BMC Neuroscience

Poster presentation

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Neural constraints in kinematics of head-free gaze

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P18 doi:10.1186/1471-2202-10-S1-P18

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P18

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Introduction

Gaze position (eye in space) does not use all three rotational degrees of freedom of eye or head mechanics [1]. In classical studies of head-free saccades, the reduction of degrees of freedom is described by Donders' law [2]: 3D-eye orientations are located on a 2D-surface [3]. But only few studies investigated the dependence of Donders' law on the direction of the saccade preceding the actual fixation. The aim of this study was to perform this analysis for eye and head movements simultaneously during head-free gaze shifts. Furthermore, we collected a data set in normal adult humans for comparison with oculomotor disorder patients.

Methods

Three-dimensional eye and head rotations were measured with the magnetic search coil technique in seven healthy human subjects as they made large head-free gaze shifts to visual targets. Target positions were aligned on a square grid of nine dots with cardinal targets at 28° eccentricity and oblique targets at 38.5° eccentricity from central gaze position ("straight ahead"). The target was pseudo-randomly shifted between these positions. Eye and head orientations during fixation of the same target position were compared for saccades from different starting positions. Second order surfaces were fitted to the torsional component of eye and head orientations. The surface width was quantified by computing the residual variance. The shape of the surface was described by its minimal and maximal curvature at central gaze position.

Results

As reported previously [3], we found the orientations adopted by eye and head to be a small subset of those possible due to biomechanical constraints. Our analysis of eye and head orientations in dependence on the preceding position shows that Donders' law holds in the strict sense. The width and the curvature of the surface are suitable for a qualitative classification of anomalies of Donders' law in patients [4]. The sum of the residual variances of eye in head (3.1 ± 1.7 deg^2) and head in space (0.9 ± 0.5 deg^2) did not differ from that of eye in space (4.1 ± 2.6 deg^2) suggesting that torsional control of eye in head and head in space were independent. Even though Donders' law holds for head-free gaze (in contrast to Listing's law [1]), we did not observe evidence for a control strategy minimizing image rotation between repeated fixations at the same gaze direction.

Acknowledgements

Supported by Deutsche Forschungsgemeinschaft (GRK 1091).

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