An Agent-Based Model of Motor Adaption in Larval Zebrafish

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1. Introduction

- Static interpretations of the brain perceive behaviour as a mapping between sensory inputs and motor outputs, showing a strong affinity to the traditional "sense, plan, act" models that defined Good Old Fashioned Artificial Intelligence (GOFAI), see fig 1a.

fig 1a

- These ignore the brains mutual interaction with the body and environment through reafferent feedback – sensory signals that result from an animal's own motions – see fig 1b. (von Holst and Mittelstaedt, 1950)

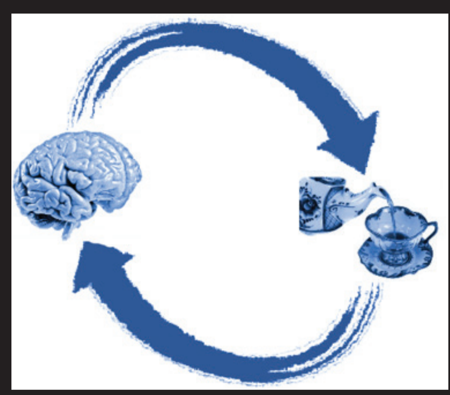


fig 1b

- There is therfore a strong need, when explaining neural dynamics in a real world system, to understand behaviour that emerges from these closed loop interactions between the brain, body and environment. (Beer, 2009)

2. Virtual Flow Simulator

- Ahrens et al. (2012) have developed technology that utilises paralysed larval zebrafish behaving in a virtual flow simulator. Activity from motor neurons along the fish's spine are interpreted as swimming power, allowing the fish to fictively swim against an oncoming flow. This is simulated by providing a visual stimulus of moving lines on a screen, see fig 2a.
- A feedback gain – a factor that translates the strength of the fictive swim signal – was used. A high feedback gain corresponded to a "strong" fish and a low feedback gain to a "weak" fish. Periodical switching of the feedback gain between high and low was used to encourage compensatory changes in motor output. (Ahrens et al., 2012)
- The fish was analysed swimming in both closed loop and open loop (replay) conditions – in the open loop condition the motor neuron activity is ignored and the virtual environment replays the preceding period of recorded activity. (Ahrens et al., 2012)

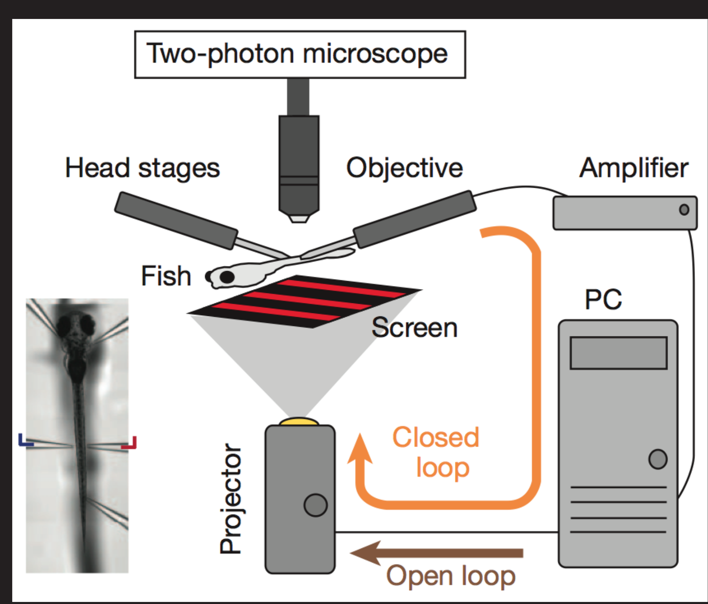


fig 2a

- The research conducted by Ahrens et al. (2012) showed decoupling the fish from the environment, through the open loop (replay) setup, produced erratic behaviour in the fish's motor neuron activity, see fig 2b.

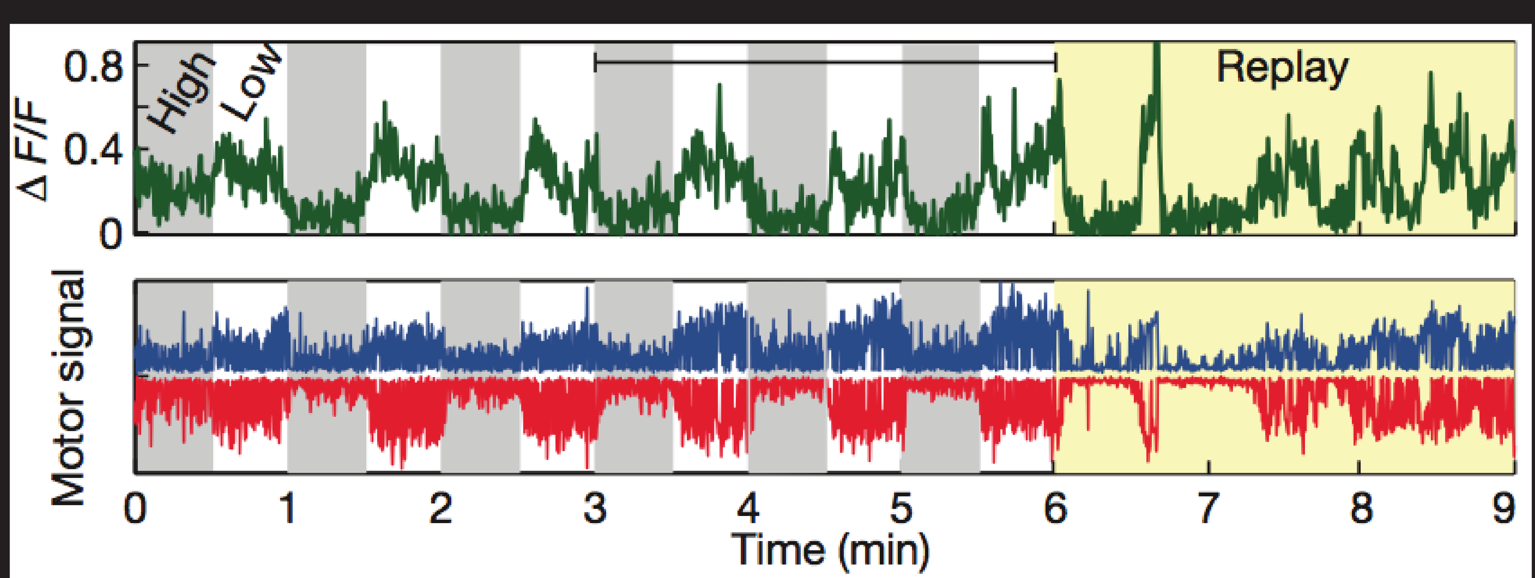


fig 2b

- Data analysed previously by Buckley (2014) showed the population averages of logarithmic low frequency power and pairwise intra-neural correlations, see fig 2c.

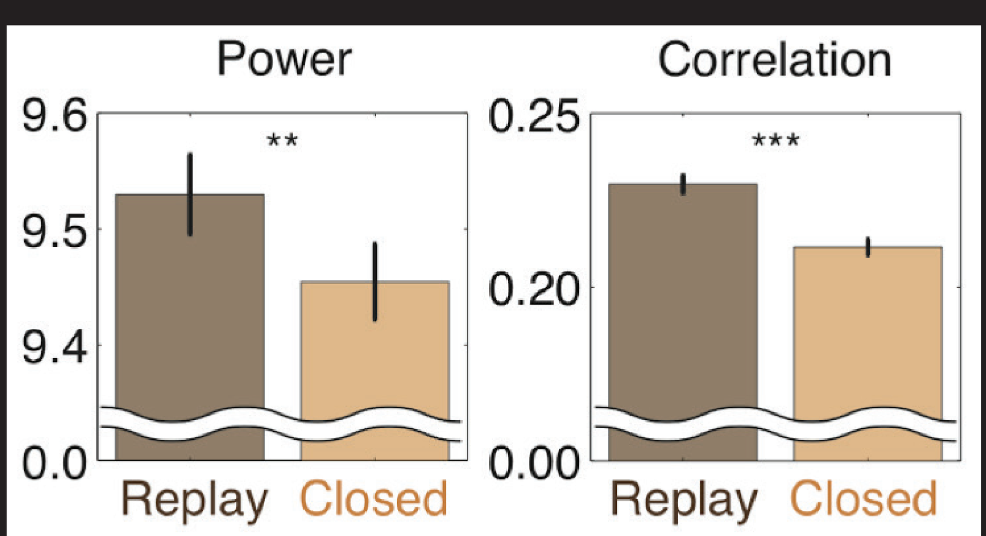


fig 2c

- It was expected that an agent-based model of this setup, that utilised feedback from the environment, would produce similar results.

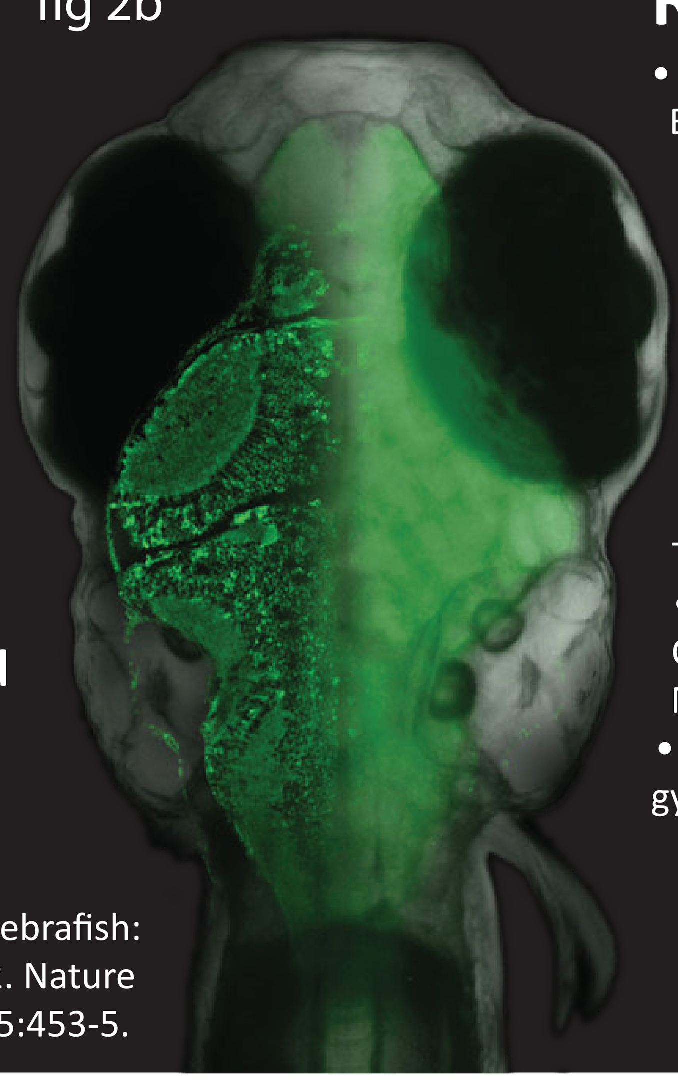


Image of Zebrafish: Fetcho J.R. 2012. Nature 485:453-5.

3. Software Model

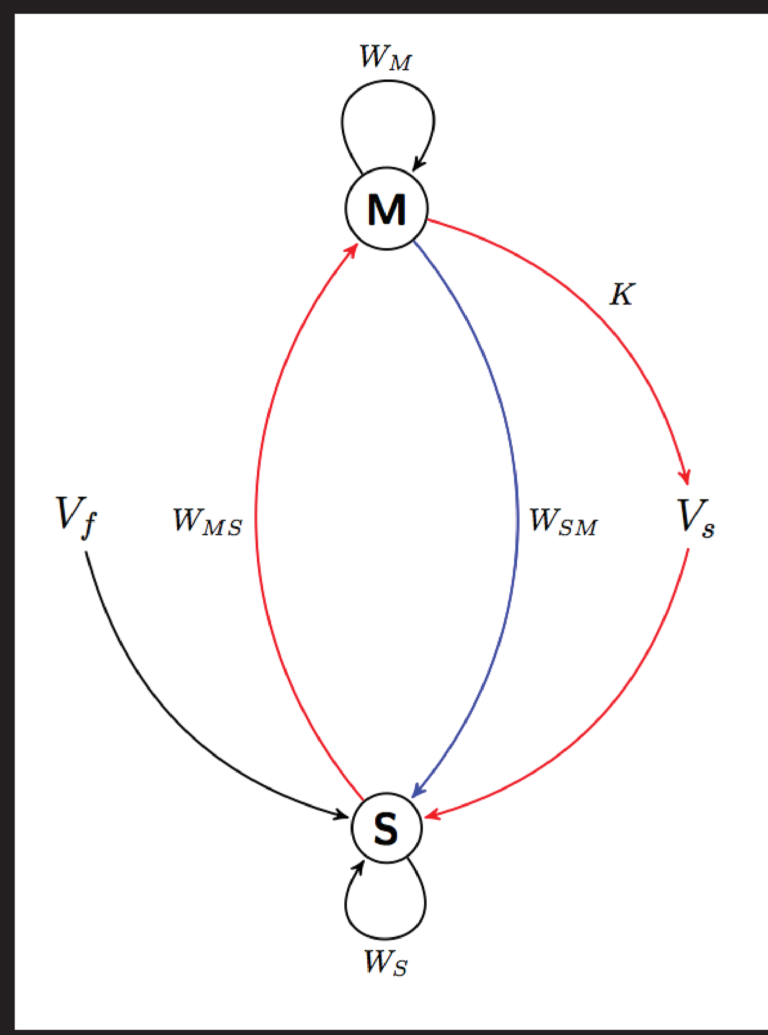


fig 3a

- A minimal software model of Ahrens et al. (2012) flow simulator was implemented in Matlab.
- An agent based dynamical system was then modelled, using a two node Continuous Time Recurrent Neural Network (CTRNN), to perform the required motor adaption behaviour, see fig 3a & 3b.

M = Motor node
S = Sensor node
V_s = Swim velocity
V_f = Flow velocity
K = Feedback gain parameter

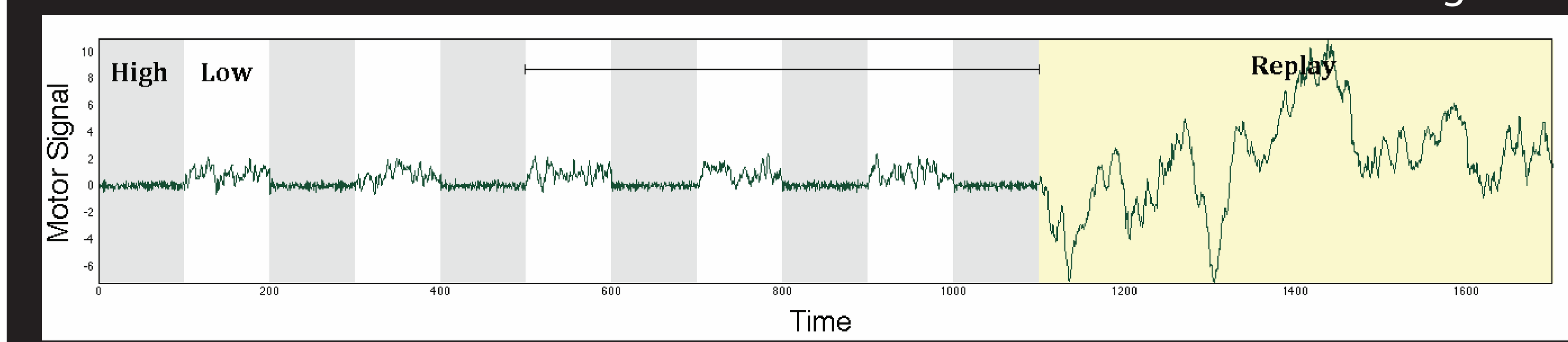
fig 3b

$$\begin{aligned}\dot{M} &= -M + W_M M + W_{MS} S \\ \dot{S} &= -S + W_S S + W_{SM} M - (V_s + V_f) + \gamma \\ V_s &= KM\end{aligned}$$

4. Results

- As predicted, the motor neuron activity in the simulated fish became erratic during the open loop (replay) period, see fig 4a & 4b.

fig 4a



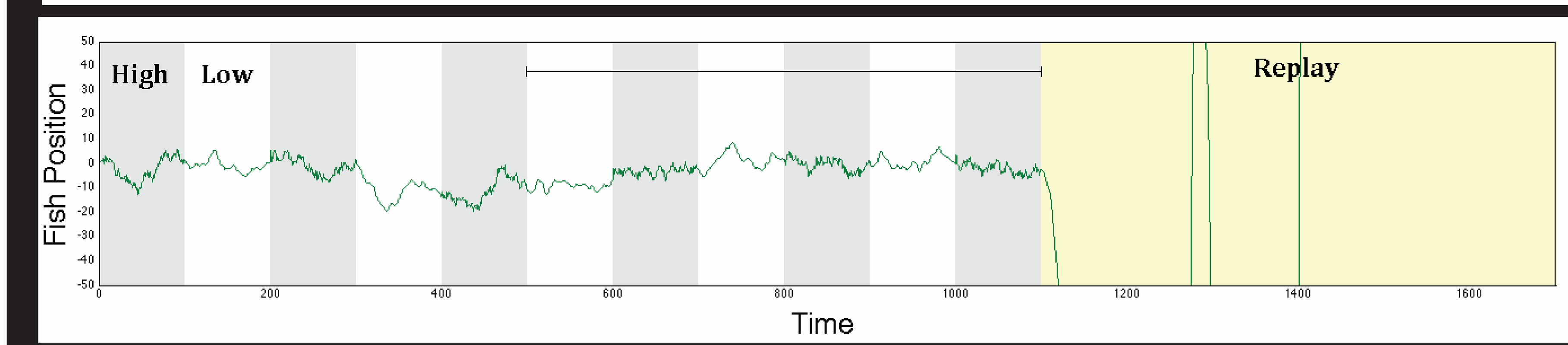


fig 4b

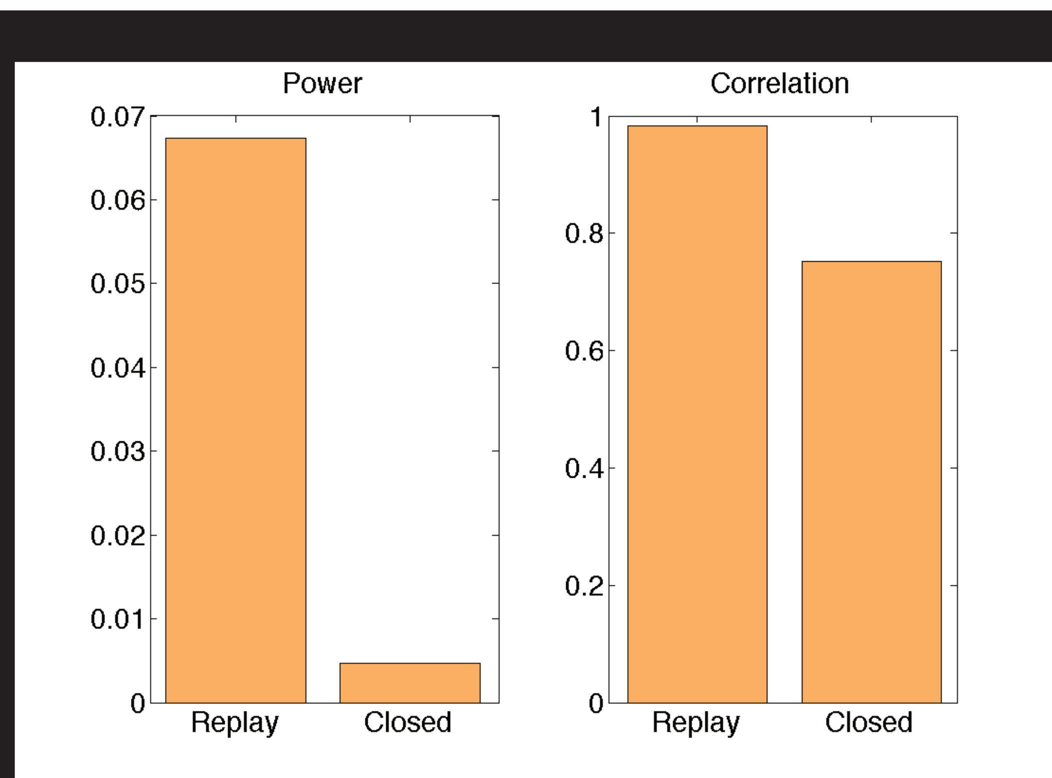


fig 4c

- The population averages of logarithmic low frequency power and pairwise intra-neural correlations were again both suppressed under the closed loop condition relative to the open loop (replay) condition, see fig 4c.

References

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Full code can be found at http://jraproject.sourceforge.net/

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