A functional explanation of otolith structure

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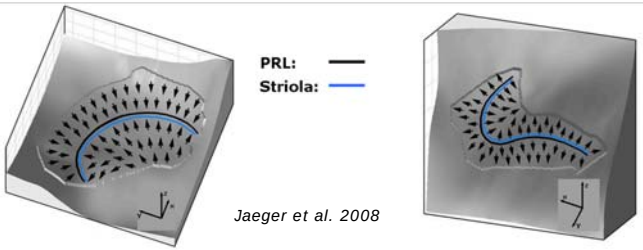
Problem statement

Otolith organs are responsible for sensing linear head accelerations including gravity.

We investigate the role that the structure of otolith organs plays in their sensory function, focusing on the role of the **striola**.

The striola is a narrow curved zone that divide each macula in two areas:

1. It is observable in all mammalians.
2. It is parallel to the line of polarity reversal (PRL).
3. It differs structurally from the extra-striolar regions.

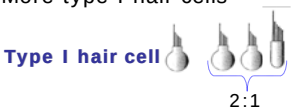


Jaeger et al. 2008

Striola vs extra-striolar regions

STRIOLA:

1. More type I hair cells

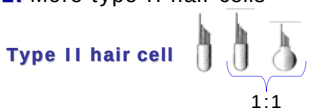


2. Calyx and dimorphic afferents:

- 2.1. Irregular
- 2.2. Phasic and phase advanced
- 2.3. Transient

EXTRA-STRIOLAR REGIONS:

1. More type II hair cells



2. Dimorphic and bouton afferents:

- 2.1. Regular
- 2.2. Tonic
- 2.3. Sustained

Calix — Dimorphic — Bouton

Goldberg, 2000

Irregular afferent discharge — Regular afferent discharge

Goldberg and Fernandez, 1971

Approach

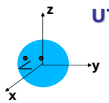
We propose a functional model that can account for the structural diversity between the striola and the extra-striolar regions as well as for the observed shape of the striola

Our model is based on two hypotheses:

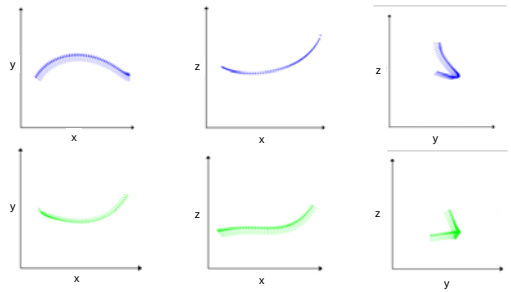
- Hair cells of type I together with striolar afferents constitutes a subsystem specialized in the detection of the direction acceleration variations (*jerk*), including gravity variations.
- The observed shape of the striola, that is a narrow curve region with curvature and torsion, is such that it allows the detection of a large domain of jerk.

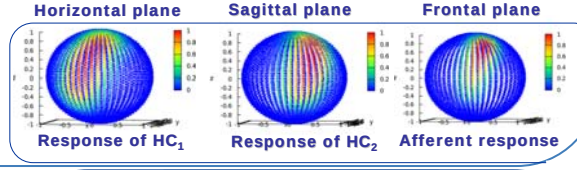
Model of acceleration detection

- The striola is modelized as a 3D curve lying on a spherical surface representing the macula.
- Available data on humans: Tribukait et al. 2001 (utricule), Tribukait et. 2005, Naganuma 2001 (saccule), Takagi et al. 1988 (utricule and saccule).
- Most striolar afferents capture several hair cells (HCs).
- Acceleration direction changes are computed by a striolar afferent as intersection of sectors associated to the hair cells it captures.
- Each sector is perpendicular to the macula and determined by the polarization vector of the hair cell.
- Curvature and torsion are necessary to the striolar afferents to detect a large domain of jerk in spite of being localized on a narrow region.



UTRICULAR AND SACCULAR STRIOLA

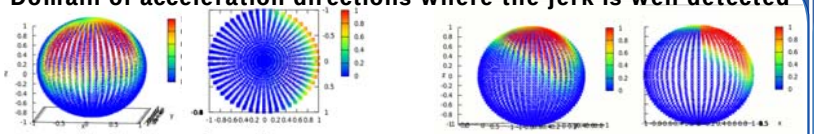




Results

UTRICULE — **SACCULE**

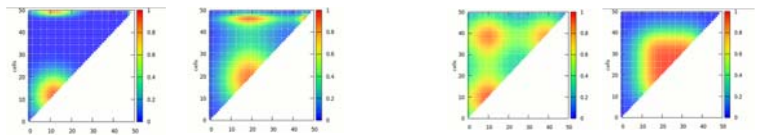
Domain of acceleration directions where the jerk is well detected



Lateral view — Downside view — Lateral view — Posterior view

These results are similar to those obtained by Goldberg & Fernandez 1976

Afferent responses to different acceleration direction stimuli



A good estimation of the original stimulus can be obtained by BPNN

Conclusions

- We have developed a functional model of the striolar system that explains:
  - The structural diversity between the striola and the extra-striolar regions
  - The observed shape of the striola
- We have proved the possibility of the existence of a striolar subsystem able to detect a large domain of jerk
- We have proved that information coded by our model can be decoded by the brain
- We have tested robustness with respect to neuronal variability

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