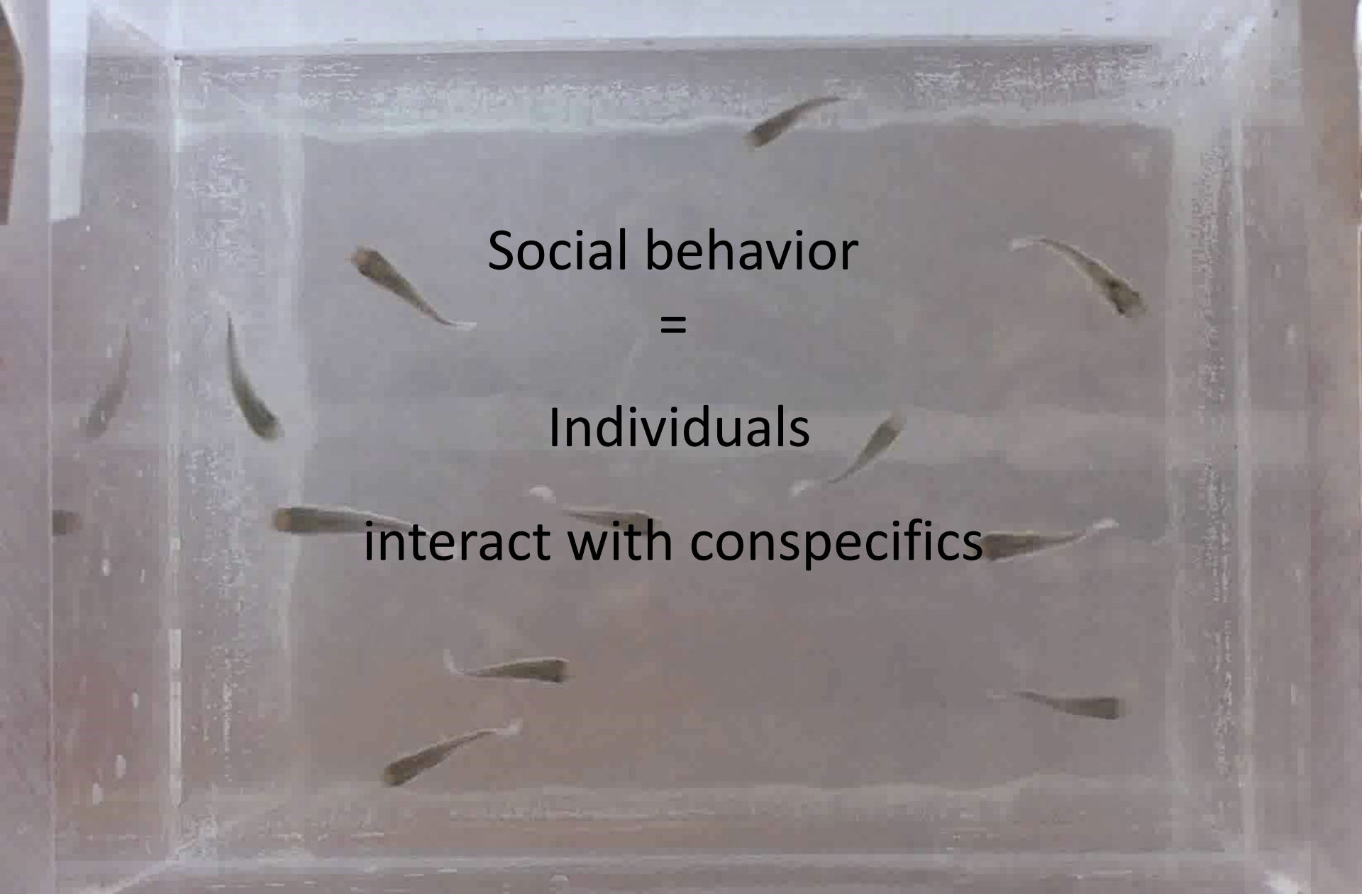
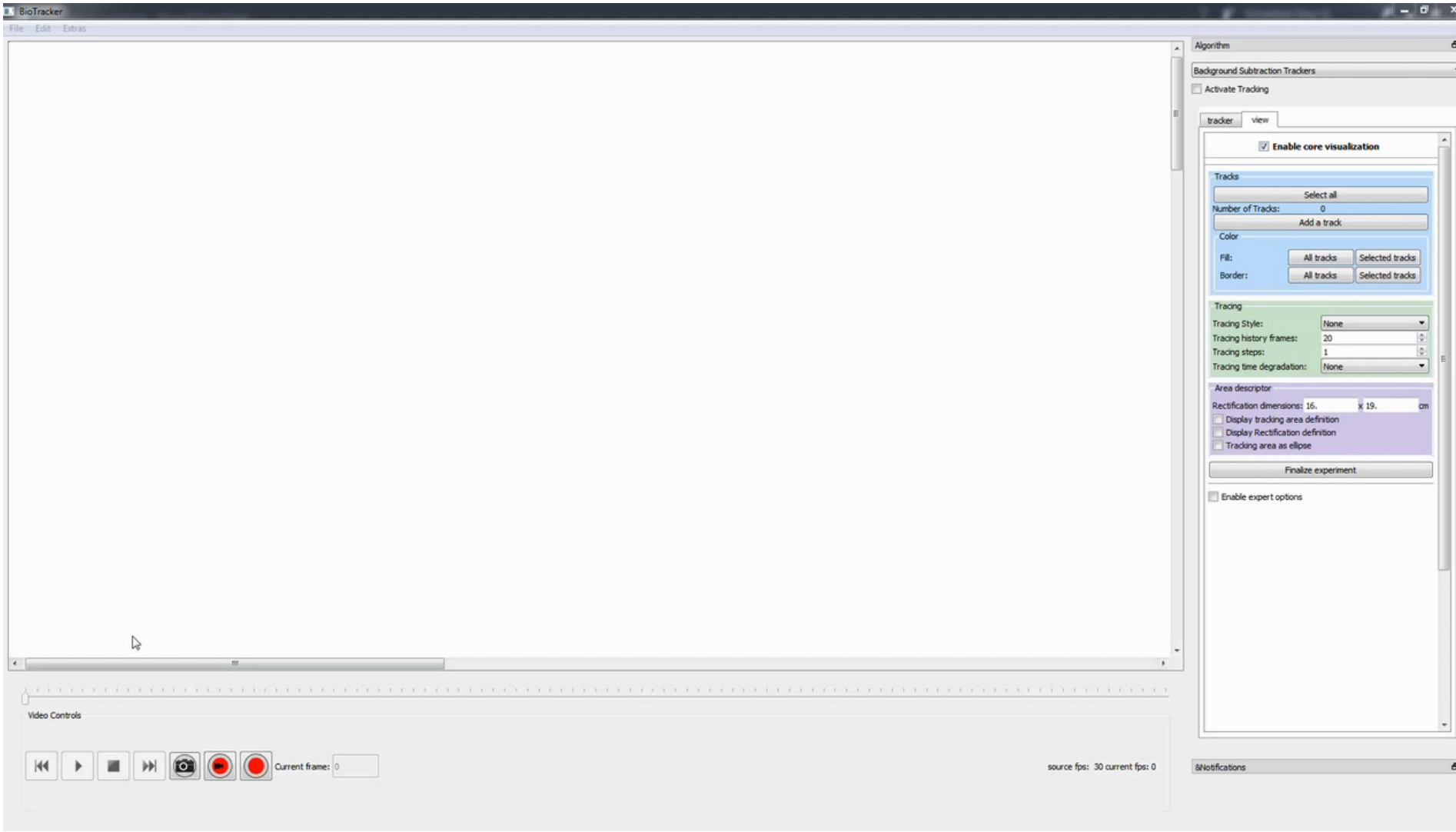
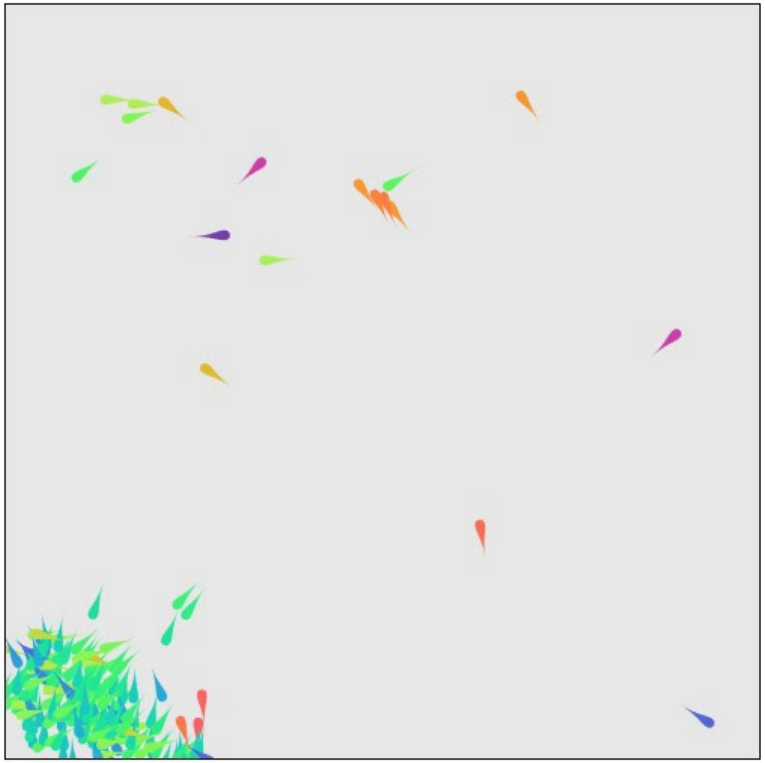
Biomimetic robots for the study of social behavior in fish


Social behavior
=
Individuals
interact with conspecifics


BioTracker
File
Edit
Extras
Algorithm
Background Subtraction Trackers
Activate Tracking
tracker
view
Enable core visualization
Tracks
Select all
Number of Tracks: 0
Add a track
Color
Fill:
All tracks
Selected tracks
Border:
All tracks
Selected tracks
Tracing
Tracing Style:
None
Tracing history frames:
20
Tracing steps:
1
Tracing time degradation:
None
Area descriptor
Rectification dimensions: 16. x 19. cm
Display tracking area definition
Display Rectification definition
Tracking area as ellipse
Finalize experiment
Enable expert options
Video Controls
Current frame: 0
source fps: 30 current fps: 0
Notifications

Individual-based simulations



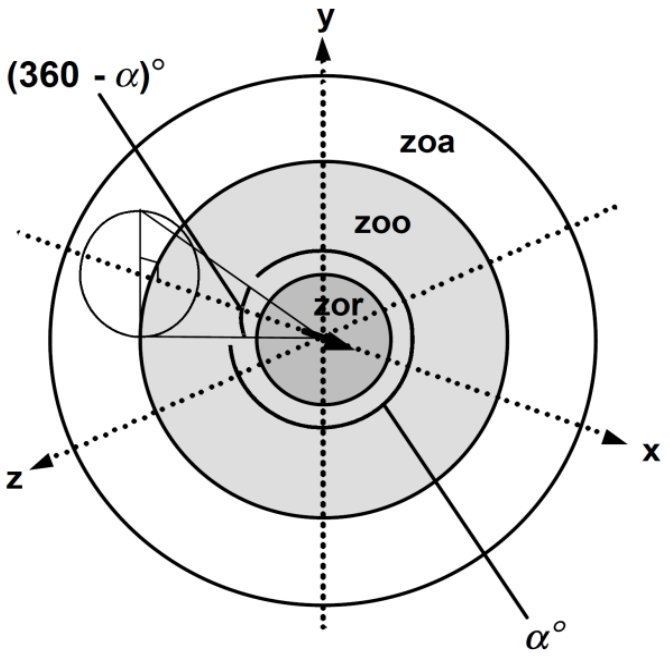
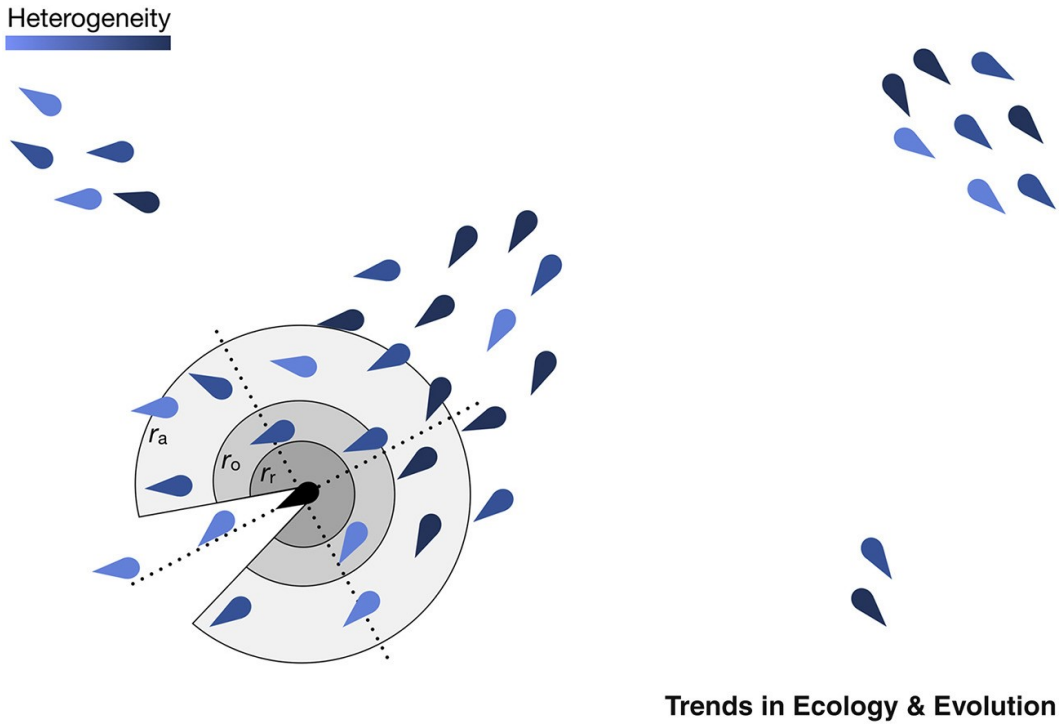


FIG. 1. Representation of an individual in the model centred at the origin: *zor* = zone of repulsion, *zoo* = zone of orientation, *zoa* = zone of attraction. The possible "blind volume" behind an individual is also shown. α = field of perception.

Couzin et al. 2003 J theor Biol

The problem is…



Jolles et al. 2020 TREE

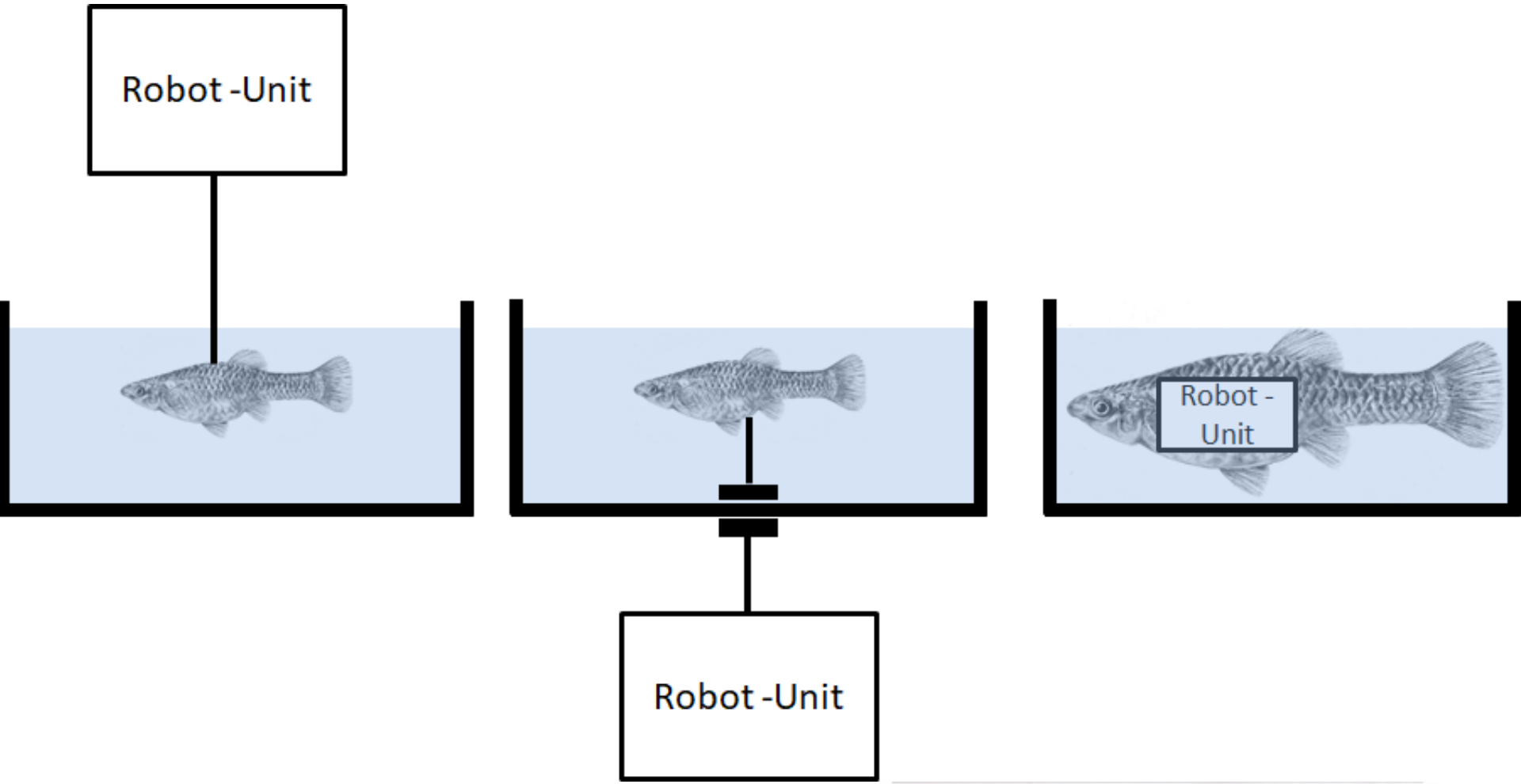
…all groups are made of individuals!

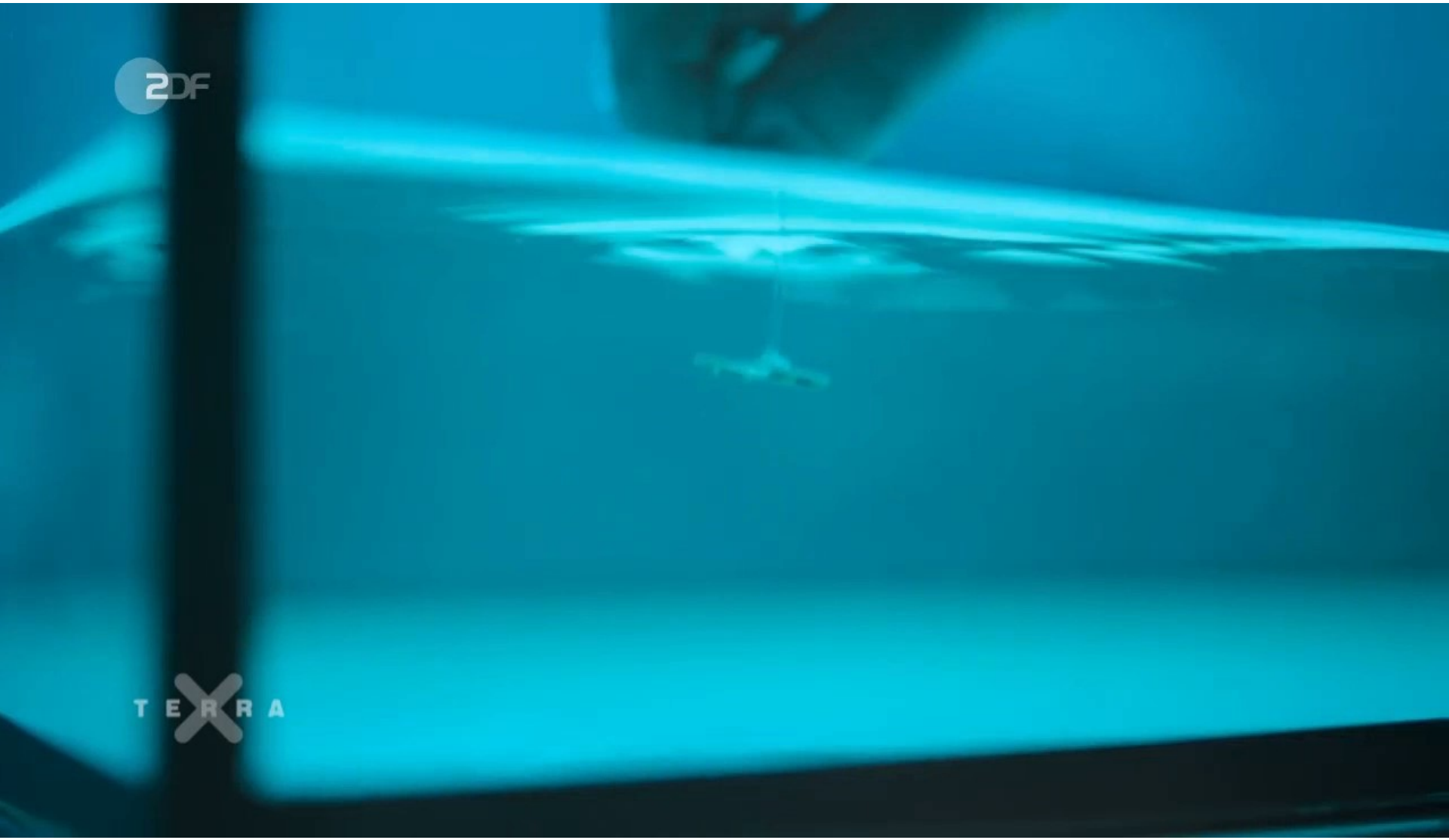
Individuals…

How can we study social behavior when we have so many variables (individuals) we cannot control?

Can we do more than just observe?

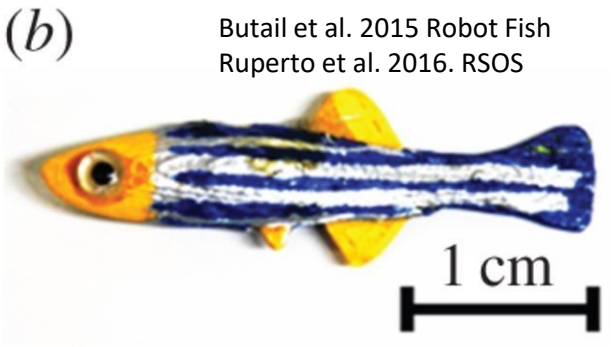
We can take control of some individuals!




2DF
TERRA

What do we have and what do we need?

Prerequisite: for social interaction studies:
Live animals accept the robot as conspecific!

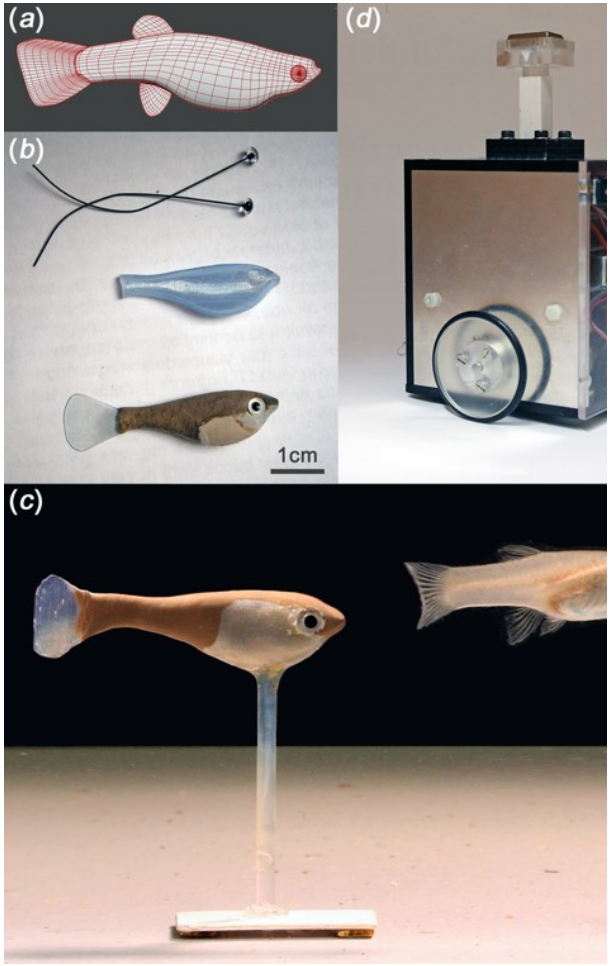


Butail et al. 2015 Robot Fish
Ruperto et al. 2016. RSOS

Bierbach et al. 2018 RSOS

Bonnet et al. 2019 SciRobot

Prerequisite: Acceptance of the robot as conspecific!



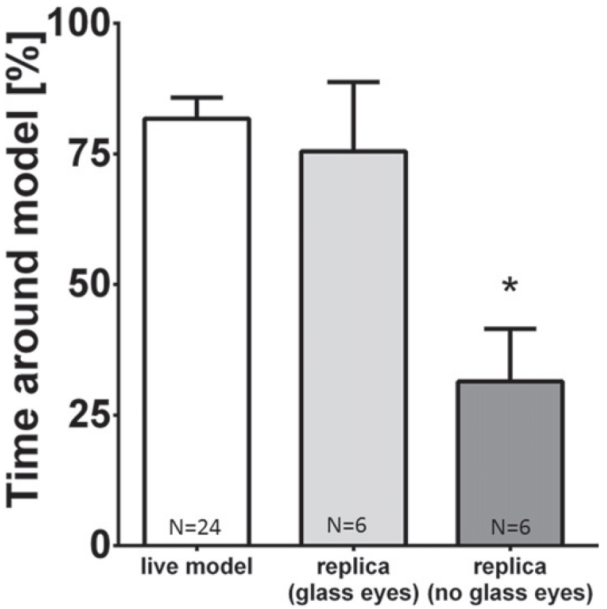
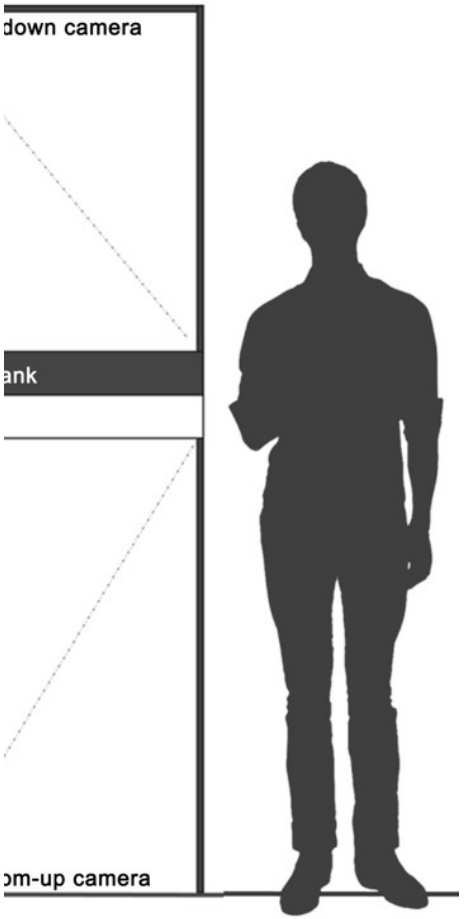
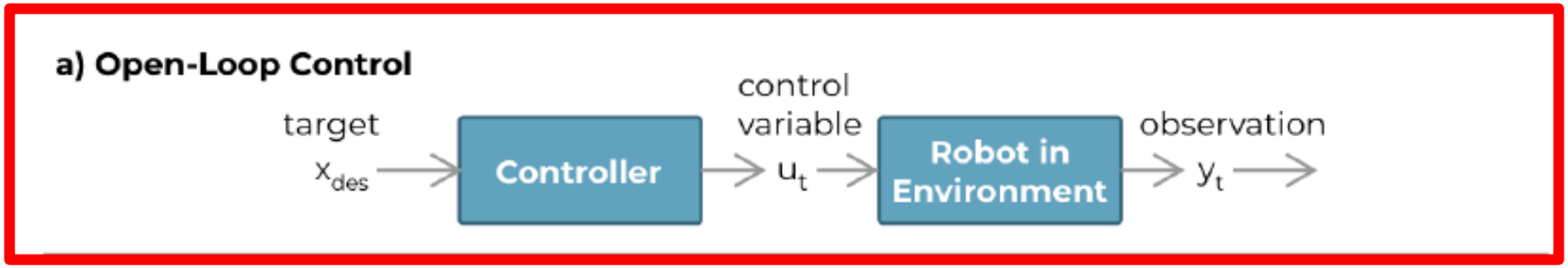


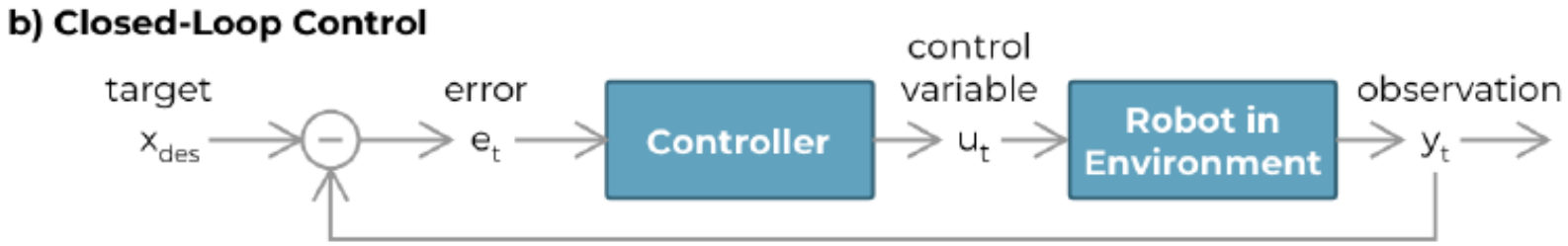
Figure 7. Acceptance of RoboFish with and without attached glass eyes by live guppy females. Depicted is the proportion of time the test fish spent within a radius of 20 cm around the replicas (mean ± SEM) that were moved on a zig-zag trajectory (see figure 6). We compared the time spent around the replicas to trials where two live fish were allowed to interact (control) through one-way ANOVA followed by Fisher's LSD tests for pair-wise *post hoc* comparison. Asterisk indicates significant differences compared to other treatments.



Landgraf, Bierbach et al. 2016 BB

What do we have and what do we need?





Animal-in-the-Loop: Using Interactive Robotic Conspecifics to Study Social Behavior in Animal Groups

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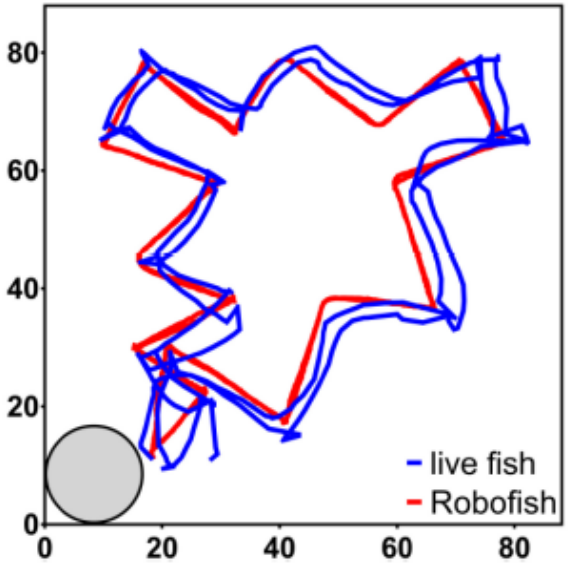
Vol. 4:- (Volume publication date May 2021)
Review in Advance first posted online on December 2, 2020. (Changes may still occur before final publication.)
https://doi.org/10.1146/annurev-control-061920-103228

Tim Landgraf,[1] Gregor H.W. Gebhardt,[1,2] David Bierbach,[3,4] Pawel Romanczuk,[5] Lea Musiolek,[6] Verena V. Hafner,[6] and Jens Krause[3,4]

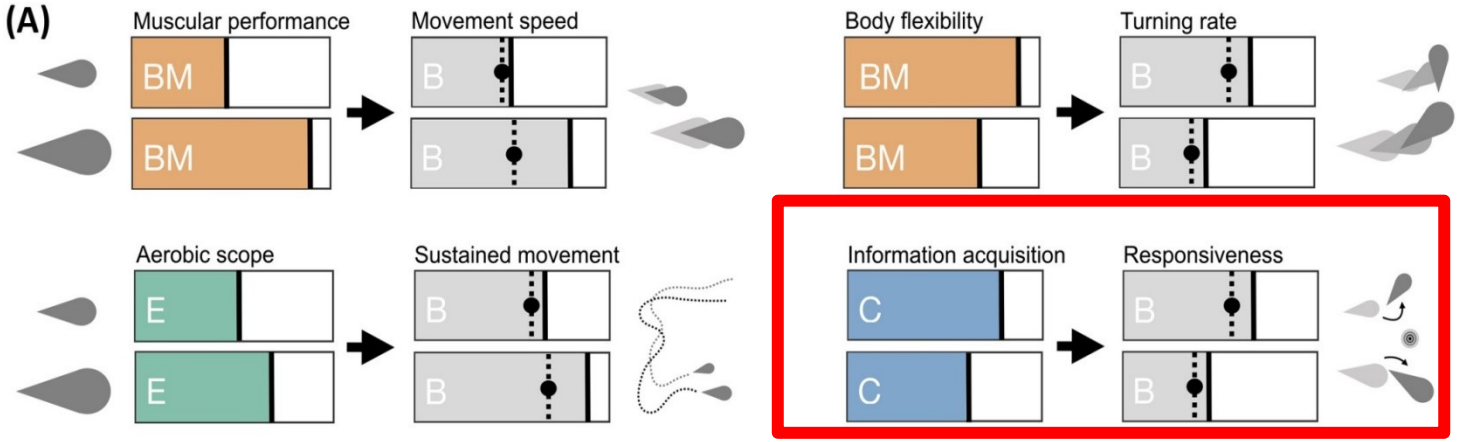
Open-loop behavior – standardized cues

A

Bierbach et al. 2020 Front. Bioeng. Biotechnol.



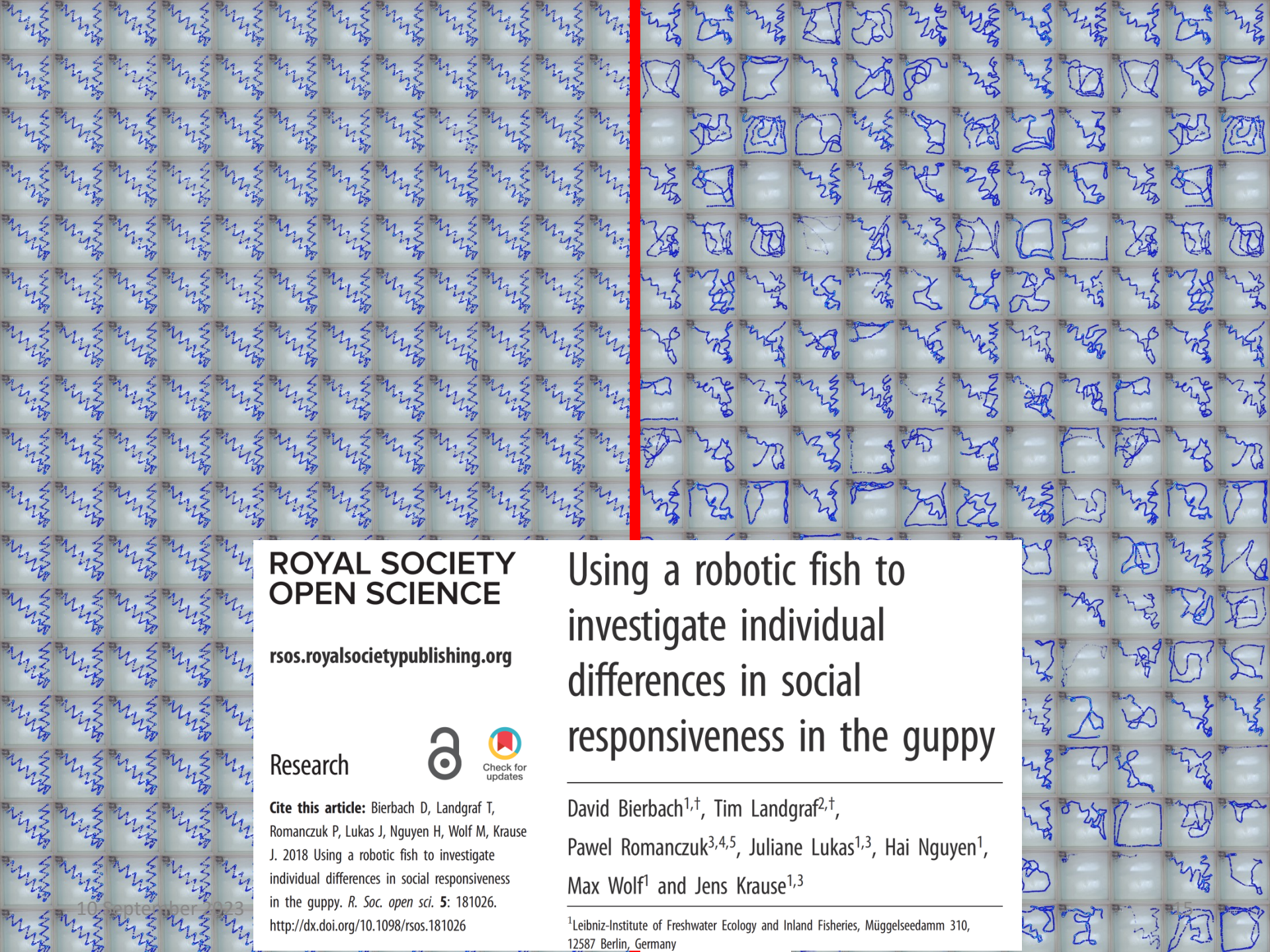
- Do fish differ in social responsiveness?



Jolles et al. 2020 TREE

Open-loop behavior

Lukas et al. 2021 Front. Ecol. Evol.



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rsos.royalsocietypublishing.org

Research

Cite this article: Bierbach D, Landgraf T, Romanczuk P, Lukas J, Nguyen H, Wolf M, Krause J. 2018 Using a robotic fish to investigate individual differences in social responsiveness in the guppy. *R. Soc. open sci.* **5**: 181026. http://dx.doi.org/10.1098/rsos.181026

Using a robotic fish to investigate individual differences in social responsiveness in the guppy

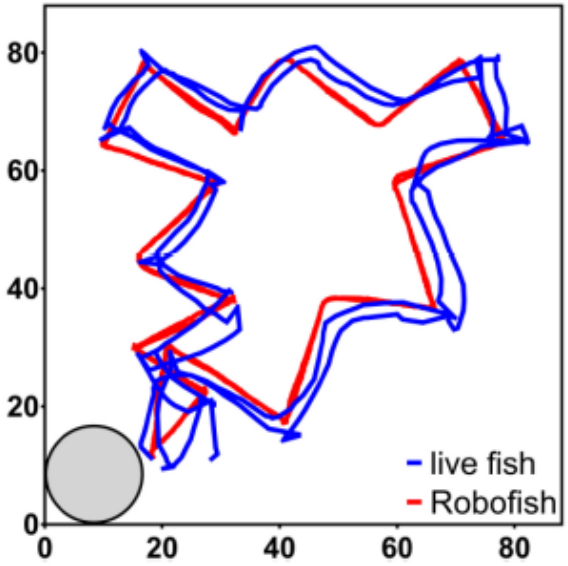
David Bierbach[1,†], Tim Landgraf[2,†], Pawel Romanczuk[3,4,5], Juliane Lukas[1,3], Hai Nguyen[1], Max Wolf[1] and Jens Krause[1,3]

[1]Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany

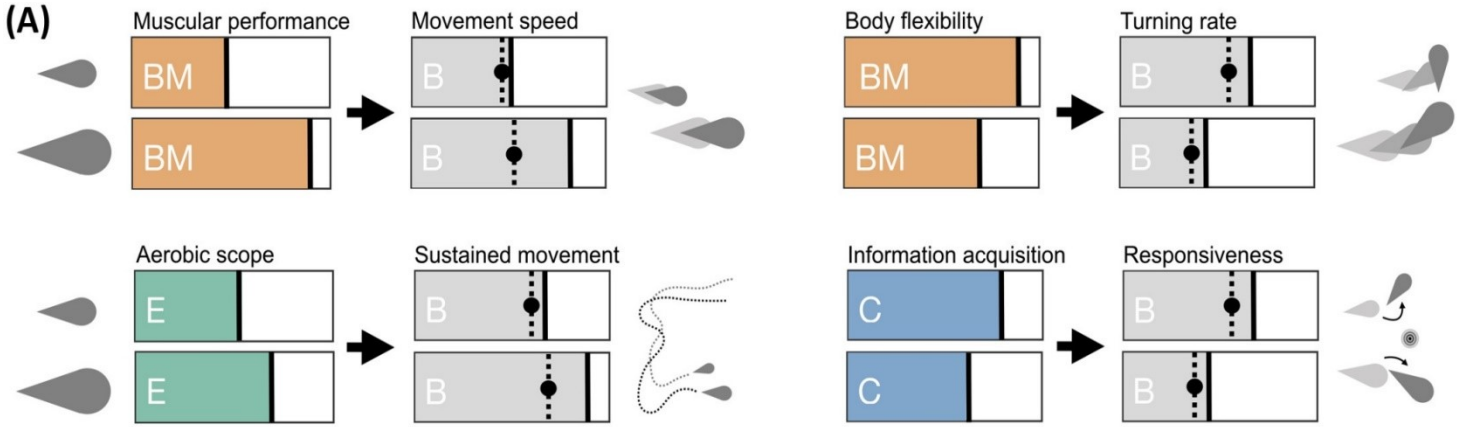
Open-loop behavior – standardized cues

A

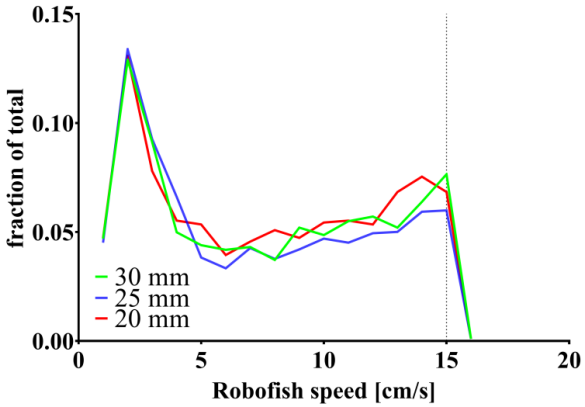
Bierbach et al. 2020 Front. Bioeng. Biotechnol.

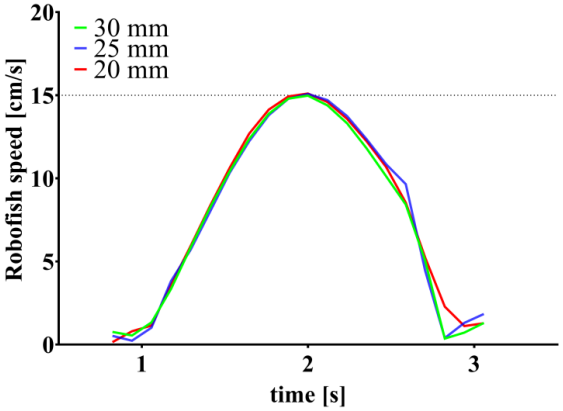


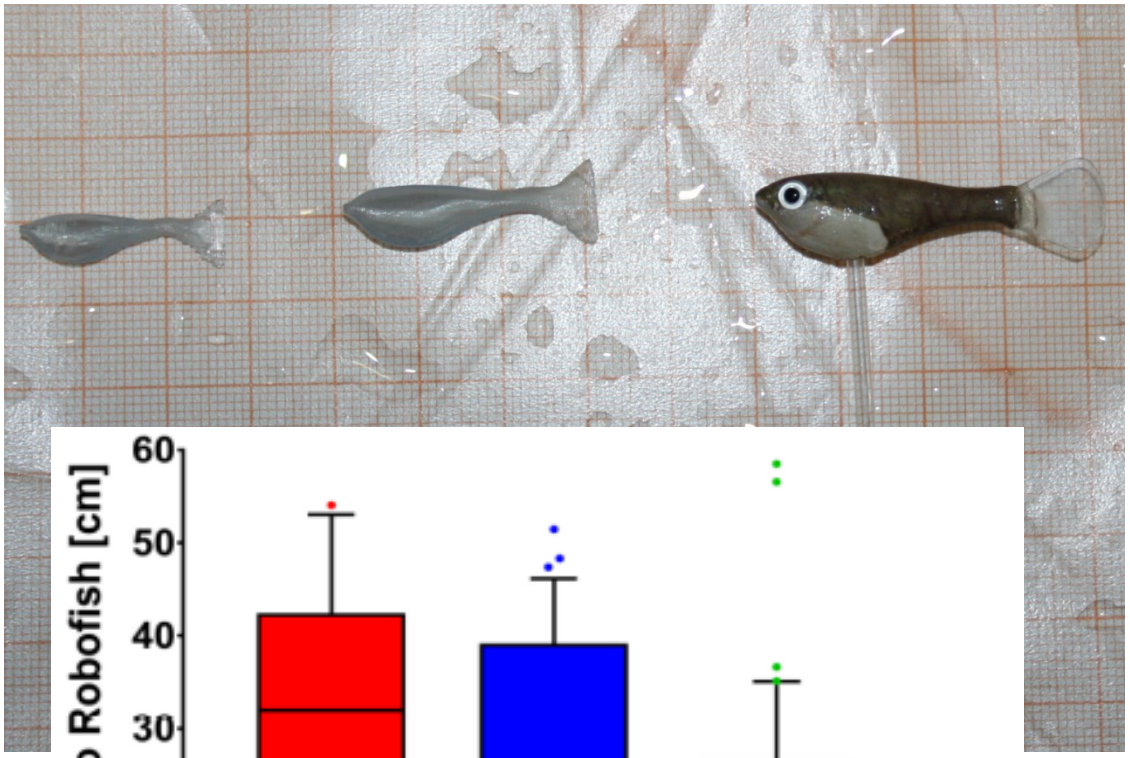
- Do fish differ in social responsiveness?
- What makes a leader: Size or Behavior?

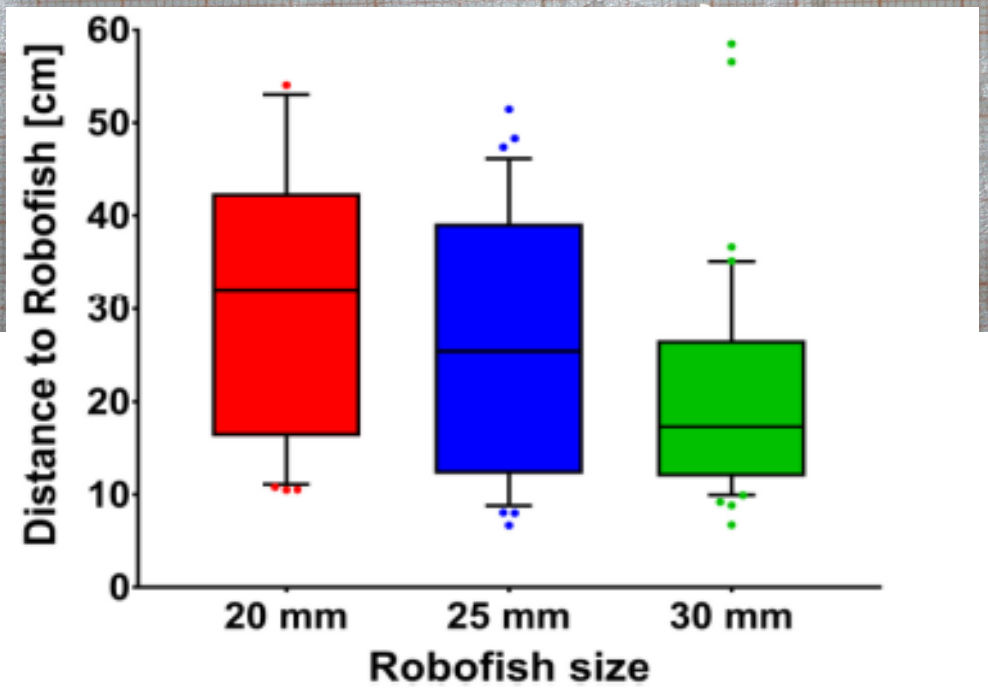


Jolles et al. 2020 TREE

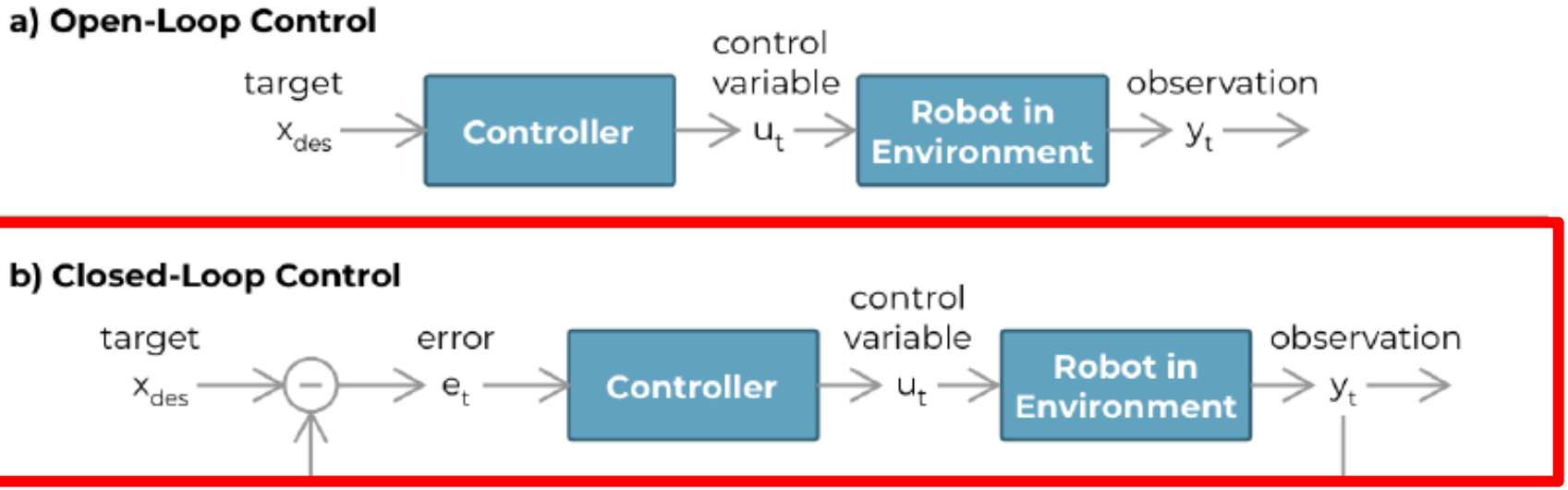

0.15
0.10
0.05
0.00
fraction of total
30 mm
25 mm
20 mm
0
5
10
15
20
Robofish speed [cm/s]


20
15
10
5
0
Robofish speed [cm/s]
30 mm
25 mm
20 mm
1
2
3
time [s]




60
50
40
30
20
10
0
Distance to Robofish [cm]
20 mm
25 mm
30 mm
Robofish size

What do we have and what do we need?



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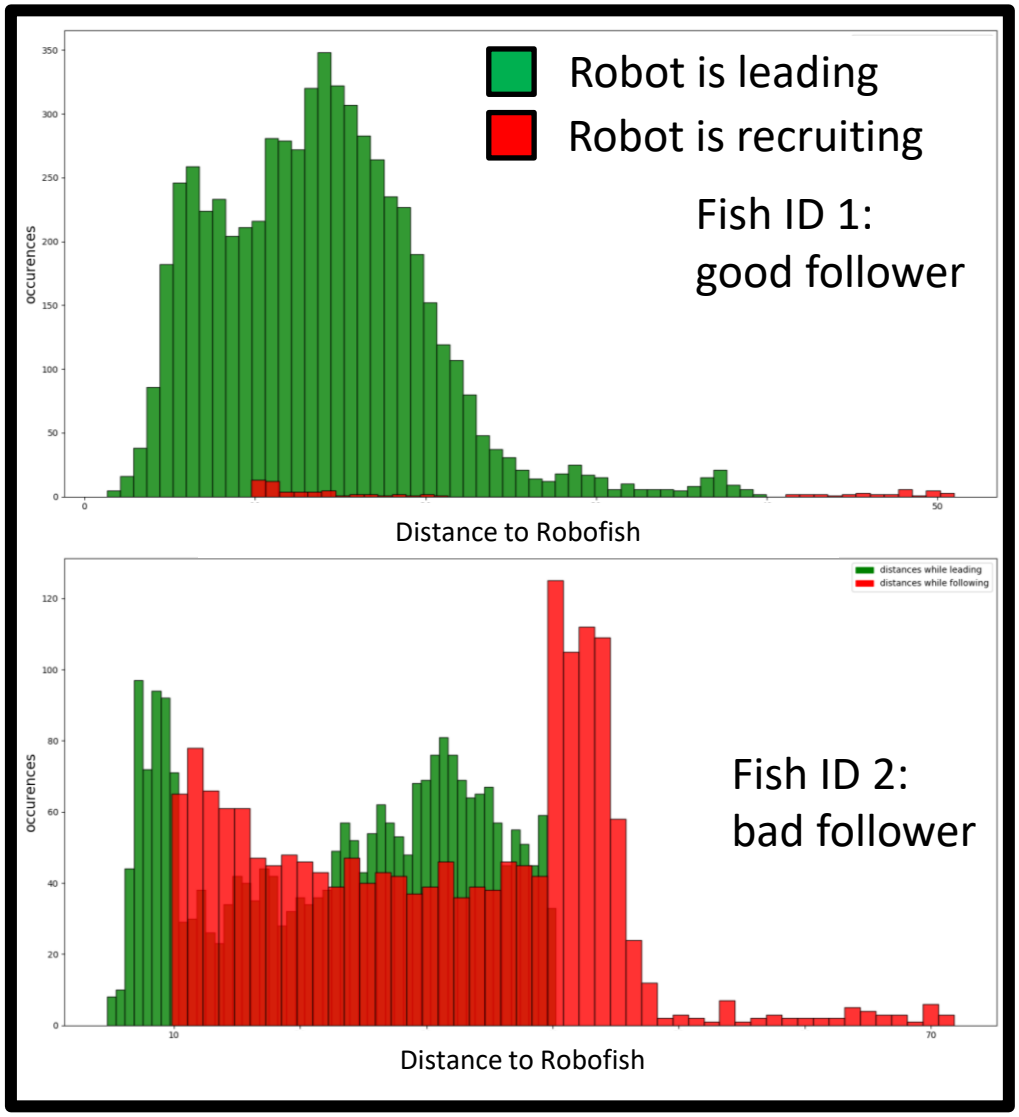
Still there is individual variation

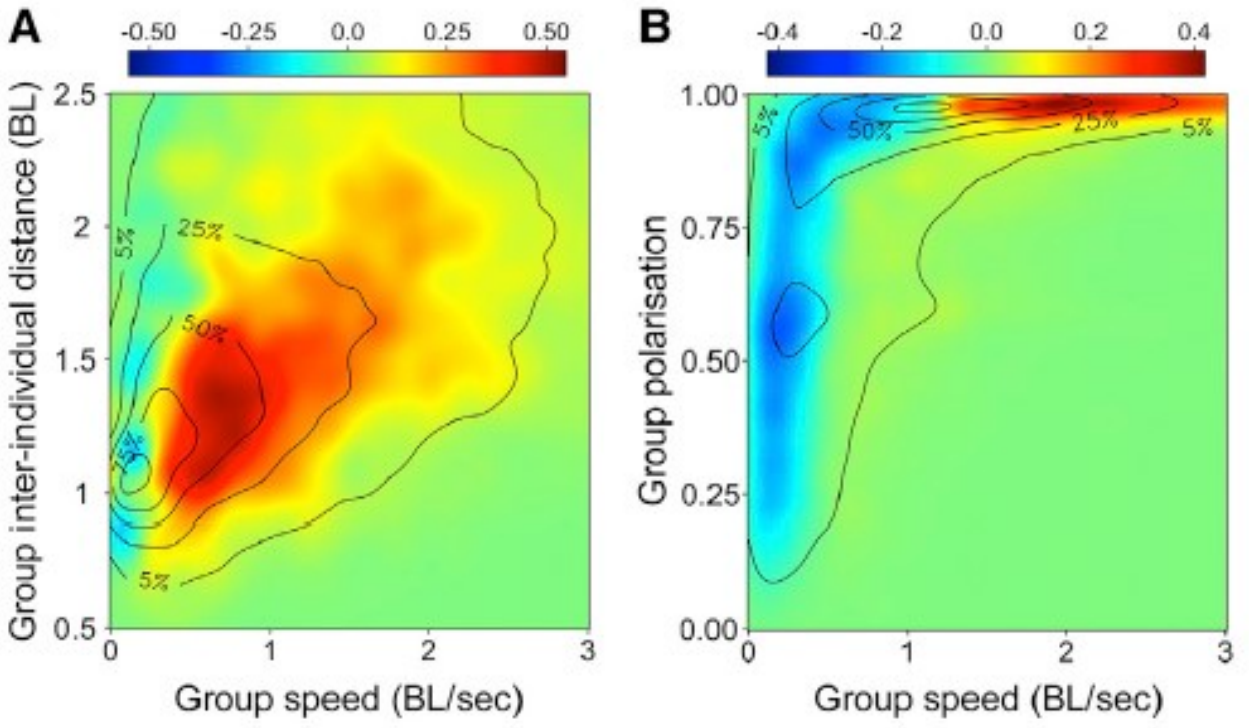


How crucial are speed differences?

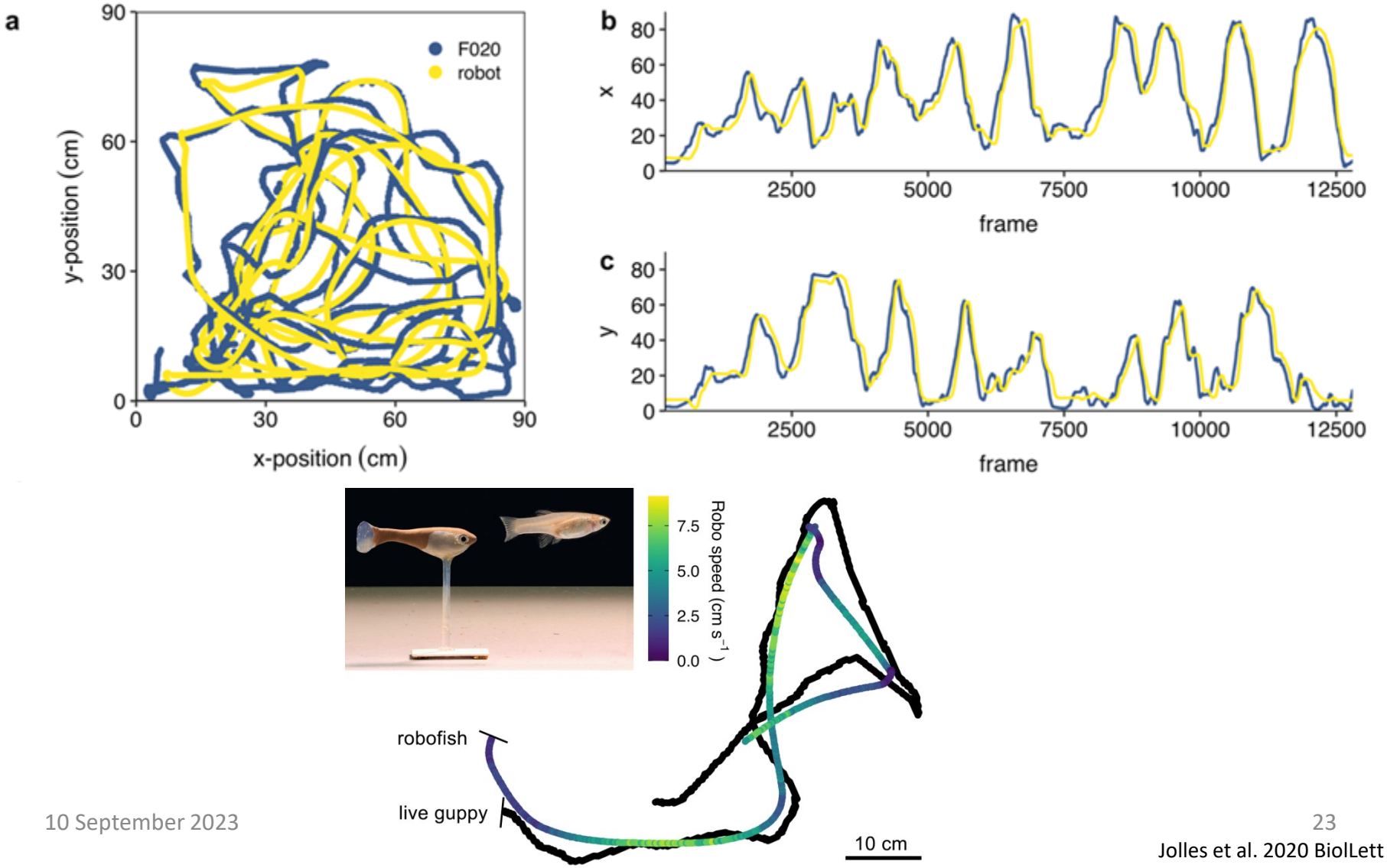
Current Biology
Report

Consistent Individual Differences Drive Collective Behavior and Group Functioning of Schooling Fish

Jolle W. Jolles,[1,2,3,5,*] Neeltje J. Boogert,[1,4] Vivek H. Sridhar,[2,3] Iain D. Couzin,[2,3] and Andrea Manica[1]

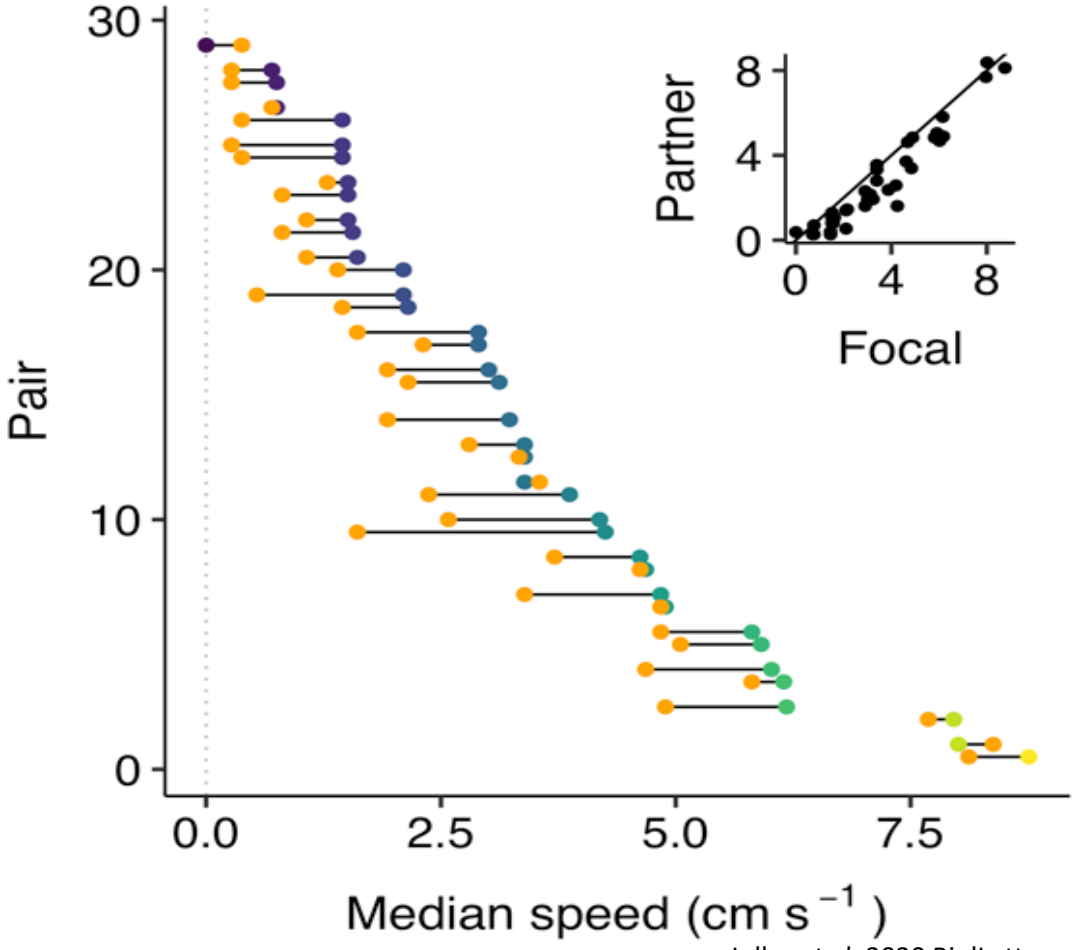


The perfect follower



Jolles et al. 2020 BiolLett

How do speed differences affect social behavior?



Jolles et al. 2020 BiolLett

Speed differences affect collective patterns

BIOLOGY LETTERS

royalsocietypublishing.org/journal/rsbl

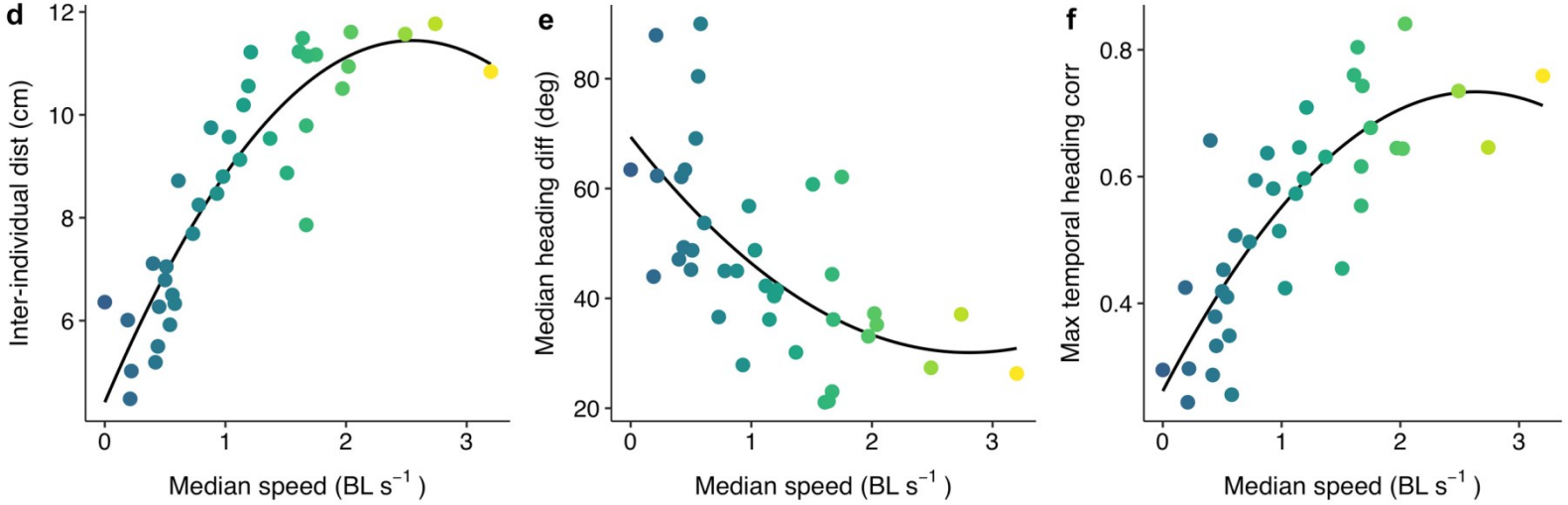
Animal behaviour

Group-level patterns emerge from individual speed as revealed by an extremely social robotic fish

Research

Check for updates

Jolle W. Jolles[1,2], Nils Weimar[3], Tim Landgraf[4,5], Pawel Romanczuk[5,6], Jens Krause[3,5,6] and David Bierbach[3,5,6]



Jolles et al. 2020 BiolLett

Ability to adjust social interactions through anticipation

Definition:

Anticipation means that an agent predicts its social partners' future behavior and adapts its own behavior according to that prediction (after Poli 2019).

Mate choice

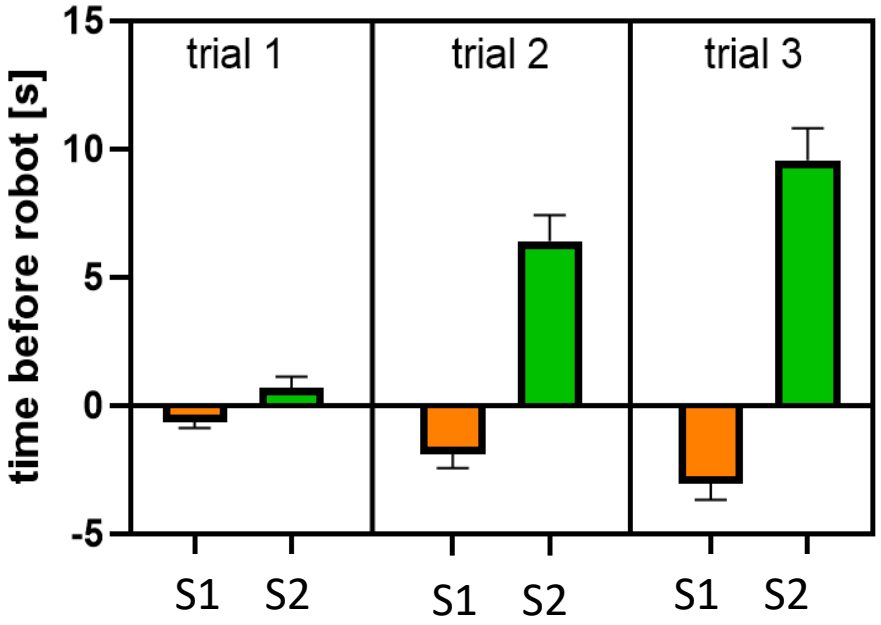
Predator-prey

Social foraging

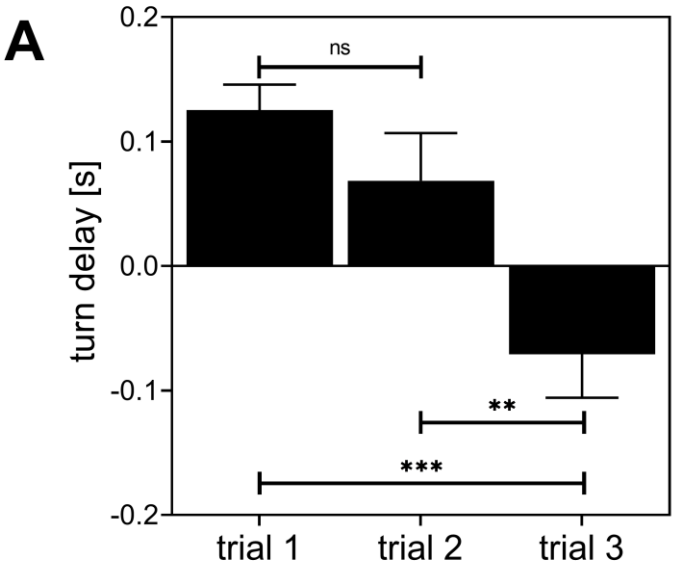
Ability to adjust social interactions through anticipation

Social foraging:

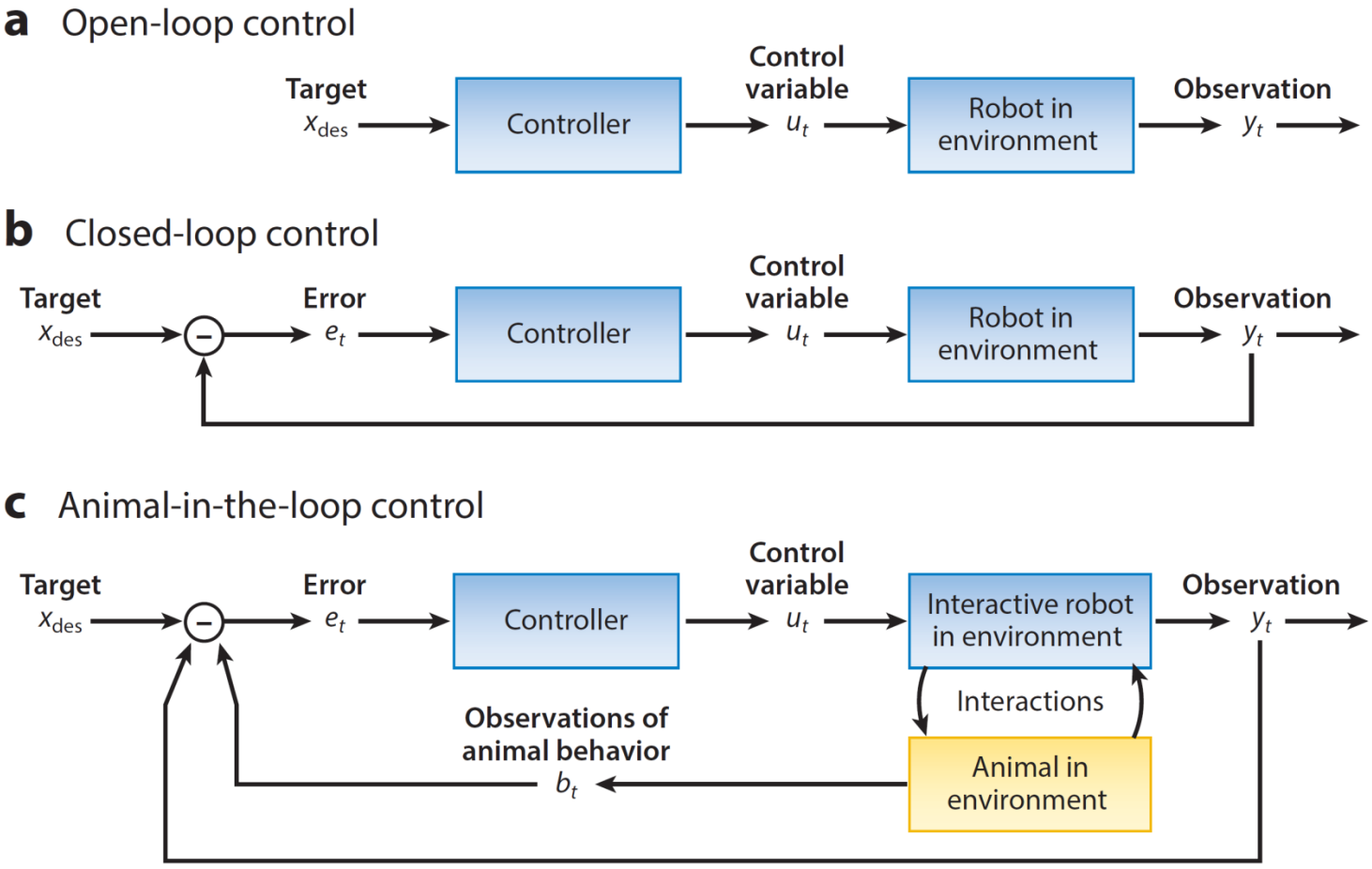
Fish reached last corner before the robot



Fish turnt before the robot



Integration of anticipatory behaviour into artificial agents



Landgraf et al. 2021 AnnuRev

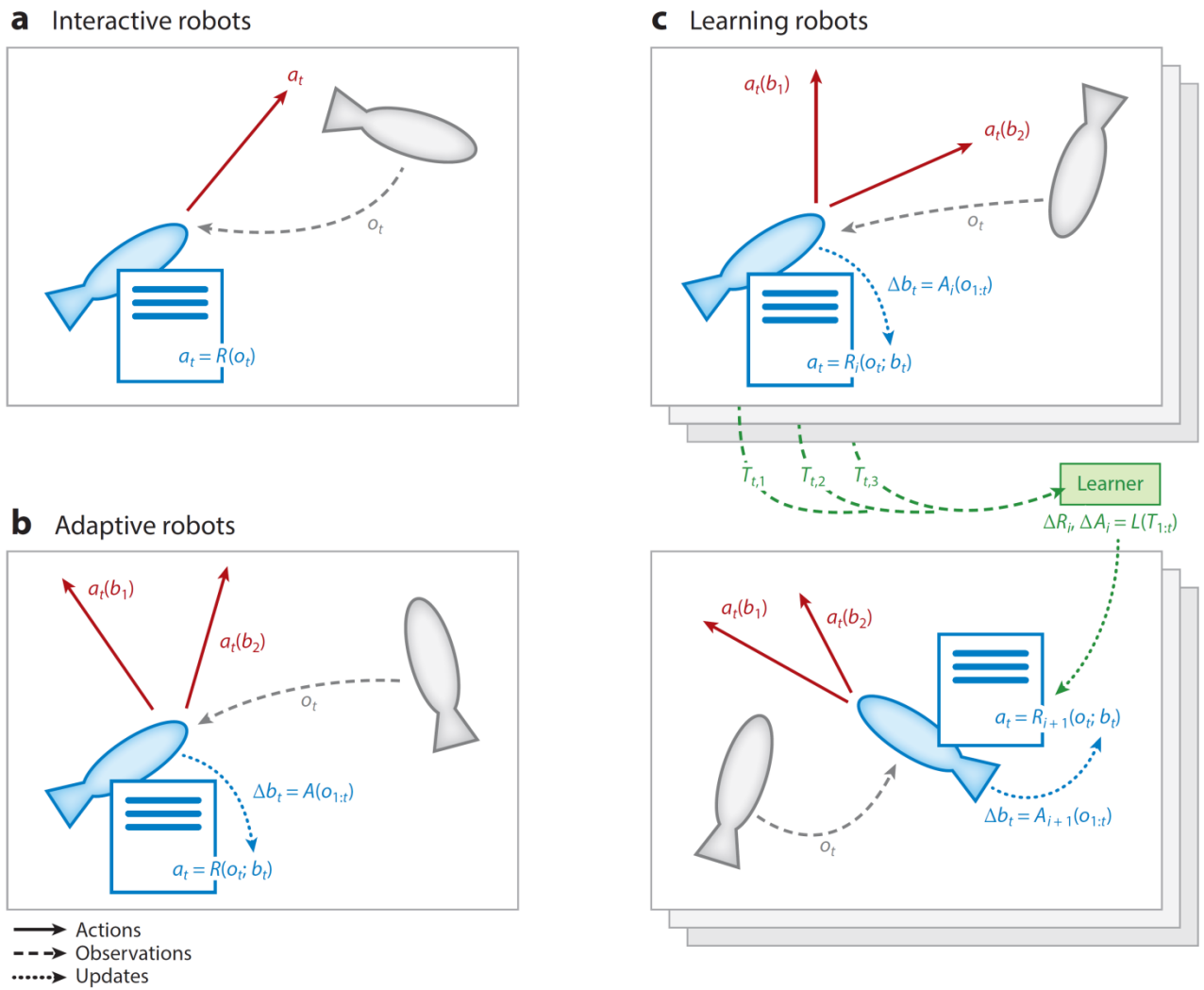
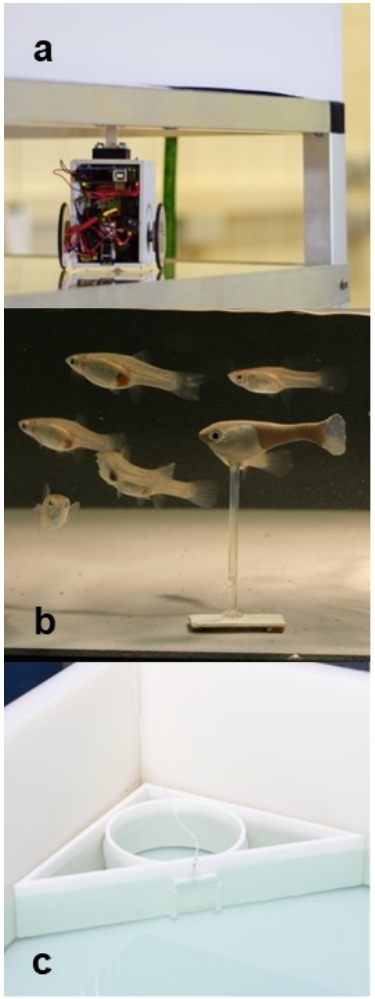
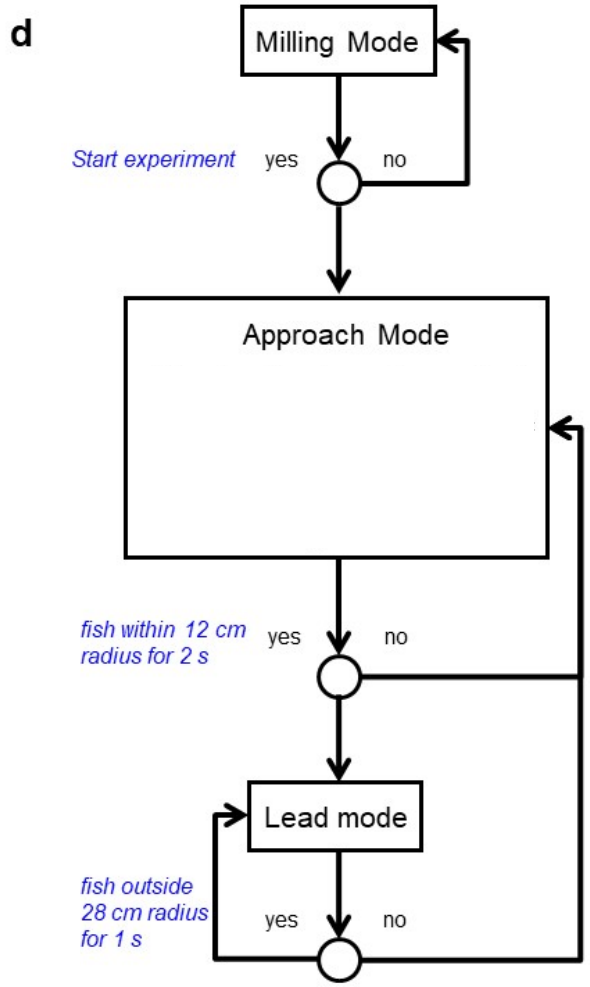


Figure 3

Interactive, adaptive, and learning robots. (*a*) Interactive robots have a fixed behavioral policy R that maps observations o_t of their interaction partners to actions a_t. (*b*) Adaptive robots amend the behavioral policy R by a parameter set b that they adjust during the experiment according to rules A. (*c*) Learning robots collect experience over many interactions and use this experience to update the behavioral policy (and in general also the adaptation rules) according to the learning algorithm L.

Integration of anticipatory behaviour into artificial agents

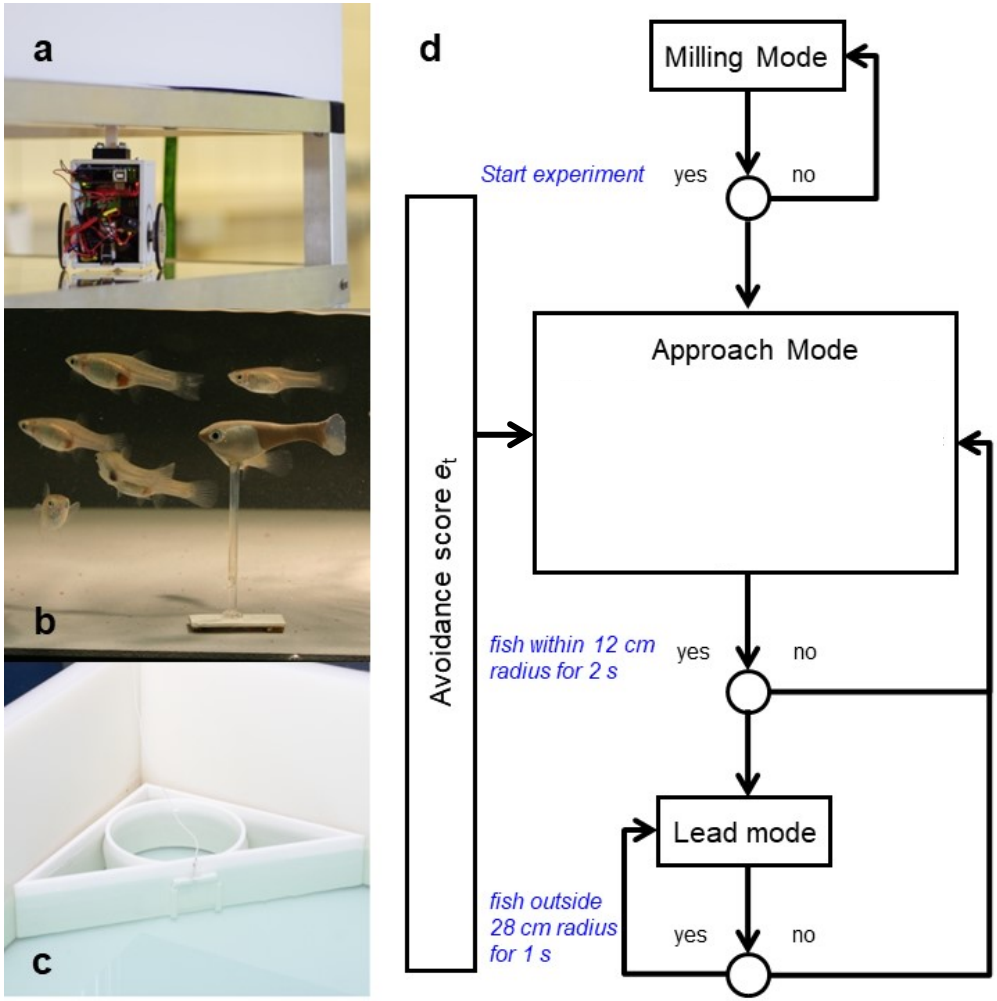




Baseline Robofish behavior (interactive)

Maxeiner et al. 2023 BB

Integration of anticipatory behaviour into artificial agents



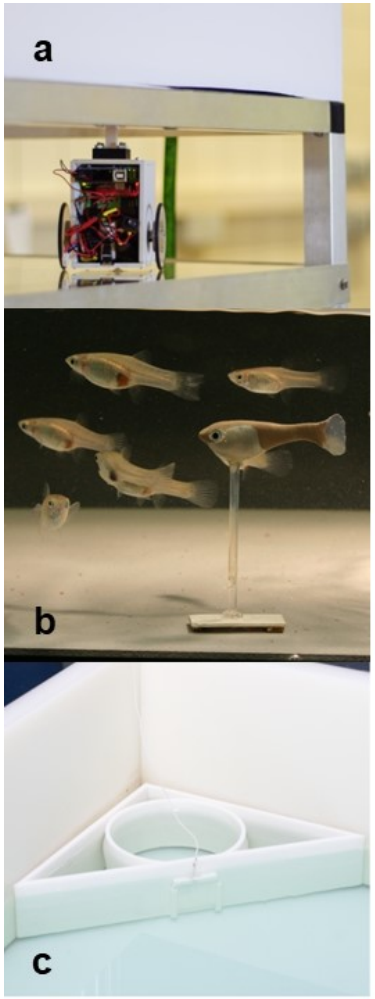
Baseline Robofish behavior (interactive)

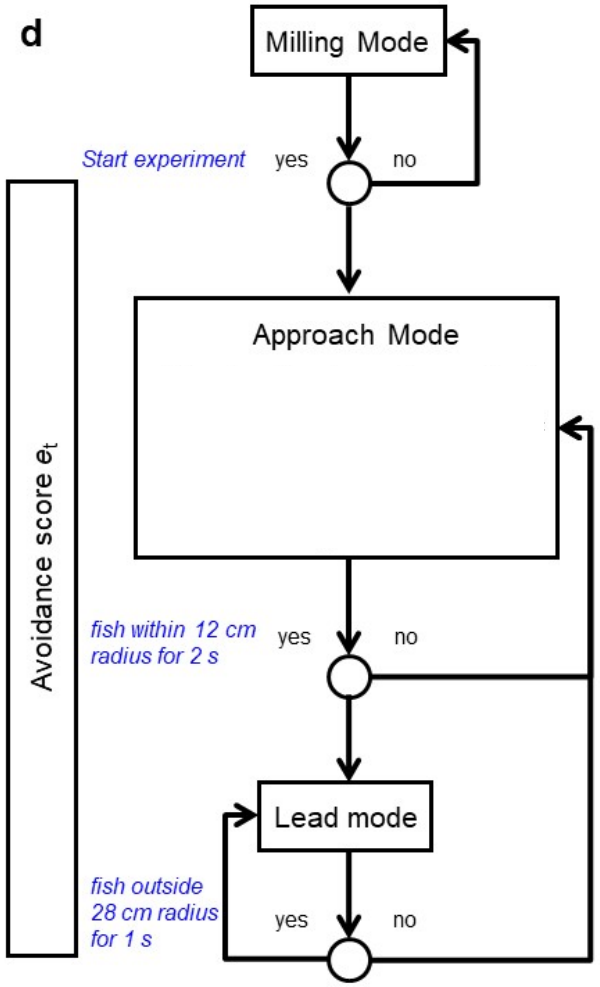
Anticipation Robofish behavior (adaptive)
-when fish flees, approach slower
-when fish stays, approach faster

Anticipation: avoiding of a social partner must be answered with more carefull approaches

Maxeiner et al. 2023 BB

Proof of concept





The experiment

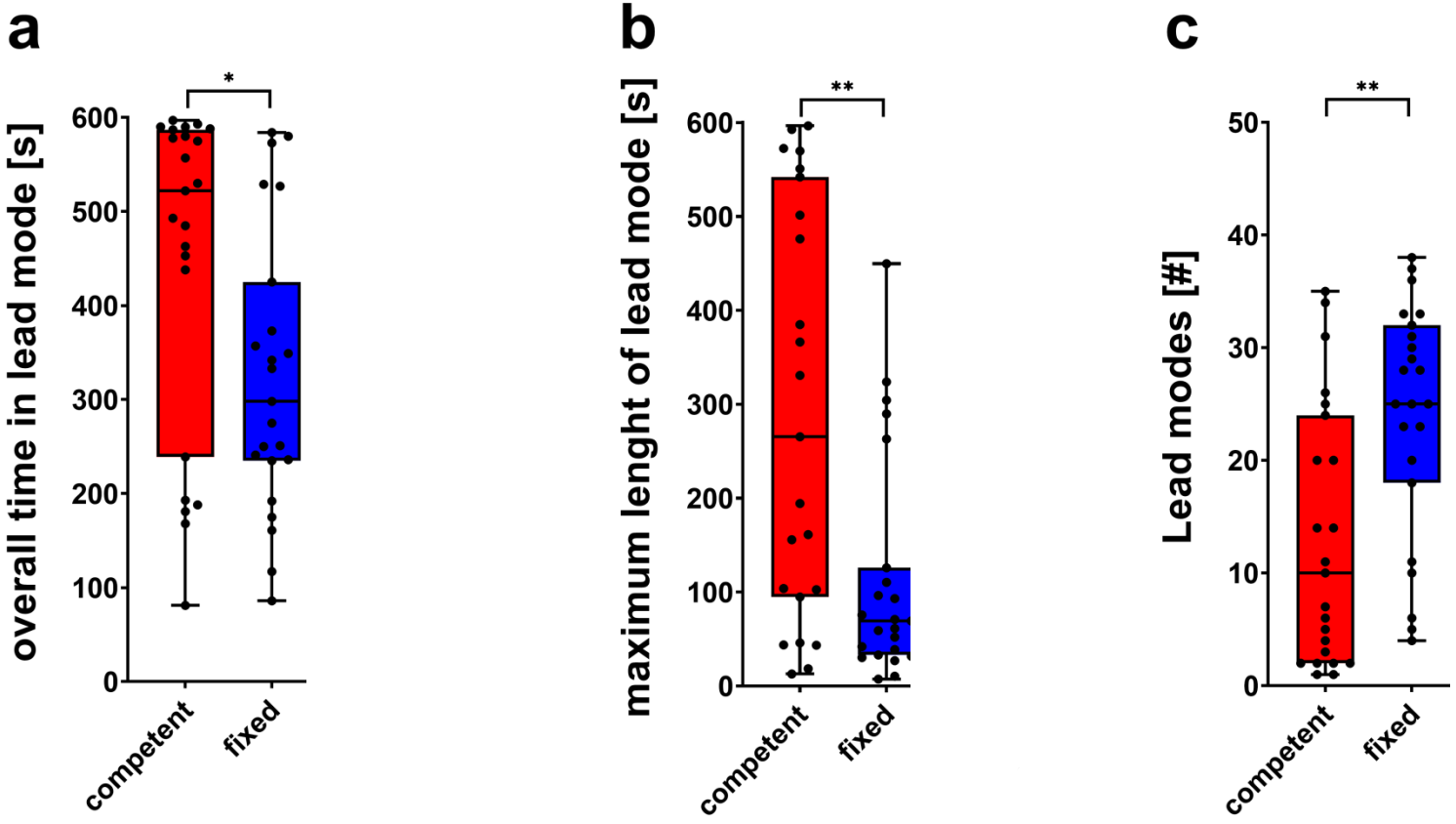
Hypothesis:

Robofish that adapts its approach behaviour based on the live fish's observed avoidance will be better accepted as leader!

avoidance → carefull approach
no avoidance→ normal approach

Maxeiner et al. 2023 BB

Proof of concept



Maxeiner et al. 2023 BB

Biomimetic robots

- provide standardized social cues
- can decouple behavior from morphology
- allow to test predictions through precise manipulation
- reduce number of used animals during experimentation