

Summary

Dennis Eckmeier

My dissertation focused on the impact of optic flow on the behavior and brain function of the zebra finch in three approaches. First we demonstrated that the zebra finch controls its gaze in a way that facilitates the perception of depth in the optic flow. Then we studied the control mechanism that underlies this strategy and added to the knowledge about its properties. Finally we studied the actual processing of object related information during presentation of naturalistic self motion and found neurons coding for specific behaviorally relevant characteristics of the optic flow that correlate with the approach towards objects.

Optic flow is the displacement of the retinal image during self motion. Due to basic optic phenomena, the flow field provides information about the distance to objects in the visual scene and about self motion. Distance information, however, can only be acquired from optic flow generated from straight (translational) self motion.

Birds highly depend on such cues and use them, for example, for the control of flight maneuvers. The need to use optic flow emerges from anatomical properties of the bird's skull. Laterally positioned eyes and a short interocular distance are common across avian species. These properties cause binocular vision to be insufficient for stereoptic depth perception. Pigeons, for example, can estimate depth from binocular cues in a range of only 5 to 19 cm distance – impractically short for fast locomotion in an unknown environment. Behavioral evidence for the actual usage of such cues was reported for birds that controlled flight maneuvers on the basis of optic flow.

Insects also depend on optic flow, due to their size and anatomy. The impact of optic flow on the behavior of insects is omnipresent especially in airborne species. One example would be the typical flight and gaze strategy in flies. Since depth information can only be derived from optic flow that is generated by straight (translational) self-motion, flies avoid flying in curves but change flight direction in fast saccadic body turns. Between such saccadic turns, they move translational. The visual input is further optimized by facilitating head movements.

To find whether zebra finches would show a similar behavior, we analyzed their head movements in free flight. We recorded high speed videos of zebra finches circling around an obstacle. The obstacle forced the birds into a curved flight during which rotational self motion components occurred. In analogy to the blowfly zebra finches changed the orientation of the gaze in geocentric coordinates only in saccades. These saccades, however, were not produced by body turns. They rather were generated by head turns instead. Between saccades gaze orientation did not change. This must have been achieved by head turns that compensated the rotational component of the flight path, as well as body turns occurring in maneuvers, such as braking. This gaze strategy optimizes the visual input for depth information. We concluded that the birds used optic flow to achieve information about the structure of the environment, e.g. the distance to the obstacle.

This gaze strategy is controlled by the optic flow produced during rotational self motion. The compensation

of rotationally induced optic flow is done via optokinetic reactions that control the neck muscles according to the overall motion of the visual scene. The optokinetic reaction can be demonstrated in the rotating drum paradigm. The bird is tethered while the visual scene – consisting of the inner walls of a drum – is being rotated around the birds. The optokinetic reaction stabilizes the retinal image by turning the head accordingly in the so called ‘slow phase’ of the response. The head is then turned back in a fast head movement during the ‘fast phase’. This is repeated as long as the visual scene is rotated.

It was assumed that the slow phase correlates with the intersaccadic intervals in free flight during which the orientation of the head in geocentric coordinates does not change. The fast phase of the optokinetic reaction in this case would correlate with the saccadic gaze shift we observed.

We used the rotating drum paradigm to test the optokinetic reaction in different conditions. The visual input to the mechanism controlling the optokinetic reaction is provided by the accessory optic system. At the first level of this visual upstream, retinal input is transferred to the nucleus lentiformis mesencephali and the nucleus of the basal optic root which code for self motion in different directions. The signal is then further processed in the inferior olive and the vestibulocerebellum.

An open question had been to what extent nucleus lentiformis mesencephali and nucleus of the basal optic root contribute to the optokinetic reaction. From our results we concluded that the contribution of nucleus of the basal optic root was insignificant or not existing. In another experiment we found that the performance of mechanism controlling the optokinetic reaction depends on illumination in a way that indicates the function of photoreceptors to be the only limiting factor for optokinetic reactions.

We then focused on the processing of optic flow in an object motion processing area, the nucleus rotundus of the tectofugal visual system. We presented anaesthetized zebra finches visual motion stimuli on a panoramic LED display during multi-unit recordings.

Due to previous results from other groups working on pigeons, areas of the tectofugal visual system were assumed to respond only to small objects but be inhibited by global motion. In our study, however, rotundal neurons responded to such stimuli with a significant increase in spike rate. We even found neurons preferring either motion patterns of virtual self-translation or such of virtual self-rotation. We concluded that the novel stimuli that provided optic flow including depth information and a panoramic stimulation allowed us to find previously unknown response properties.

In a further step towards more realistic motion stimuli we presented a virtual flight in the perspective of the bird. This was constructed from data acquired by our previous behavioral study.

We found neurons responding to objects in the visual scene of the naturalistic stimulus. One neuron signaled precisely when the obstacle appeared within its receptive field. Since the receptive field was located in the lateral part of the visual field, the neuron signaled that the object was being passed. Two other neurons produced peaks in spike rate when an object was located in heading direction. In other words, these neurons signaled the approach towards an object.

Our data indicates some parallels to the research conducted on the blowfly. Approach signaling neurons were found to prefer rotationally induced optic flow in the previously described test. In the blowfly, a neuron assumed to code for horizontal rotational self motion (yaw turns) was found to signal the spatial relation between the fly and the walls in a naturalistic replay experiment. In both animals the visual motion induced by saccadic gaze shifts did not elicit a response as it would have been expected if the neuron’s purpose was to signal rotational self motion.

Taken together, we were able to demonstrate new response properties in single neurons which could not be predicted by the response to more conventional stimuli like it was also shown for the blowfly. Realistic stimuli allowed us a new perspective on the function of motion selective neurons.