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Neurophysiology of gaze visual orientation: a synthesis of the contribution of animal studies

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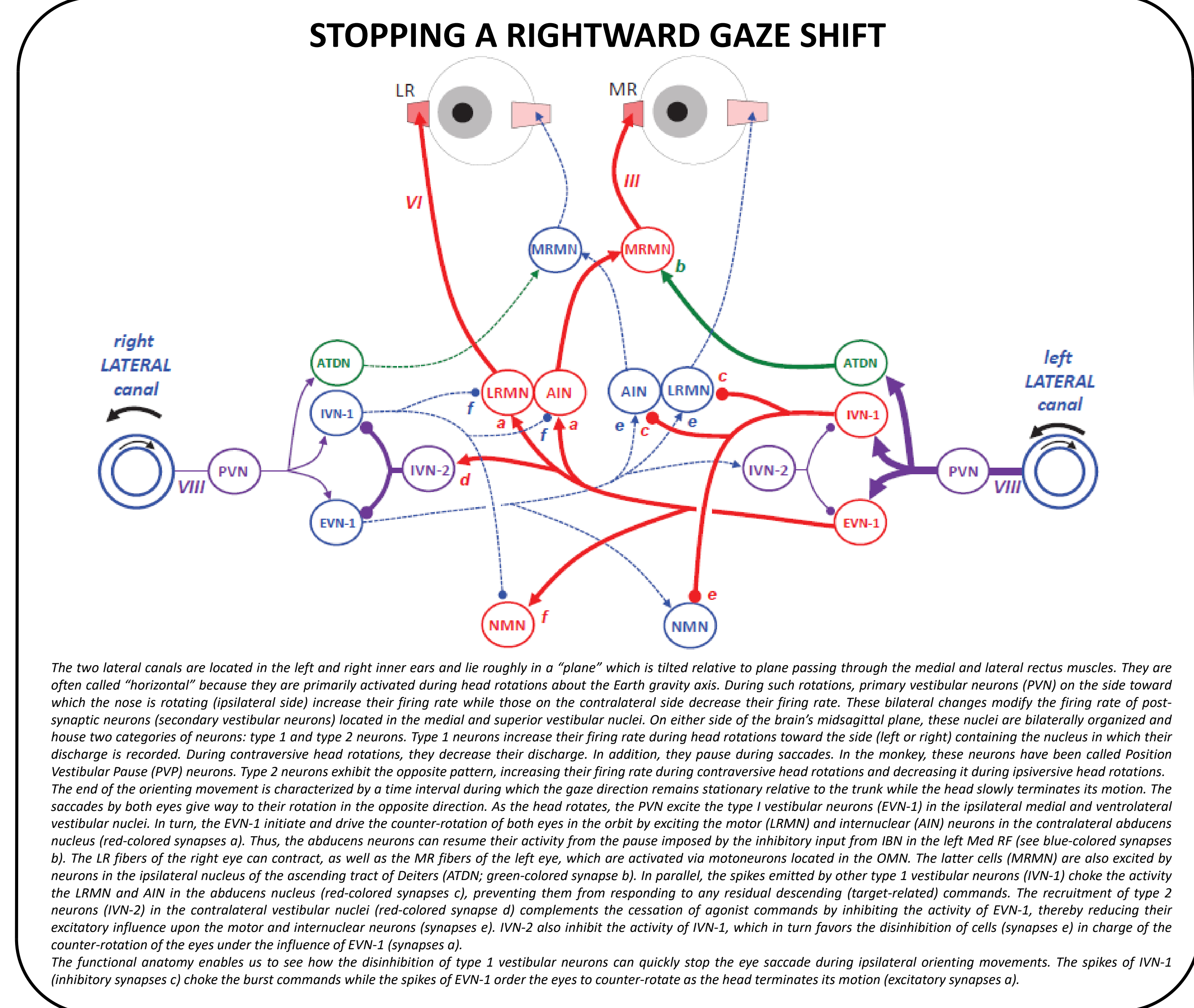
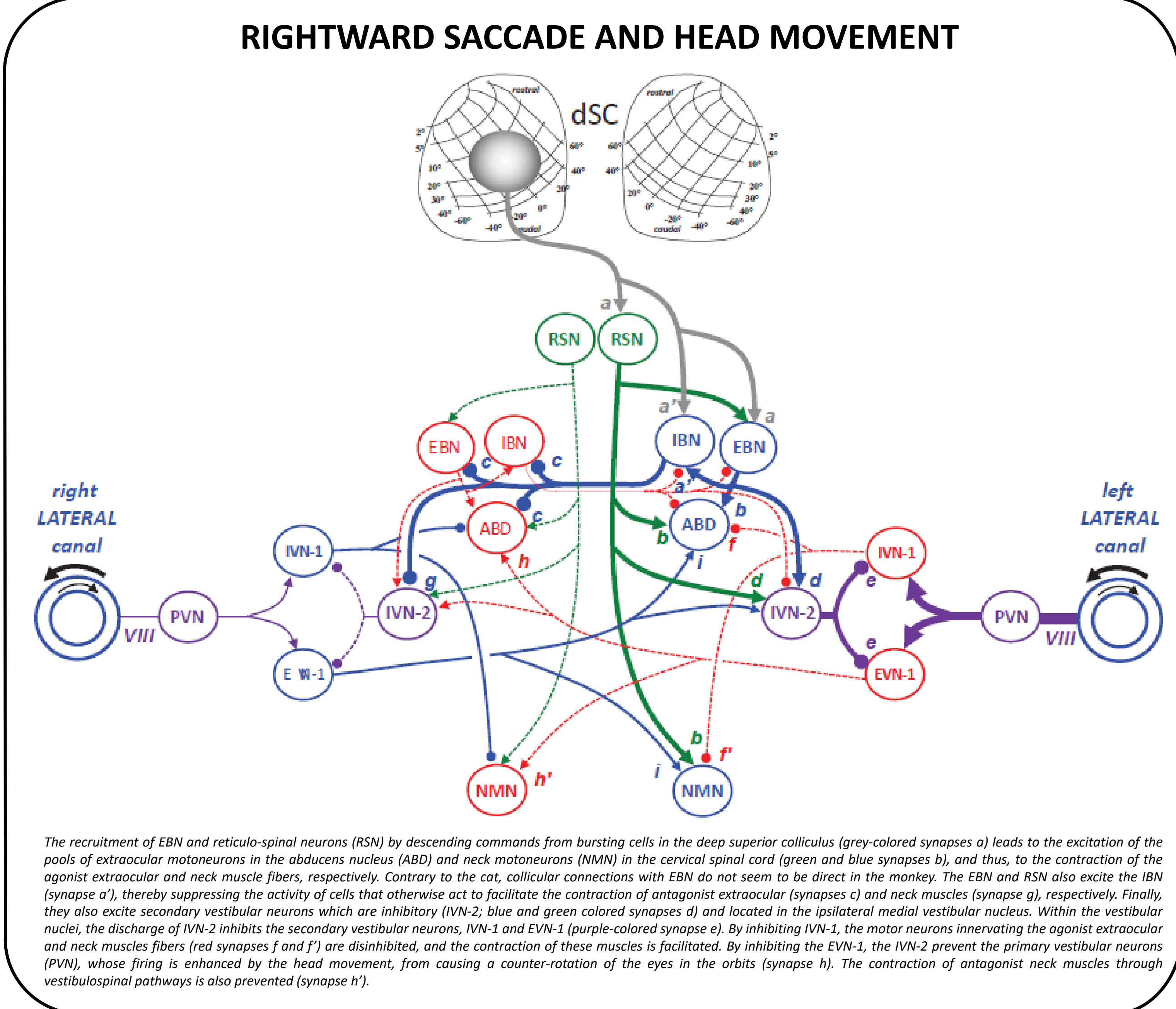
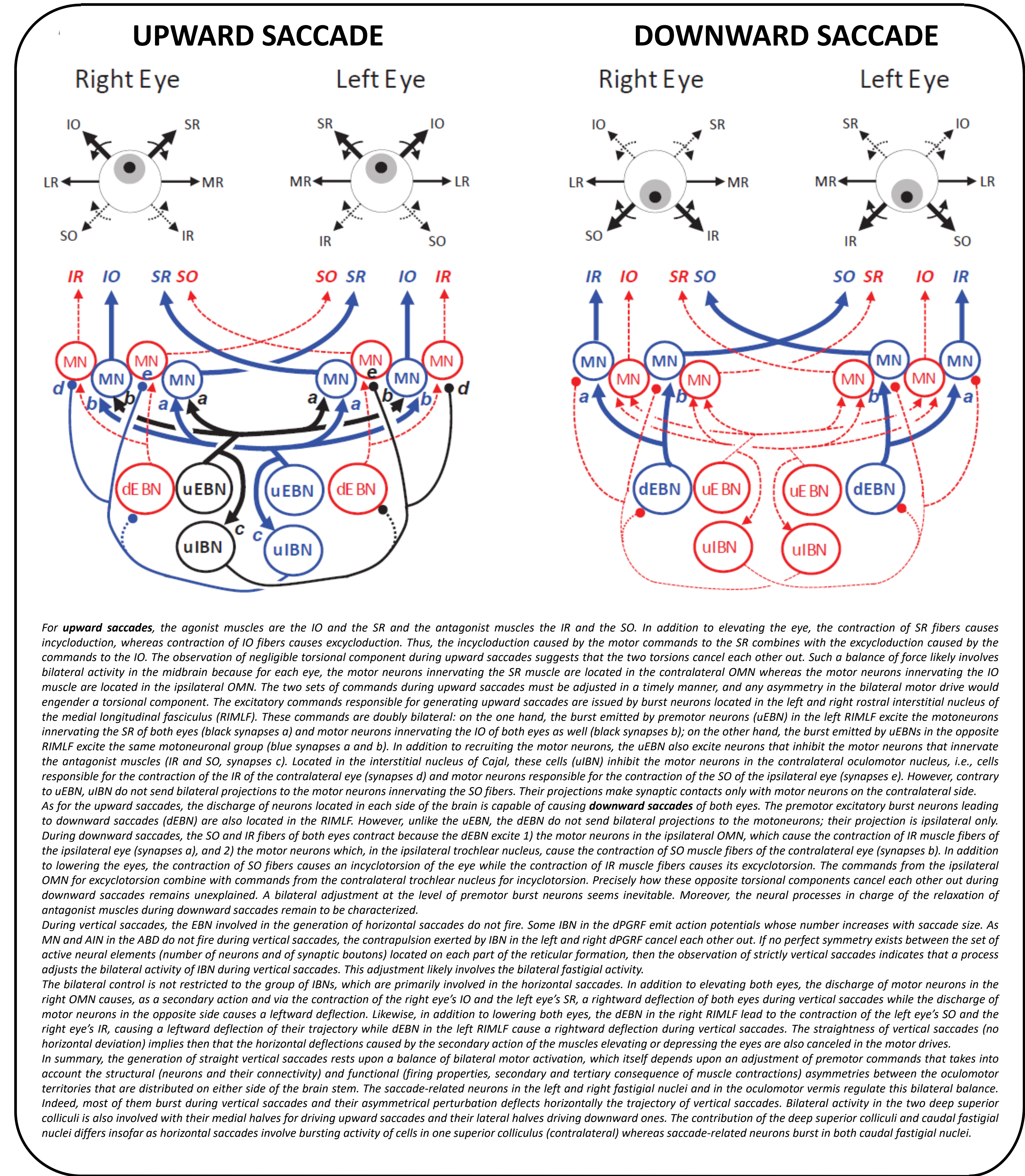
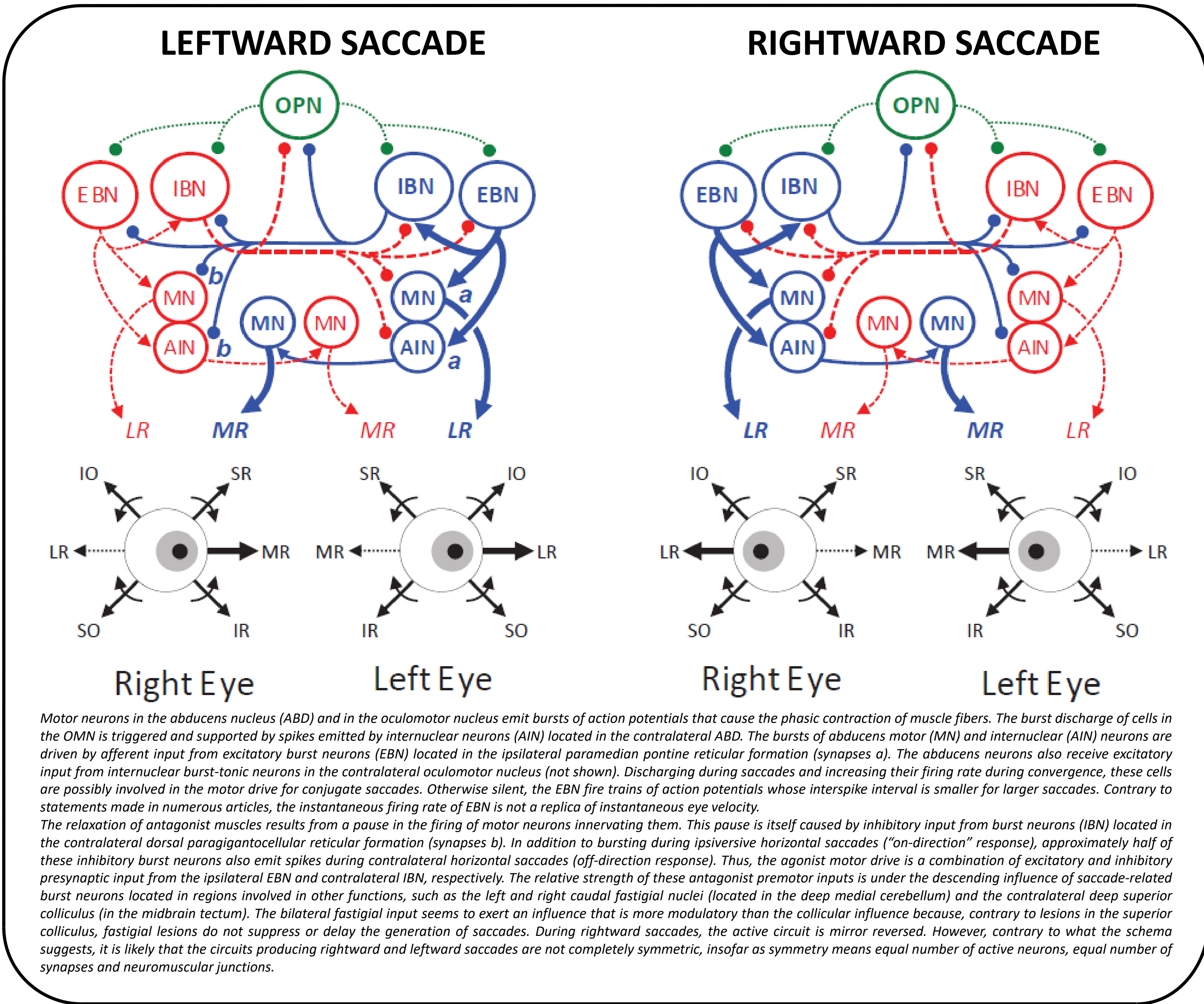
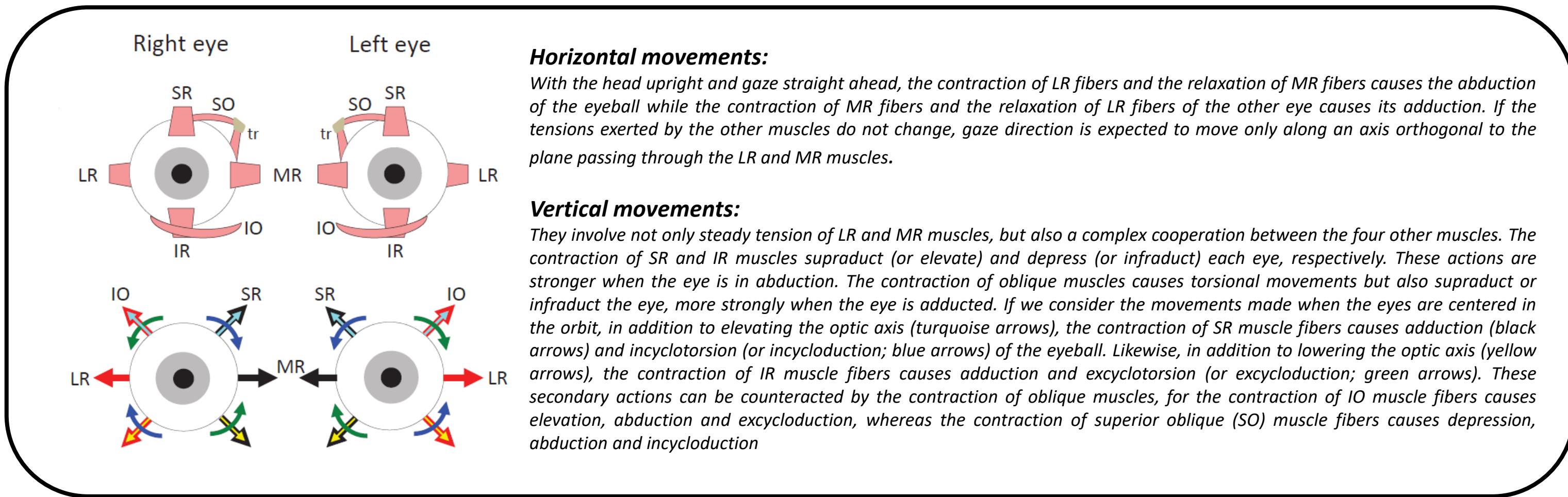
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The appearance of an object in the visual field triggers a rapid gaze shift toward its location. This orienting response consists of a rapid rotation of the eyes, the saccade, which can be accompanied by a rotation of the head. If the target moves, the saccade is followed by a slow movement of the eyes and a catch-up saccade. Instead of describing the path leading from the target-evoked retinal activity to the changes in muscle tension, we shall take the reverse path. Starting from the muscle contractions, we shall proceed upstream and describe the organization that, in the brainstem and cerebellum, enables us to rapidly and accurately orient the foveae towards visual targets located at different eccentricities. Thus, we shall discover the considerable knowledge that neurophysiologists and neuroanatomists gathered during the last six decades with non-human species (mostly monkey and cat).

Technical developments offered the possibility to measure precisely the time course of eye and head movements and to study correlations between the firing rate of neurons and kinematic parameters (amplitude, velocity, acceleration and various differences called errors). These correlation studies should not lead us to believe that a one-to-one correspondence exists between the multiple neuronal networks within which activities propagate and the homogeneous mathematical medium with which the movements are quantified. Contrary to the physical space, the medium of neuronal activity is neither homogeneous nor passive. Moreover, reducing the neuronal chains to units encoding geometric or kinematic relations between gaze target directions conceals the antagonisms between muscles but also the antagonisms between the multiple channels that drive each movement.



In the majority of models proposed during the last decades, the movements were considered as driven by error signals encoding displacement vectors in physical space. These models were definitely useful to communicate concepts and to bring a comprehensive picture of the complexity underlying the generation of movements. However, embedding geometric and kinematic notions within the inner functioning of the brain (i.e., mapping intrinsic neuronal signals with extrinsic behavioral measurements) may be misleading because different constraints characterize the neurophysiological and kinematic descriptions. Rather than outcomes of processes reducing geometric or kinematic errors, the eye movements merely consist of transitions between multiple equilibria opposing populations of neurons whose activity leads to mutually antagonist movement tendencies.

Further empirical investigation is still required to determine and explain several other issues: i.e., whether and how the networks underlying orienting movements of the eyes and head interact with those generating other types of goal-directed action such as reaching movements of the hand or locomotion; whether and how they interact with the networks involved in the navigation and the memory of locations; and whether and how they support the learning of new skills and possibly the acquisition of more abstract knowledge such as geometry or counting. With the recent multiplication of cognitive studies that use eye-tracking techniques to explore the so-called "inner space" with quantitative methods, more effort is required to characterize what exactly are those covert processes that eye movements would express.