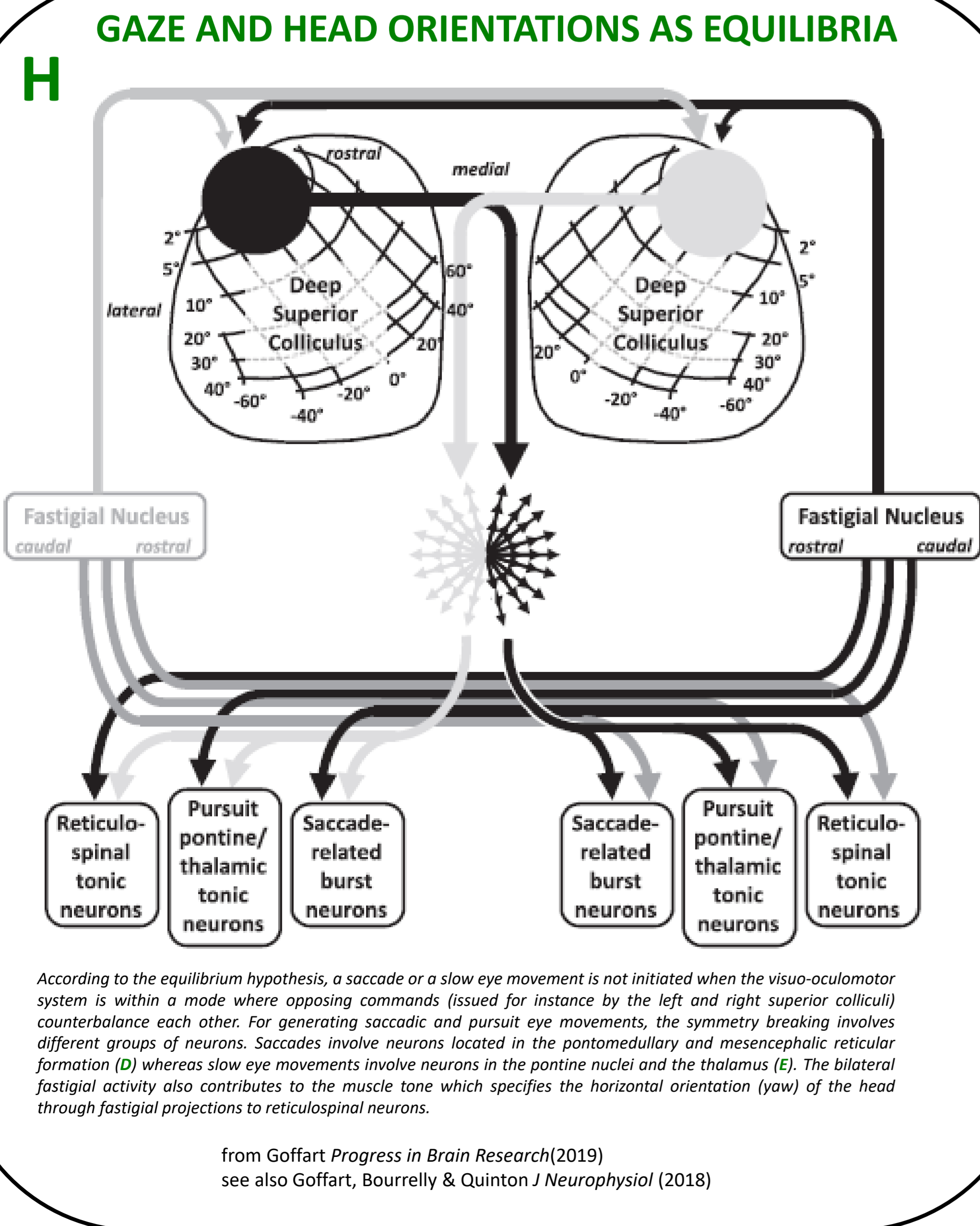
from Pellionisz & Linas *Neuroscience* 1982



from Sparks *Nat Neurosci Rev* (2002)

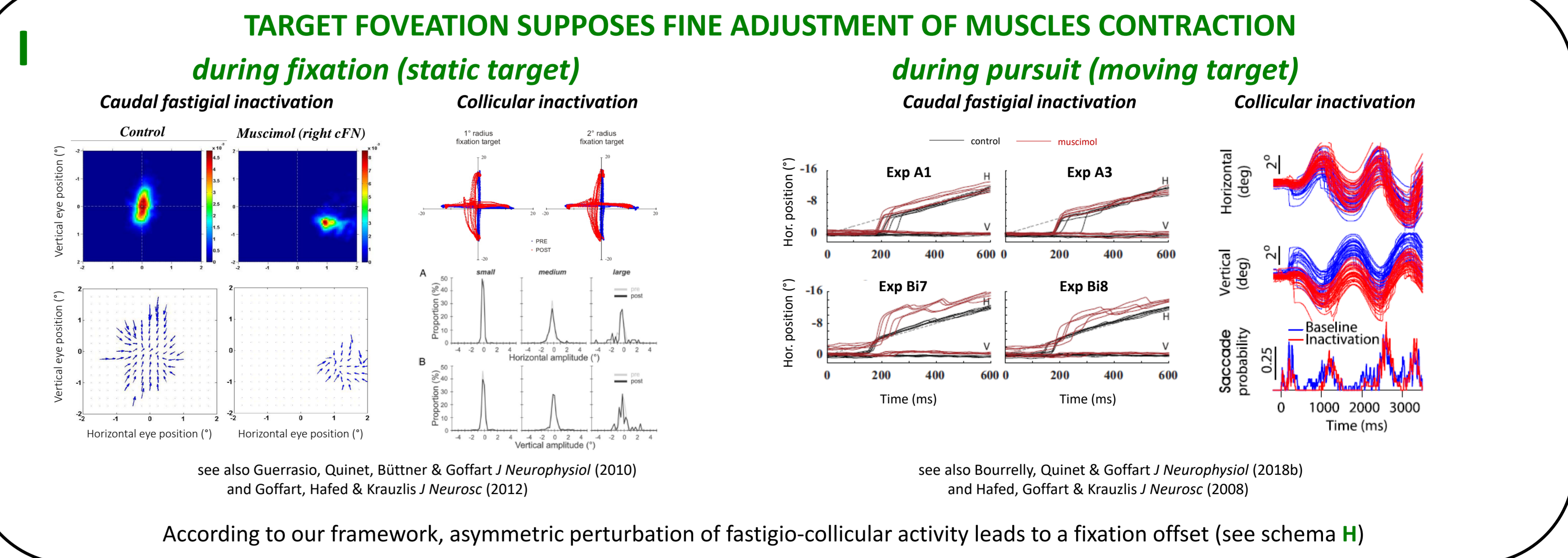


from Lisberger, Morris & Tychsen *Annual Rev Neurosci* (1987)

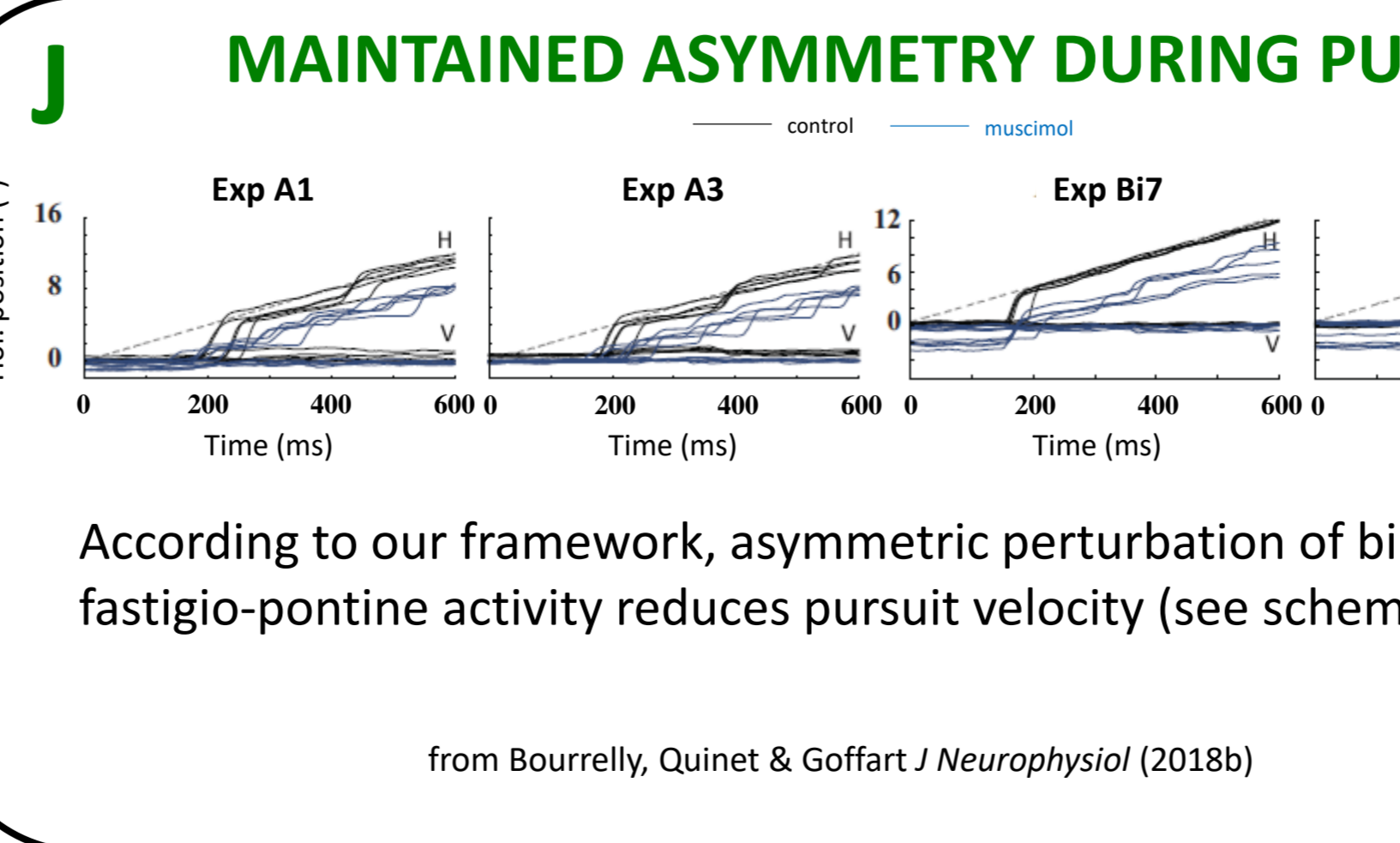


According to the equilibrium hypothesis, a saccade or a slow eye movement is not initiated when the visu-oculomotor system is within a mode where opposing commands (issued for instance by the left and right superior colliculi) counterbalance each other. For generating saccadic and pursuit eye movements, the symmetry breaking involves different groups of neurons. Saccades involve neurons located in the pontomedullary and mesencephalic reticular formation (D) whereas slow eye movements involve neurons in the pontine nuclei and the thalamus (E). The bilateral fastigial activity also contributes to the muscle tone which specifies the horizontal orientation (yaw) of the head through fastigial projections to reticulospinal neurons.

from Goffart *Progress in Brain Research* (2019)
see also Goffart, Bourrelly & Quinton *J Neurophysiol* (2018)

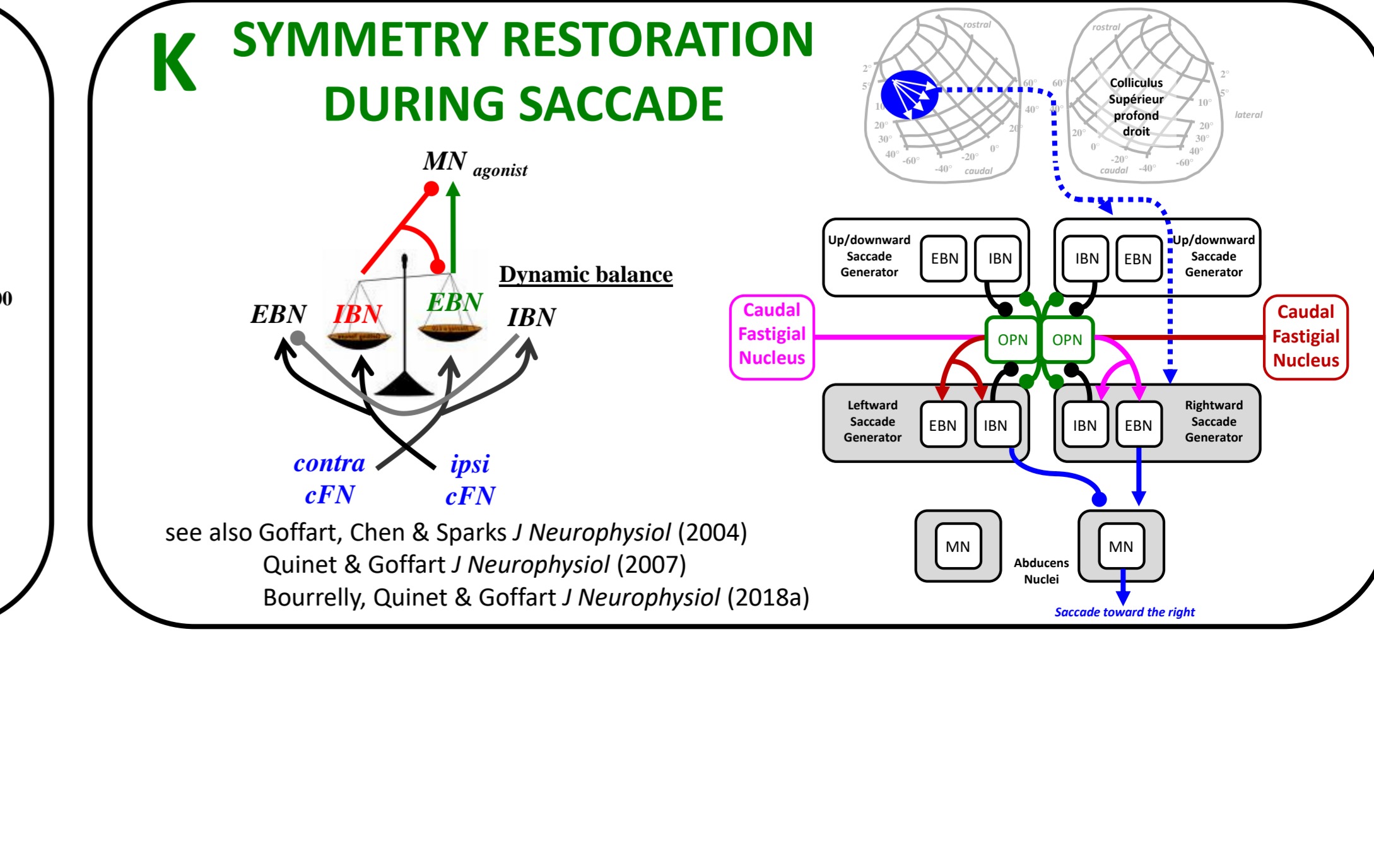


According to our framework, asymmetric perturbation of fastigio-collicular activity leads to a fixation offset (see schema H)



According to our framework, asymmetric perturbation of bilateral fastigio-pontine activity reduces pursuit velocity (see schema E)

from Bourrelly, Quinet & Goffart *J Neurophysiol* (2018b)



see also Goffart, Chen & Sparks *J Neurophysiol* (2004)
Quinet & Goffart *J Neurophysiol* (2007)
Bourrelly, Quinet & Goffart *J Neurophysiol* (2018a)