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Progress in Retinal and Eye Research 26 (2007) 486–515

Progress in RETINAL AND EYE RESEARCH

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Physiology and pathology of eye–head coordination

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Abstract

Human head movement control can be considered as part of the oculomotor system since the control of gaze involves coordination of the eyes and head. Humans show a remarkable degree of flexibility in eye–head coordination strategies, nonetheless an individual will often demonstrate stereotypical patterns of eye–head behaviour for a given visual task. This review examines eye–head coordination in laboratory-based visual tasks, such as saccadic gaze shifts and combined eye–head pursuit, and in common tasks in daily life, such as reading. The effect of the aging process on eye–head coordination is then reviewed from infancy through to senescence. Consideration is also given to how pathology can affect eye–head coordination from the lowest through to the highest levels of oculomotor control, comparing conditions as diverse as eye movement restrictions and schizophrenia. Given the adaptability of the eye–head system we postulate that this flexible system is under the control of the frontal cortical regions, which assist in planning, coordinating and executing behaviour. We provide evidence for this based on changes in eye–head coordination dependant on the context and expectation of presented visual stimuli, as well as from changes in eye–head coordination caused by frontal lobe dysfunction.

Keywords: Head movements; Eye–head coordination; Oculomotor; Saccades; Pursuit; Aging; Schizophrenia; Pathology; Physiology

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Abbreviations: FEF, frontal eye field; SEF, supplementary eye field; SC, superior colliculus; cMRF, central mesencephalic reticular formation; riMLF, rostral interstitial nucleus of the medial longitudinal fasciculus; PPRF, paramedian pontine reticular formation; NRG, nucleus reticularis gigantocellularis region; DLPFC, dorsolateral prefrontal cortex; CEF, cingulate eye field; OKN, optokinetic nystagmus; VOR, vestibulo-ocular reflex; PD, Parkinson's disease; CIN, congenital idiopathic nystagmus; PANSS, Positive and Negative Syndrome Scale; KB, Kamin blocking; O-LIFE, Oxford-Liverpool Inventory of Feelings and Experiences; MRI, magnetic resonance imaging; fMRI, functional magnetic resonance imaging; E_{PRED}, predicted eye eccentricity.

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1350-9462/$ - see front matter
doi:10.1016/j.preteyeres.2007.03.004

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1. Introduction

1.1. Why do we move our head?

The control of gaze can be considered as the coordination of eye movements around three rotational axes (horizontal, vertical and torsional eye movements) in harmony with the coordination of head movements. The coordination of eye and head movements presents a challenging scenario to the brain since the head rotates around three rotational axes, which are not equivalent to the axes of eye rotations and the head can also move in three translational directions.

With respect to oculomotor control in humans, a sophisticated array of eye movements are available to optimise the acquisition of visual information falling on the retina (Leigh and Zee, 2006). Saccades serve to rapidly bring a target of interest onto the fovea. Fixational eye movements keep a static target on the fovea and smooth pursuit tracks a moving target. If the whole visual field is moving the vestibulo-ocular reflex (VOR), driven by vestibular input, and optokinetic nystgamus (OKN), driven by visual input, act to reduce movement of retinal images.

Since such refined and rapid eye movements are available to direct our gaze one might ask the question why we should need to move the head at all. In general, there are three reasons. Firstly, head movements can be used as an extension of the oculomotor system to aid with the acquisition of visual targets. For example, head movements are frequently used during or following gaze shifts. This effectively extends our range of gaze beyond the oculomotor range by head movements contributing to gaze shifts and also by bringing the eyes back towards a central position to assist in apprehending future visual targets. Secondly, compensatory head movements are made during movements of the body in space. Neck movements driven by the vestibular apparatus are used to keep the head in a fixed position in space during movements of the body. In fact, the neck is an outstanding biomechanical linkage with an exceptional range of motion due to the mobility of the cervical spine (Dutia, 1991). Ranges of motion for active neck movements are about 150° in rotation (yaw), 125° in extension/flexion (pitch) and 90° of lateral bending (roll)