Abstract

Listing’s law is a condition on eye movements which is obeyed by healthy subjects, and solves the ‘non-commutativity’ problem associated with rotations in three-dimensional space. Recordings of eye movements in a patient with a disorder known as Congenital Nystagmus (CN) are shown to be in violation of Listing’s law [1]. The question is whether the abnormal movement behavior seen in these CN patients originates from an abnormal neuronal drive, or from abnormal location of tissues surrounding the eye. To answer this question, a three-dimensional recording setup using dual search coils is implemented [17]. Measurements of two healthy subjects are performed, using protocols intended to violate Listing’s law. In addition, an existing implementation of an eye movement model [21, 30, 33] is further adjusted to incorporate the physiology of the eye muscles by adding pulley structures. Muscle pulleys are anatomical entities which constrain the movement of the bellies of the eye muscles. With this improved model, simulations are performed to see if the violation of Listing’s law is generated by the neural system or by the anatomy of the eye.

The measurements show that in normal controls the eye, in principle, always obeys Listing’s law, even for the protocols used to generate a violation of this law. Simulations with a dynamical model of the oculomotor plant show that a displacement of pulley structures may offer an explanation for the deviations from Listing’s law seen in the recordings of CN patients. Another finding of the model simulations is that the neural system used for the generation of eye movements does not need to be more complex than for a healthy subject, in the sense that the model explains the recordings with a two-dimensional neural input, and the neuronal system is the same as in healthy controls. In simulations for CN patients, only a horizontal oscillatory drive (nystagmus) was introduced. When this drive is used together with a changed pulley parameter (reflecting a displaced pulley) for the horizontal muscles while keeping the vertical pulley at optimal value, the model generates 3D eye movements with oculomotor instabilities (CN) in all three directions, that are in good agreement with recordings in CN patients.