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► **To cite this version:**

Julien Bacqué-Cazenave, G Courtand, Mathieu Beraneck, D Combes, F M Lambert. Locomotor-driven oculomotor behavior that stabilizes gaze is timed to mid-tail region undulations during swimming in larval *Xenopus*. 10th SFN Satellite Symposium on Motor Systems, Nov 2017, Washington, DC, United States. hal-04724115

HAL Id: hal-04724115

<https://hal.science/hal-04724115v1>

Submitted on 7 Oct 2024

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Locomotor-driven oculomotor behavior that stabilizes gaze is timed to mid-tail region undulations during swimming in larval Xenopus

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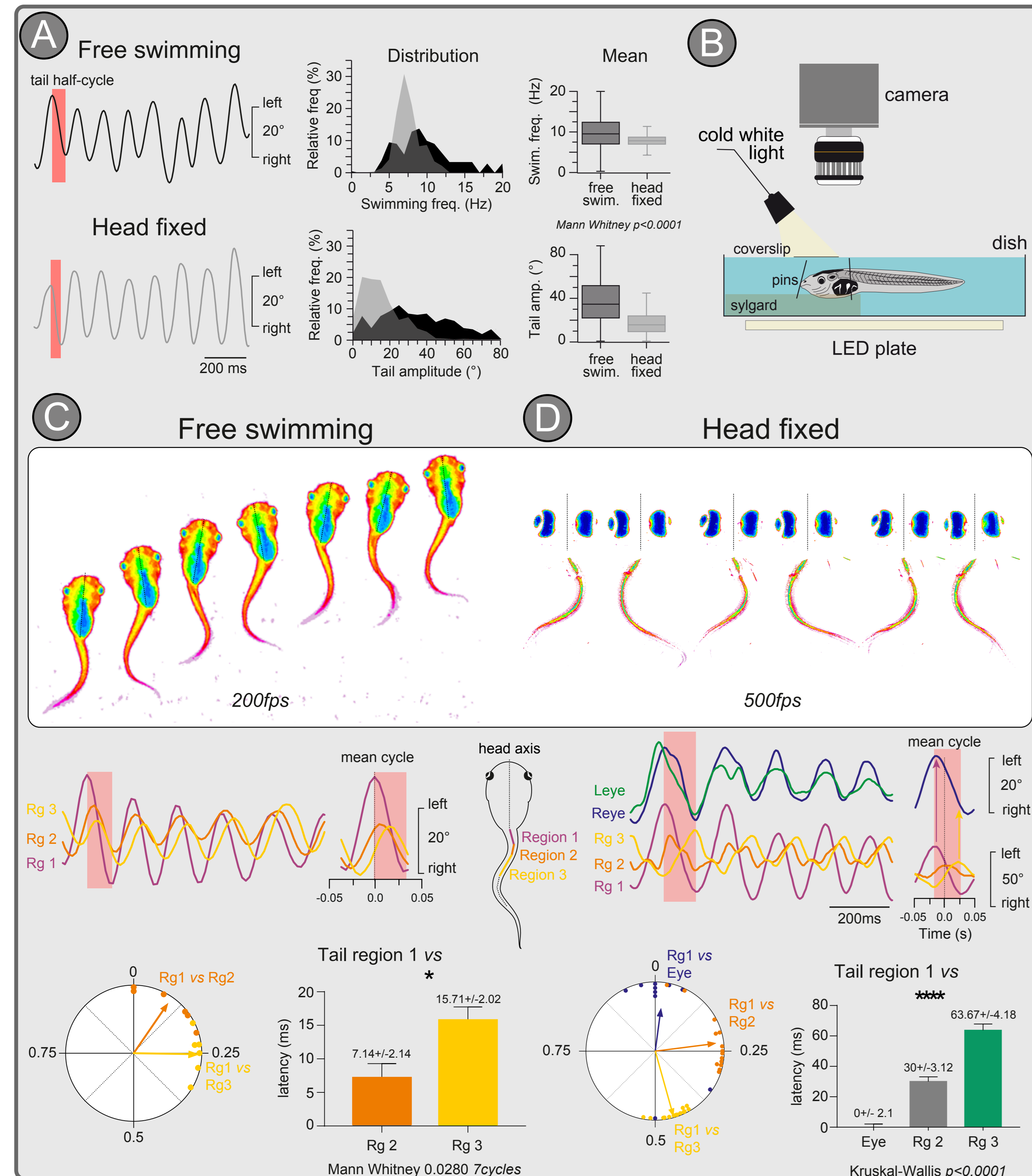
November 10th 2017
Motor Systems Symposium
Washington DC

Introduction

- > Locomotor efference copy signaling produces bursting activity in horizontal extraocular motor nerves coupled with burst discharge in spinal ventral root nerves (Vr). In order to produce compensatory conjugate eye movements during swimming, discharge in the lateral rectus (LR) (and the opposite synergistic medial rectus (MR)) extraocular motor nerve of each eye occurs in phase with contralateral spinal bursts. During robust undulatory swimming, this spino-extraocular motor coupling originates from CPG circuitry in rostral spinal cord segments (until the 10th segment).
- > Tail undulation results from a multi-segmental wave of left-right alternate contractions occurring with a rostro-caudally directed delay along the tail. This delay determines the timing of the undulation of each part of the tail during swimming.
- > Therefore thus extraocular motor output must be time-adjusted to the multi-segmental CPG locomotor rhythm in order to produce appropriate compensatory eye movements during tail undulation.

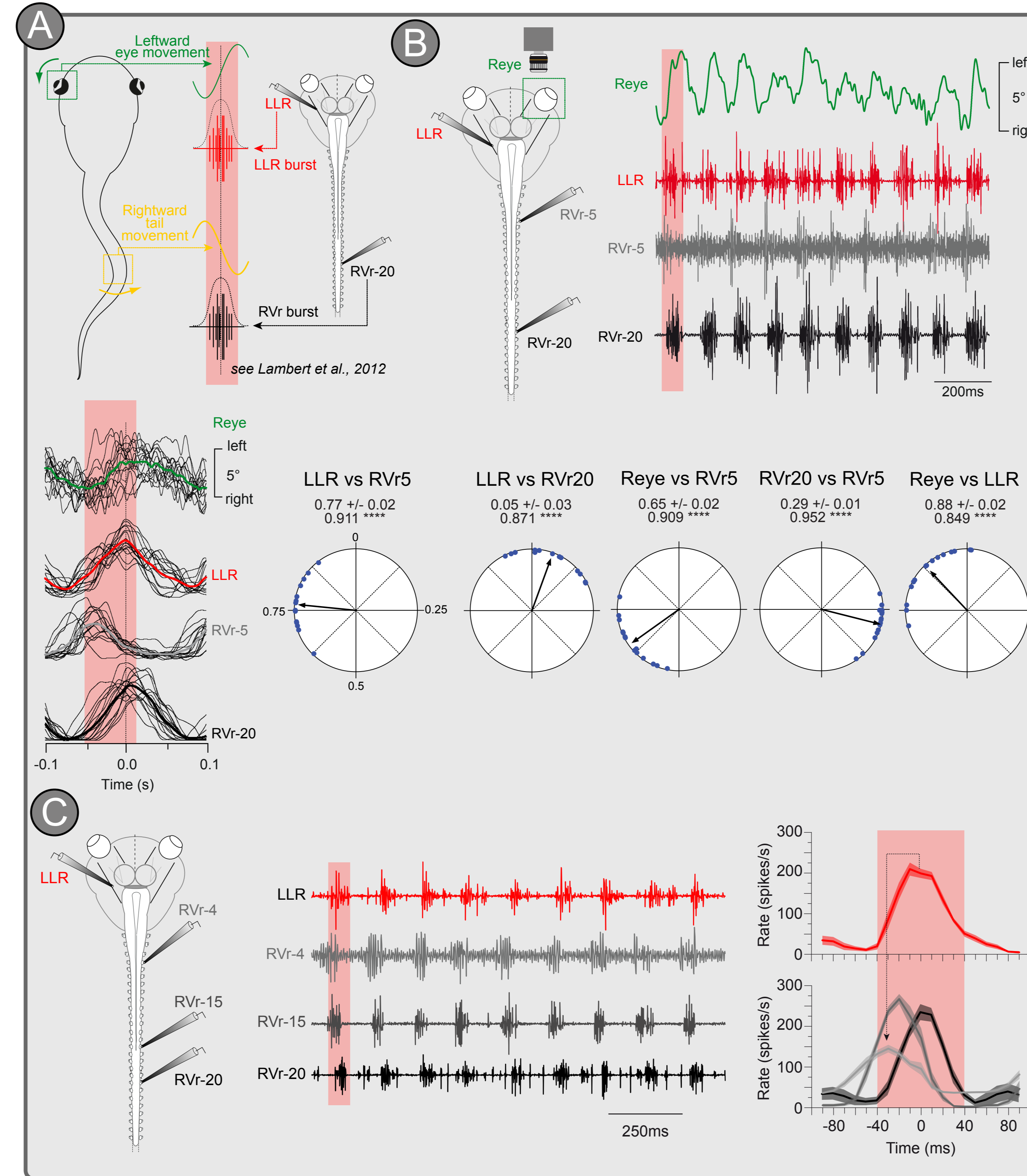
Conclusion

- > Spino-extraocular motor coupling originates from rostral spinal CPGs that generate a locomotor efference copy signaling to produce conjugate eye movements to stabilize the gaze during undulatory swimming.
- > This locomotor-induced oculomotor behavior is produced to compensate the undulation of the mid-tail region. Consequently the discharge pattern in horizontal extraocular motor nerves is calibrated to be in phase with the bursting activity in spinal CPGs that are responsible for the alternative bilateral myotom contraction in mid-tail segments.
- > The mid-tail region is the most efficient for the forward displacement by performing the maximum thrust in the water. Therefore it appears necessary for the larva to stabilize the gaze in order to compensate the biomechanical effect of the mid-tail segments during swimming.



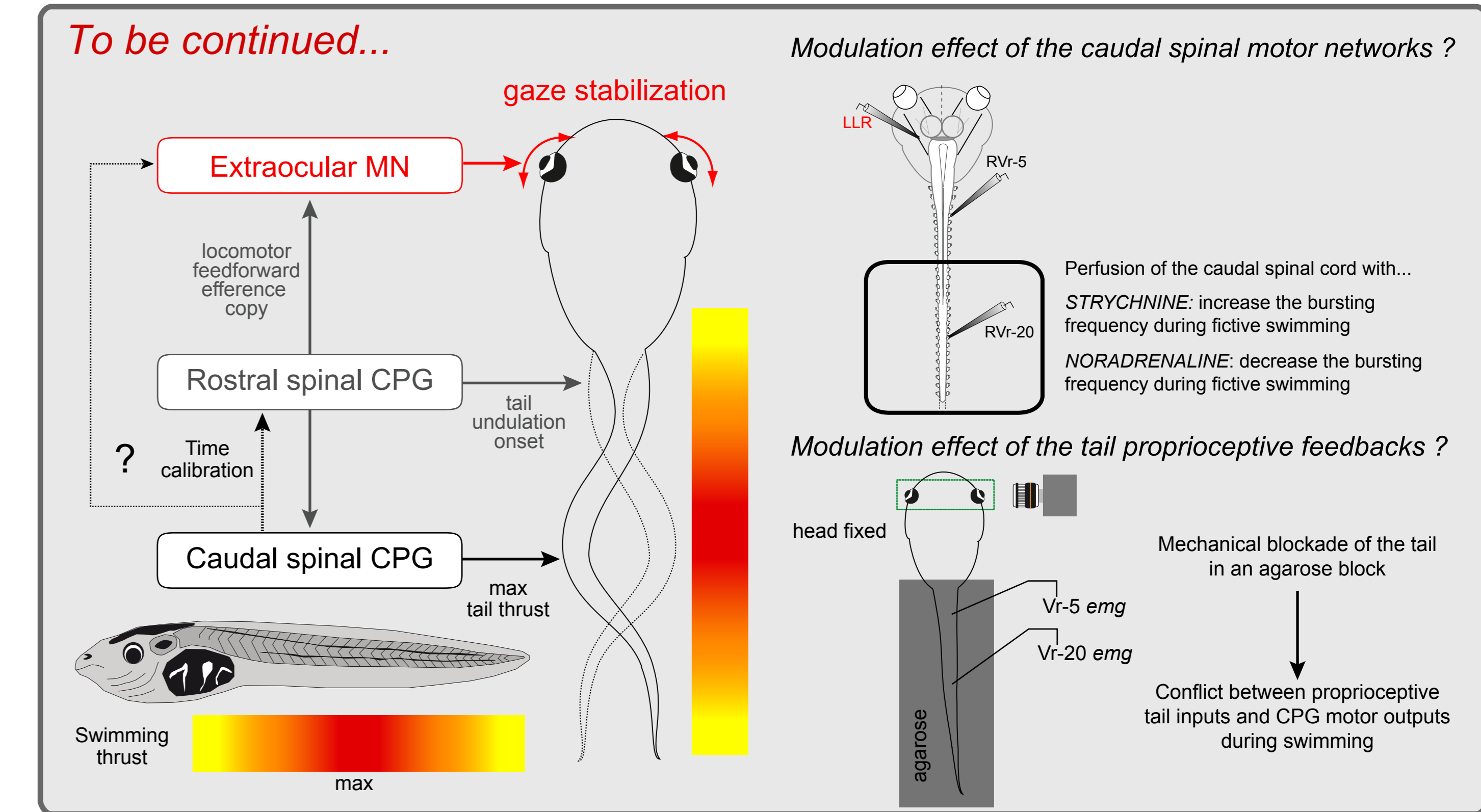
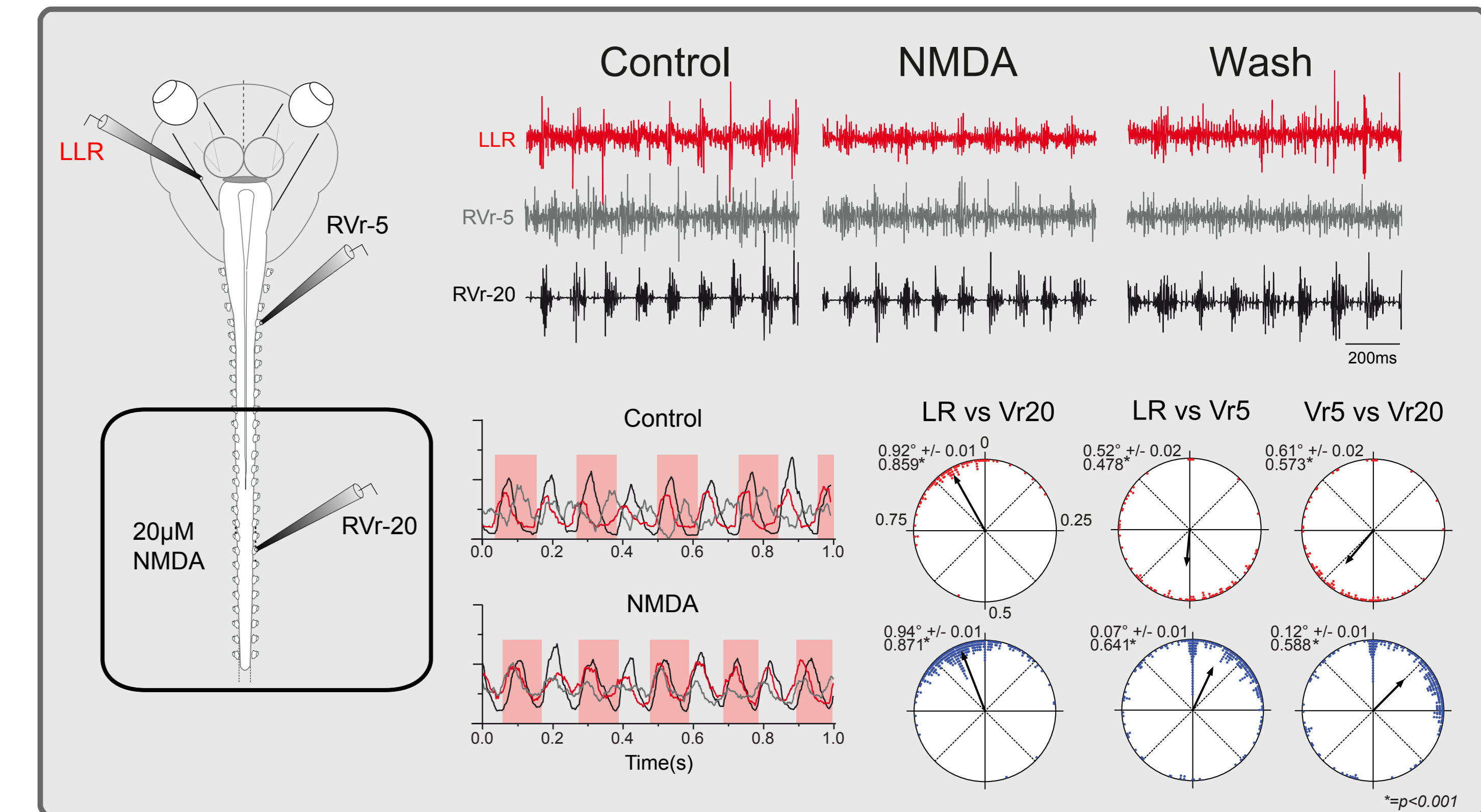
Undulatory pattern of the tail and locomotor-induced eye movements

- > Semi-intact preparations with the eyes and tail kept intact were used to video record locomotor-induced oculomotor behavior during swimming sequences in head-fixed stage 54-56 larvae (B).
- > Comparable undulatory swimming patterns in free swimming and head-fixed larvae (A).
- > The rostro-caudal myotomal contraction wave produced by the axial CPG chain produced a phase shift of 0.25 between the rostral and mid-caudal tail regions, with a latency of 15.7ms (C).
- > In head-fixed semi-intact preparations, locomotor-induced conjugate eye-movements that moved in the opposite direction to tail movement were closely coordinated with bending of the medio-caudal portion of the tail (segments 15-20) (D).



The spino-extraocular motor command is timed to mid-cord CPG activity

- > Spino-extraocular pathways (A) generate conjugate eye horizontal movements that compensate for head movements produced by left-right alternation of the tail. Thus, left LR (LLR) burst discharge (leftward movement of the left eye) occurs in phase with right Vr (RVr) discharge (rightward tail movement). This coupling originates from the rostral spinal CPGs (Lambert et al., 2012)
- > In vitro preparations (B) were used to record locomotor-induced eye movements and concomitant discharge in the LR and Vr motor nerves. During fictive swimming, right eye movement was associated with left LR bursting activity. Eye movement (Reye) and correlated extraocular activity (LLR) was in phase with right Vr20 bursts, whereas Rvr5 bursts occurred with a phase lead.
- > Segments 8 and 15 displayed Vr burst discharge with an intermediate phase shift (C).



Effect of mid-cord CPG activity on spino-extraocular time calibration?

- > Perfusion of mid-cord segments with NMDA changed the phase shift between LR and contra Vr5 and Vr20. Whereas LLR displayed burst discharge in phase with RVr20 and out of phase with RVr5 burst in control, this last rostral Vr showed a bursting activity with a reduced phase shift with LLR and RVr20 burst discharge during NMDA application (upper panel).
- > We want to investigate the possible effect of caudal spinal motor networks on spino-extraocular motor coupling by triggering different fictive swimming frequency between rostral (until 10th) and caudal (15-22) CPGs in the same preparation (lower panel).
- > We want to test the possible effect of tail proprioceptive feedbacks in the spino-extraocular time calibration by generating a sensory-motor conflict.