Transfer learning in larval zebrafish (*Danio rerio*)

Javier J How*1/2/3, Gregor Schuhknecht*2, Misha B Ahrens∞3, Florian Engert∞2, Joshua T Vogelstein∞1
[1]Johns Hopkins University, Baltimore, MD, [2]Harvard University, Cambridge, MA,
[3]Janelia Research Campus, Ashburn, VA, */∞ authors contributed equally

Introduction

- Artificial intelligences (AIs) tend to have a fairly narrow area of applicability and cannot continuously accumulate knowledge. One way to address this shortcoming is to develop AIs that can perform transfer learning.
- Larval zebrafish (*Danio rerio*) readily adapt how strongly they swim to translate by a fixed distance [1, 2]. However, it remains unknown if fish can transfer their adapted state between tasks: if trained on whole-field motion in one direction, will they transfer their swim vigor to a novel direction?
- We found that 1) fish adapt how strongly they swim to match the artificially set gain in any direction and that 2) fish transfer the swim vigor they had learned for motion in one direction (e.g., forward) to a novel direction (e.g., leftward). These results set us up to study how the larval zebrafish brain performs transfer learning.

Methods

Baseline Task	Base Task	Transfer Task
Assess baseline performance on a task	Learn something	Previously learned info. improves performance

Figure 1 Transfer learning requires an intelligence to learn something on the Base Task, and transfer this knowledge to a different, yet related, Transfer Task. The Baseline Task serves as a comparison.

Visual stimulus reliably induces the optomotor response (OMR)

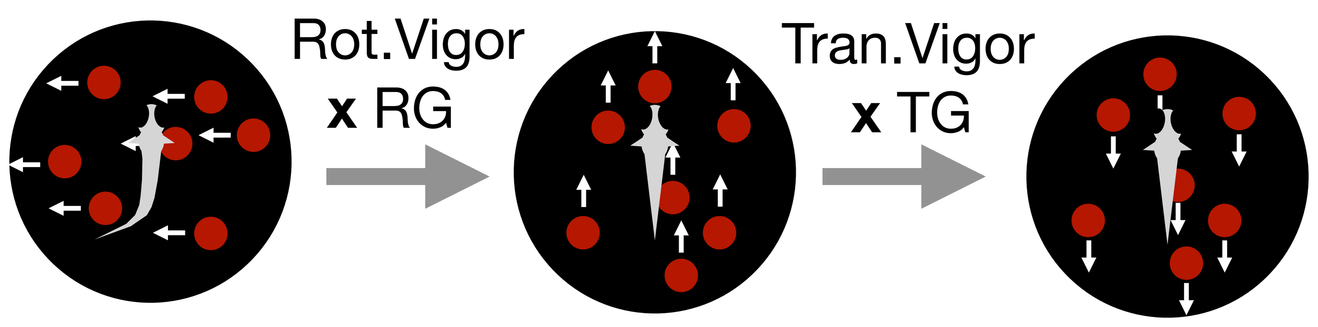

Figure 2 Larval zebrafish are embedded in agarose and their tails are freed. Moving dots are projected from below, and a camera above the fish tracks their tails. The deflection of each fish's tail is used to simulate movement by rotating and translating the stimulus. An experimenter-set rotational gain (RG) controls how much the stimulus rotates; translational gain (TG) controls how much it translates. Setup described in [3].

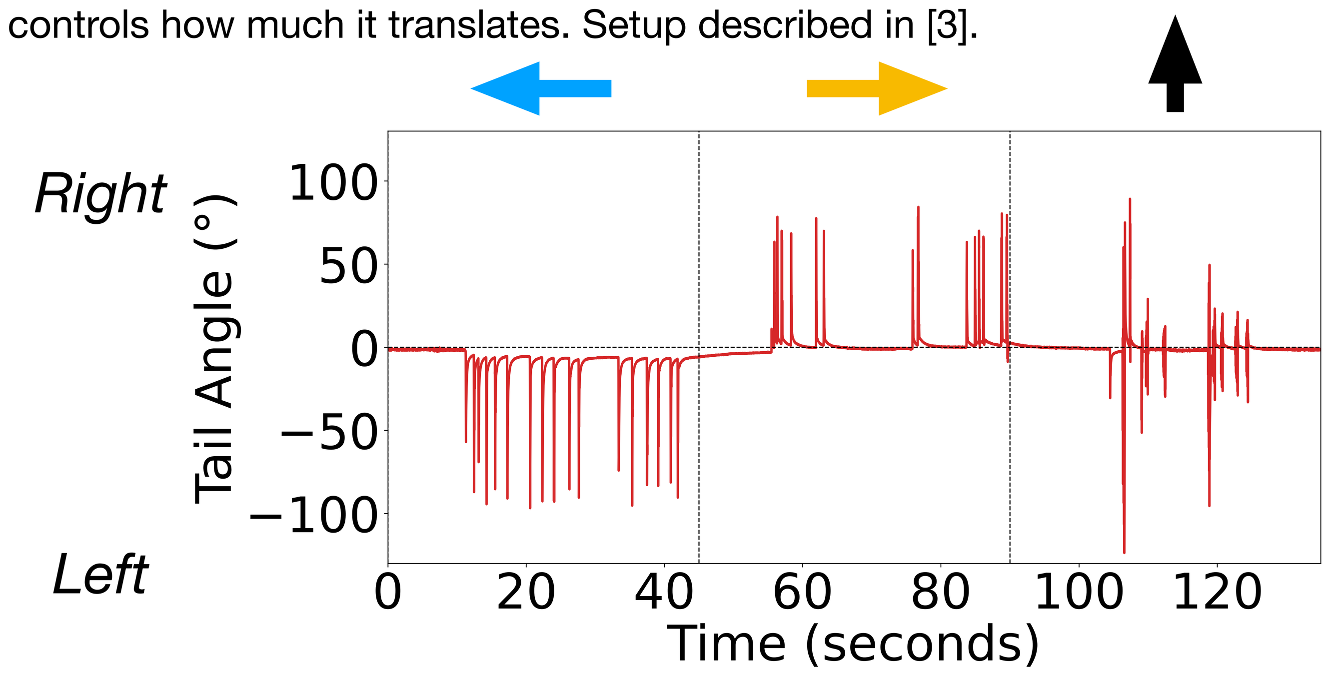

Figure 3 The visual stimulus reliably induces the OMR. This example trace from one fish shows that fish move left when shown leftward moving dots (blue arrow), right when shown rightward moving dots (yellow arrow), and make symmetric bouts to move forward when shown forward moving dots (black arrow). Dashed line at 0°. N = 1 fish.

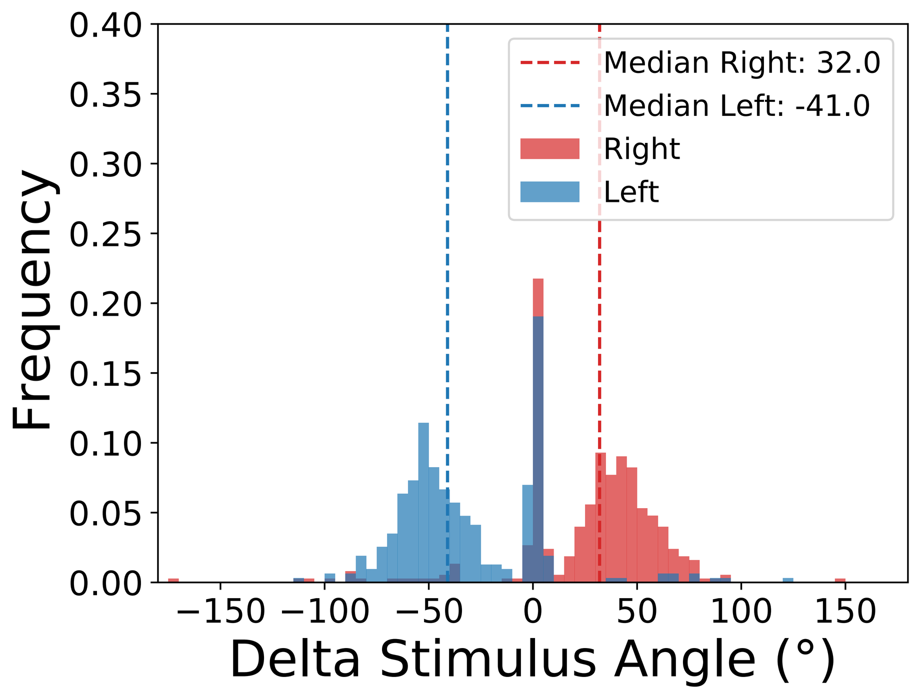

Figure 4 Fish turn the stimulus by a natural amount in response to leftward (blue) or rightward (red) moving dots. Gains linking tail movement to stimulus rotation were manually set to reproduce turning histograms in free-swimming larval zebrafish. N = 32 fish.

Kinematic features of the fish tail during swimming

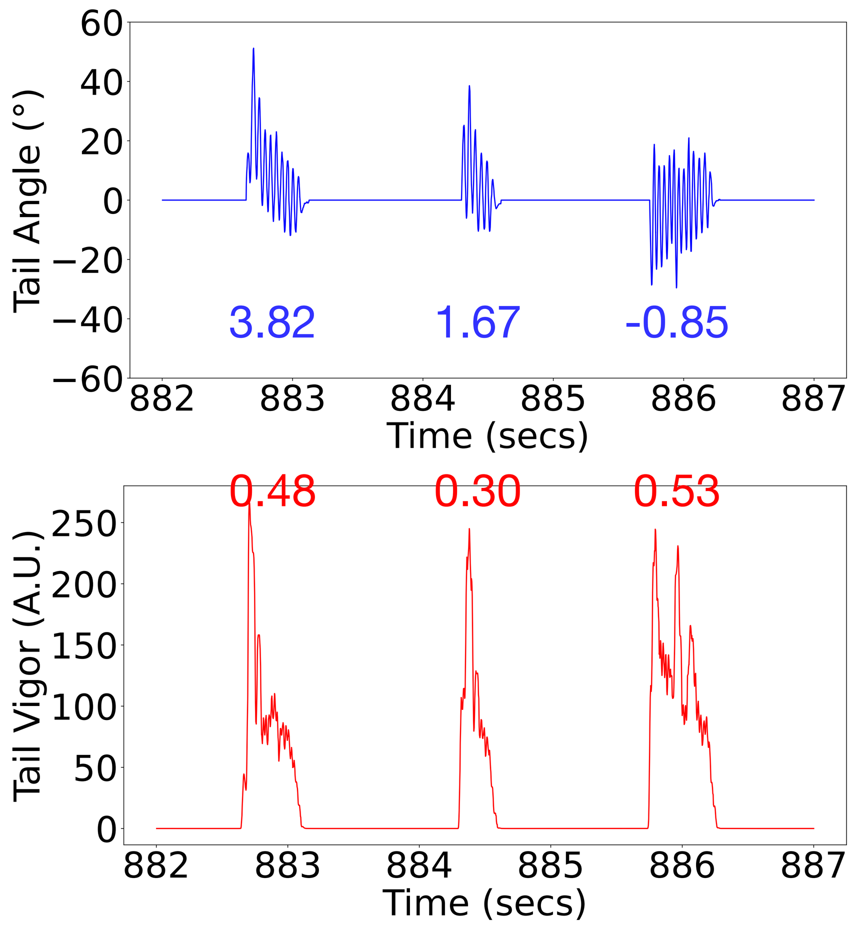

Figure 5 The angle between the fish's midline and the tip of its tail (i.e., tail angle, blue) is used to simulate turns (by rotating the stimulus). The 50-ms rolling window variance of the tail angle (i.e., tail vigor, red) is used to simulate forward movement (by moving the stimulus backward). The numbers indicate the integral of tail angle (blue) or vigor (red) for a single bout.

Results

Larval zebrafish demonstrate translational and rotational gain adaptation

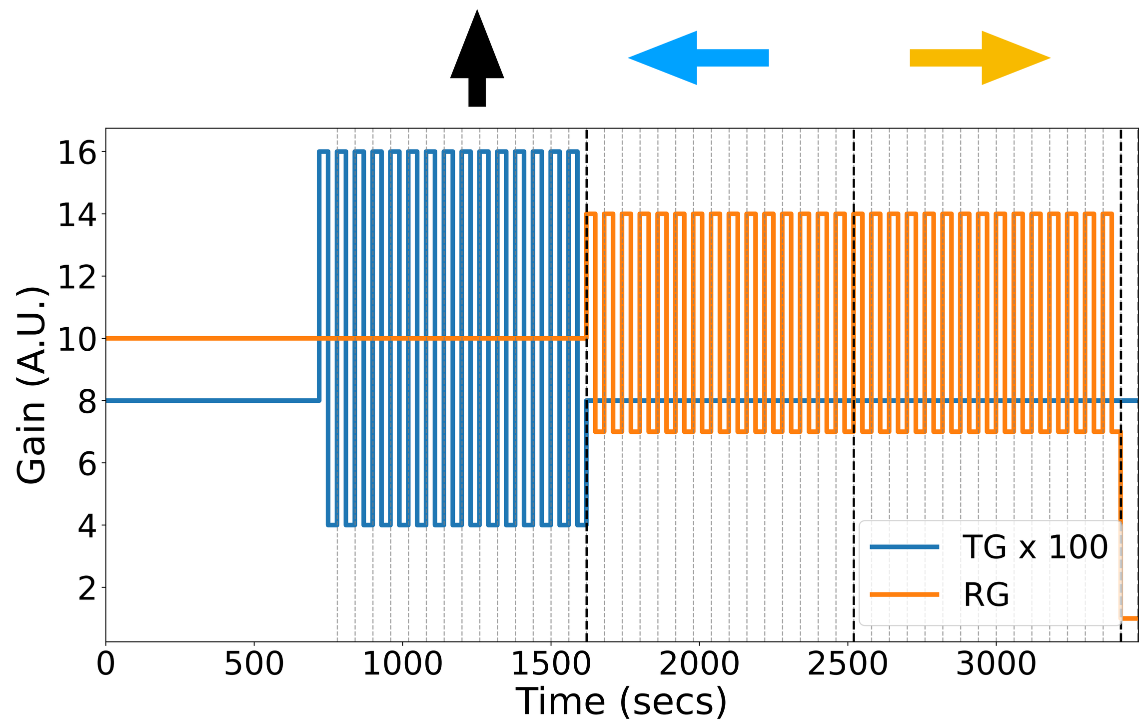

Figure 6 Motor learning paradigm. Fish first underwent a 12 minute-long habituation period where dots moved forward and both translational and rotational gains were fixed. We then interleaved 30 high- and low-translational gain periods (blue) while dots moved forward (black arrow). We then interleaved 30 high- and low-rotational gain periods (orange) while dots moved leftwards (blue arrow) or rightward (yellow arrow).

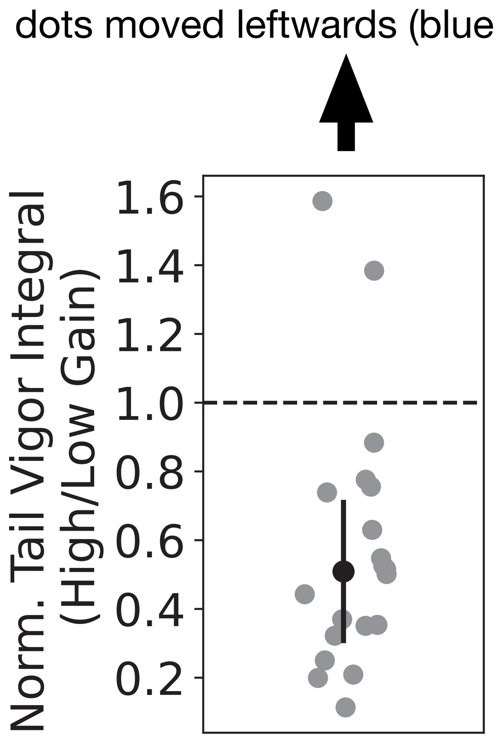

Figure 7 Fish learn to swim less strongly during high-gain periods compared to low-gain periods. The dashed line indicates the point at which the tail vigor integral during high-gain periods is equal to the tail vigor integral during low-gain periods (i.e., fish do not perform translational gain adaptation); values below this line indicate gain adaptation occurred. Each dot is the median of a fish across 15 trials (see Figure 6); N = 20. The black dot and bar is the median ± median absolute deviation.

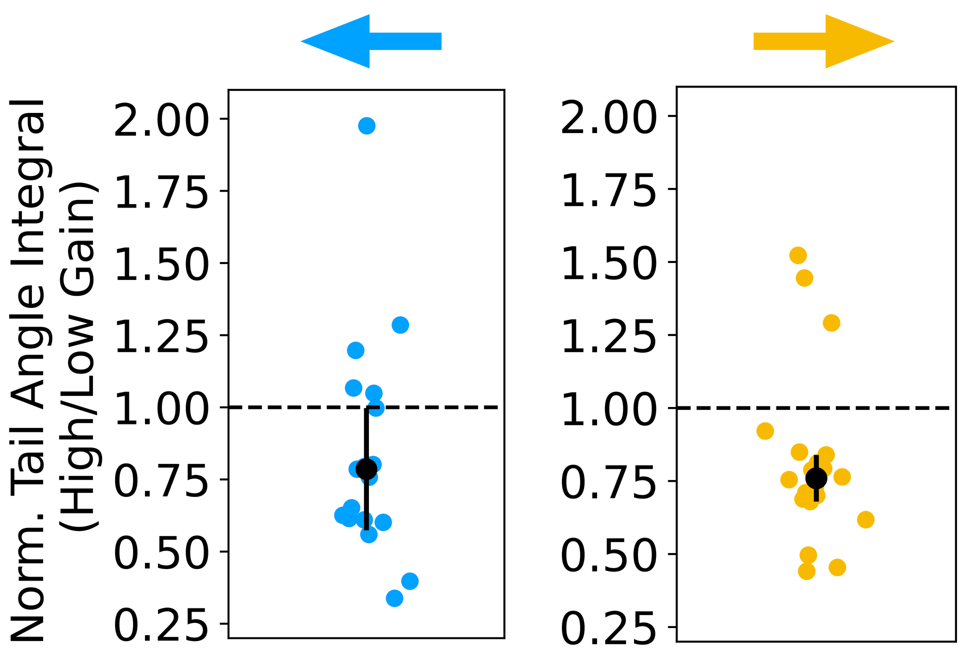

Figure 8 Fish learn to turn less strongly during high-gain periods compared to low-gain periods. Arrow indicates direction of motion (i.e., left or right). N = 17 for left, 20 for right.

Results (continued)

Larval zebrafish demonstrate transfer learning

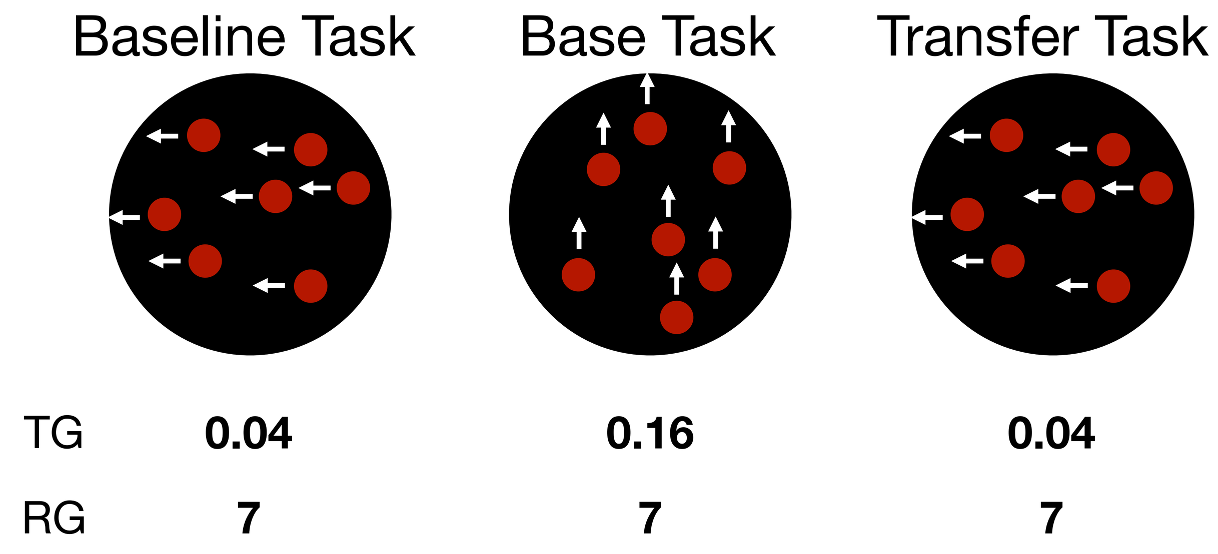

Figure 9 Transfer learning paradigm to test if fish can transfer learned translational vigor to rotational vigor. First, we measure their baseline rotational vigor in the Baseline Task. Then, we increase the translational gain (TG) during the Base Task and show forward-moving dots - this elicits forward swims, and should lead to translational gain adaptation (see Figure 7). Finally, we remeasure rotational vigor in the Transfer Task - if the fish transferred its adapted state, it will turn less strongly. Note that rotational gain (RG) is held constant.

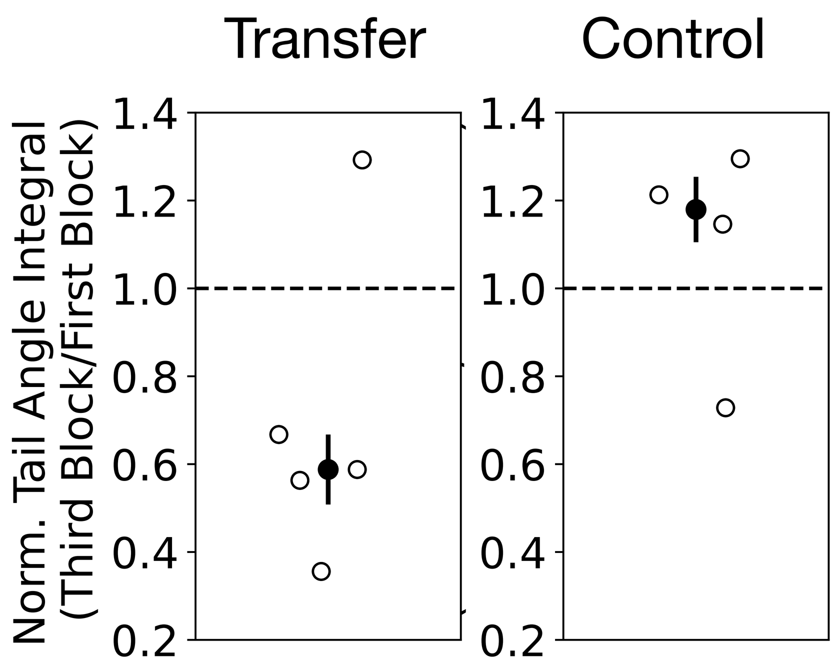

Figure 10 Fish transfer their adapted state during the Transfer (left), but not Control (right) setting. The Transfer setting is described in Figure 9. Unlike the Transfer Setting, the TG is not changed during the Control setting; thus, there should be no change in rotational vigor. N = 5 for Transfer, 4 for Control Settings.

Conclusions

1. Larval zebrafish adapt how strongly they swim forward (i.e., translational vigor) and how strongly they turn (i.e., rotational vigor)
2. Larval zebrafish transfer translational vigor to rotational vigor for leftward swims

Future Directions

- Can larval zebrafish transfer between all directions (i.e., F -> R, L -> R, R -> L, L -> F, and R -> F)?
- Can larval zebrafish transfer increases in vigor as well as decreases in vigor (shown above)?
- Do larval zebrafish also demonstrate backwards transfer?
- How does the brain support translational and rotational gain adaptation?
- How does the brain support transfer motor learning?

References

1. Ahrens, M. B. et al. (2012). Brain-wide neuronal dynamics during motor adaptation in zebrafish. Nature, 485(7399), 471–477.
2. Portugues, R., & Engert, F. (2011). Adaptive locomotor behavior in larval zebrafish. Frontiers in Systems Neuroscience, 5, 72.
3. Bahl, A., & Engert, F. (2020). Neural circuits for evidence accumulation and decision making in larval zebrafish. Nature Neuroscience, 23(1), 94–102.