Neural pathways for eye movements during self-moved object guiding

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Introduction. It is clear that human eye movements, used for different tasks, are different by means of nature, timing and synchronisation with visual stimuli. The nature of these movements is restricted to six types: fixations, vestibulo-ocular reflex, optokinetic reflex, vergence, saccadic and smooth pursuit movements. Each of the eye movement type involves different neural pathways. In a case of real life tasks, eye movements can be complex. E. g. smooth pursuit movements are alternated by catch-up saccades in cases, when the object of interest moves with a high velocity [1]. It is natural that an additional set of eye movement parameters can be extracted in such cases. These parameters alone or together with parameters of basic eye movements, can be used for various purposes: brain structure research, engineering of synthetic human-like systems, development of intuitive human computer interfaces, neurological and mental disorder diagnosis.

Most promising area of application is the diagnostics [2]. Thanks to rapid development of technologies, eye movement data acquisition is an easy, accurate and significantly non-invasive and relatively cheap task. It is possible to use observational relationships between eye movement parameters and disorders, but the better way would be to use the brain-map. If one or more parameters of eye movements in a patient differ from the majority of population, it could be stated that one or another part of the brain is affected.

Despite the possible applications, understanding eye movement parameter rivalries is essential for further and deeper investigation of all the eye movements.

Eye-hand coordination. It is known that hand movements are affected by and affects movements of eyes [3]. The character of the influence depends on the executed action. Participation of the hand can change some parameters of eye movements e.g. latency [4]. It also can change the scan-path because of the need for supervision. It can even introduce a new type of eye movements. This is the case of eye movements utilised while guiding a hand-moved object.

When the task is to manually move the object through a visible path, eye movement nature is similar to smooth pursuit with catch-up saccades (Fig. 1). But parameters of such movements indicate else: comparing to the task of target following, the gain of smooth eye movements (ratio eye movement velocity to object/target movement velocity) is different and usually 1.6 - 4 times lower; the synchronisation of the gaze and the object is also different by means of timing. Saccade landing position is always preceding the hand-moved object what makes these eye movements different from catch-up saccades. Also the gaze is regularly moving smoothly at the same time preceding the object. Such smooth movements are very similar to smooth pursuit, but could not be called this way, because they are not pursuing any target. Also they are not similar to any other type of eye movements. One of the hypotheses could explain such eye movements as a position shifted smooth pursuit (attention precede the foveal region of the retina). This hypothesis was addressed and denied in a work of J. Tramper and M. Flanders [5].

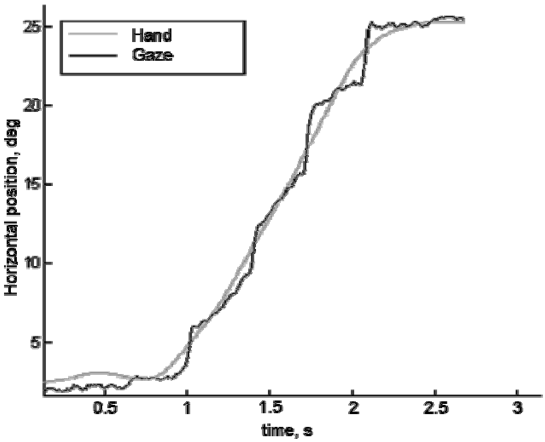

Fig. 1. Eye-hand coordination while guiding a hand-moved object

The nature of smooth eye movements in the guiding of an object. The similarity with smooth pursuit eye movements, leads to an analysis of the models on neural dynamics of saccadic and smooth pursuit eye movement coordination during visual target tracking (Fig. 2).

Neural pathways involving FEF and SC brain areas are responsible for the decision on voluntary saccade targets [6]. Saliency maps are used to determine the target of the planned saccade. In the object guiding over the visible path task, the corners, visual obstacles and other complex parts of the path [3, 7] has the highest saliency and attracts the attention so a saccadic eye movement is elicited. The time of the decision to trigger a saccade depends on the distance from the hand-moved pointer to the obstacle.

The smooth eye acceleration needed for the tracking of moving target is determined in NRTP which uses the signal of the actual eye movement velocity from MVN/rLVN and the target movement velocity from the FPA. The gain of smooth pursuit is set and maintained by the MT-DLPN-CBM pathway [6].

The lower layers involving the motor neurons, TN, MVN/rLVN and the PPRF (which has a formation with OPNs for suppression of smooth eye movements during saccades and saccade suppression during near-accurate pursuit, also the negative feedback involved in saccade landing situations) are mainly controlled by the CBM and at the same time by the SC. Also the rostral part of SC can engage OPNs to suppress a catch-up saccade if the target is about to come to the fovea within specific time interval [6, 8].

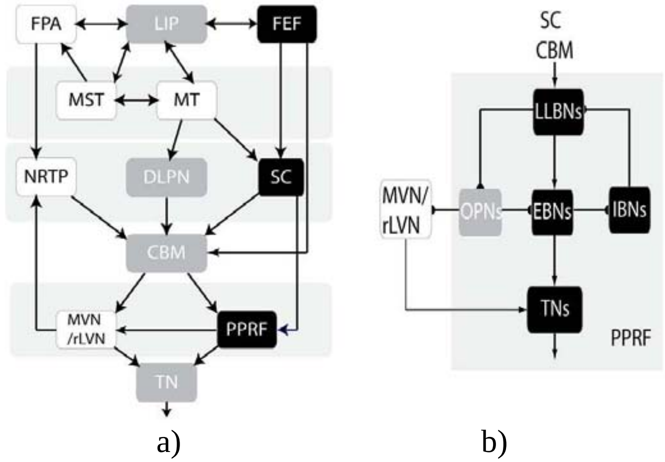

Fig. 2. Modelled interactions among brain regions implicated in oculo-motor control [6]. Black boxes denote areas belonging to the saccadic eye movement system, white boxes - the smooth pursuit eye-movement system, and grey boxes - both systems. (a) LIP – Lateral Intra-Parietal area; FPA – Frontal Pursuit Area; MST – Middle Superior Temporal area; MT – Middle Temporal area; FEF – Frontal Eye Fields; NRTP – Nucleus Reticularis Tegmenti Pontis; DLPN – Dorso-Lateral Pontine Nuclei; SC – Superior Colliculus; CBM – cerebellum; MVN/rLVN – Medial and Rostro-Lateral Vestibular Nuclei; PPRF – a Peri-Pontine Reticular Formation; TN – Tonic Neurons. (b) Constituents of the saccade generator in the PPRF, and projection of omnipauser neurons to the pursuit neurons of the MVN/rLVN. Arrows indicate excitatory connections, and semi-circles indicate inhibitory connections. OPN – Omni-Pauser Neurons; LLBN – Long-Lead Burst Neuron; EBN – Excitatory Burst Neuron; IBN – Inhibitory Burst Neuron; TN – Tonic Neurons.

CBM is the region of the brain, where signals on intended motor actions are translated to signals for motor-related neurons. This translation is done using weights learned depending on the shape of the muscular system.

What is different between the smooth pursuit with catch-up saccades and the visual guiding is the timing and the gain of smooth eye movements. Changes in the gain can be explained by the presence of the information (in CBM) on prosecuted hand movement velocity and direction. As it is known that the signal processing in the CBM is almost entirely feed-forward, but some recurrence that exists consists of mutual inhibition [9], this signal of hand movements induces an inhibition on DLPN-CBM pathway. Also it is known that arm movements influences eye movements via feedback of arm kinesthetics within the dentate nucleus of the CBM thus significantly decreasing the eye movement latency while executing the eye-hand coordination tasks [10].

Triggering of catch-up saccades is based on the estimation of the gaze-target crossing time: a saccade is triggered if the crossing time is estimated to be less than 180 ms while decreasing (pre-crossing) or more than 40 ms while increasing (post-crossing) [8]. The same mechanism is still suitable to explain the triggering of saccades in visual guiding. The only difference is the landing position of saccades. While having information on current hand movement, the saccade landing position is calculated to precede the position of the hand-moved object (Fig. 3). The target for catch-up saccades is always the object being tracked, but in tasks of the visual guiding, the saccade landing position is a spatial area based on attention [11]. Attention is the factor driving the build-up activity of neurons in the SC. And the build-up process of the SC is used for eye movement planning [12].

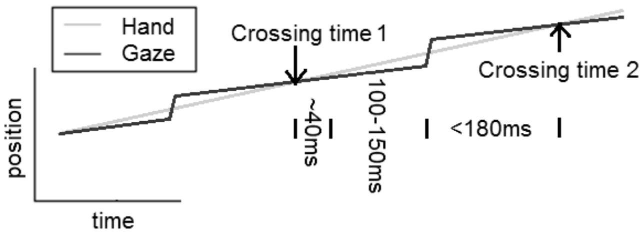

Fig. 3. Saccade timing in the tasks of visual guiding. Amplitude of the saccade is calculated for the estimated crossing time to be less than 180ms (otherwise a catch-up saccade could be triggered).

Conclusions. Investigation of eye-hand coordination in visual guiding task reveals that the nature of eye movements involved is the same as of a smooth pursuit with catch-up saccades. However, smooth eye movements introduced, could not be called “smooth pursuit” because of their purpose. The main reason for different gain and timing is the presence of current hand-movement signal in the cerebellum. This signal inhibits the Dorso-Lateral Pontine Nuclei – Cerebellum pathway, thus decreasing the gain of smooth eye movements. Mechanisms in the cerebellum for the Eye-hand coordination, allows the gaze to periodically precede the hand-moved object too. Decreased gain and precedence-allowed saccade amplitudes assure the convenient movement of the scene in the retina while maintaining a stable and catch-up free crossing time to saccade time interval.

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During an execution of visuo-manual guiding tasks, eye movements, different from those observed in oculo-motor or oculo-manual tracking, are observed. These eye movements, even being similar to smooth pursuit with catch-up saccades, could not be called "smooth pursuit". They are anticipating instead of pursuing the object being guided. In this work we analyse the differences between the smooth pursuit with catch-up saccades and the guiding eye movements. In this work it is shown that the nature of these two types of eye movements is the same and the model on the neural dynamics of guiding eye movements is the augmented smooth pursuit model. Significant differences in parameters of both eye movement groups are explained by determining the brain areas and pathways involved, thus indicating their purpose.