Synchronized Movement

By: William Randall

What is Synchronized Movement?

- Describes how animals can move together in different patterns
- This can be seen in zebrafish as they stay in groups called
  - "Schools" - when moving in a coordinated fashion
  - "Shoals" - when in less directed groups
- But this knowledge is being applied also to drone technology

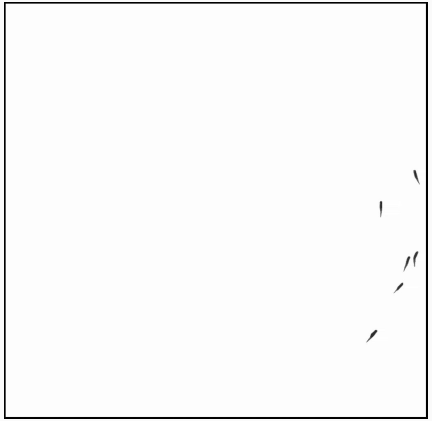


Figure 1

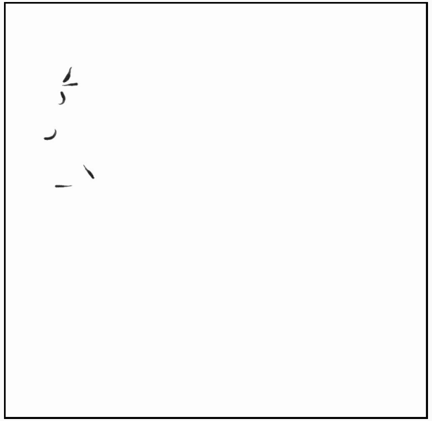


Figure 2

Figure 1 - "coordinated fashion"
Figure 2 - "huddled"

How can genetic modification affect synchronized movement?

- In a study done by Harvard University and the Max Planck Institute of Animal Behavior
- They introduced a genetic modification to zebrafish and studied the movement patterns of unmodified vs modified zebrafish
- 90 different genes
  - To see effect on social behavior

Figure 3 - normal group behavior in unaltered fish

Figure 4 - group formation in fish with mutations

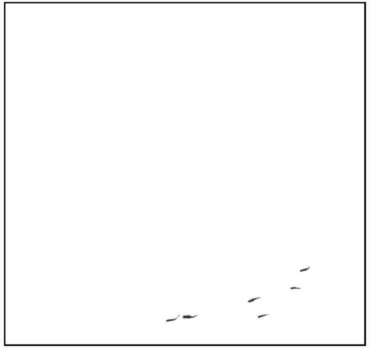


Figure 3

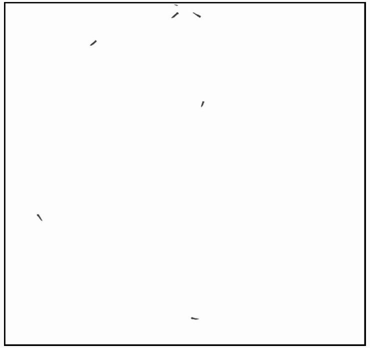
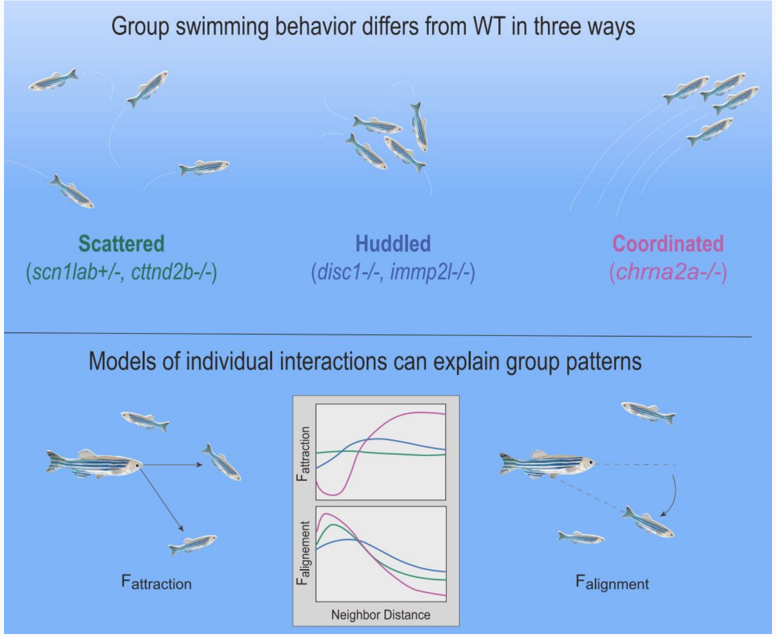


Figure 4

How can we quantify the movement of zebrafish?



- 3 groups of swimming behavior
  - Scattered - reduced cohesion
  - Huddled - dense but disordered groups
  - Coordinated - aligned schools
- 2 vectors to determine group patterns
  - $F_{attraction}$ - vectors to other fish
  - $F_{alignment}$ - vectors to determine angle between current direction and direction to other fish

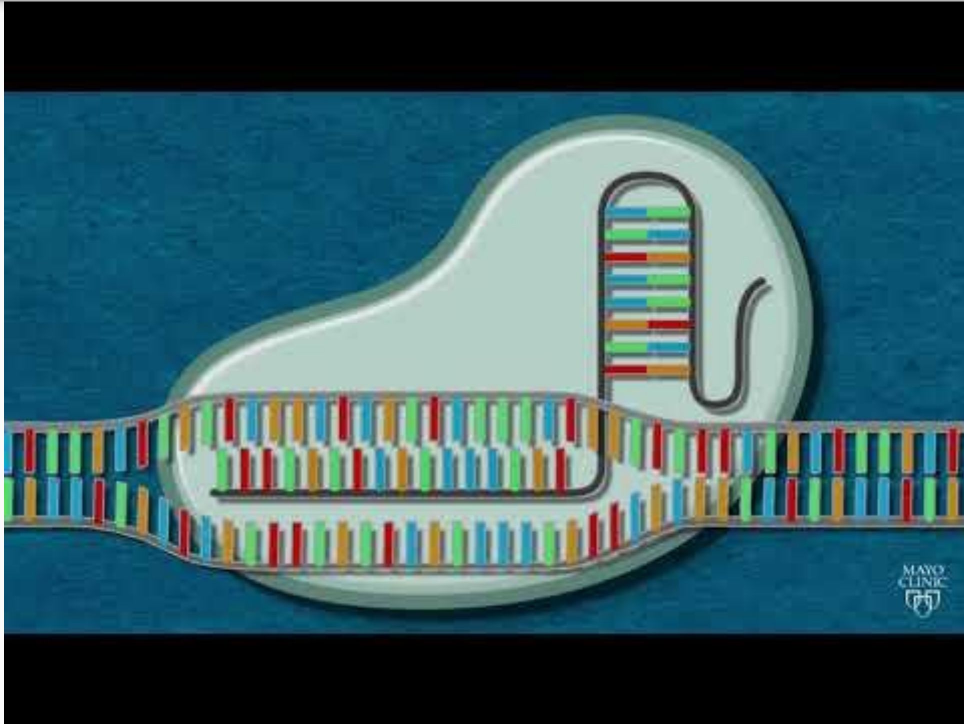
Why do animals form groups?

- Group dynamics help protect from predators
- Humans rely on social interaction as seen in the dysfunction caused by
  - Autism
  - Schizophrenia
- Group patterns in animals can come about through
  - Genetic composition
  - Local interactions
- Zebrafish are used in this experiment because genetic, behavioral, and neutral experimental techniques have been developed to study zebrafish and their behavior in groups

How do we edit the genes?

This genetic modification is accomplished by CRISPR-Cas9

CRISPR - Clustered Regularly Interspaced Short Palindromic Repeats



The Setup and Computer Visualization of Fish

A - 6 adult fish in circular arena

B - trajectories from aligned fish

C - trajectories from grouped fish

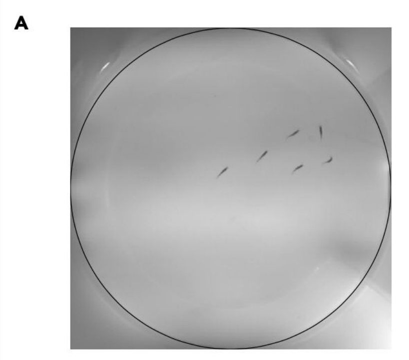


Figure 5

Figure 6

Figure 7

Automated Data Collection

- Video - 1880x1880 pixels, 60 fps
- Log all relevant metadata
- Real time user visualization, verification, and modification of data
- File generation to streamline later analysis
- Fish trajectories found with automated tracking
    - fingerprint libraries to minimize switching of fish IDs after repeated crossings
- Locomotion qualifications such as trajectory, angle, speed, pairwise distance, and convex hull area
- This does not guarantee that fish ID’s are not transferred
    - Analysis is thus done on variability across trials instead of the variability among individuals within a trial

The Data

- Median Speed (cm/s)
- Group spacing (cm)
- Polarization - the reflection of polarized light from the fish’s skin cells

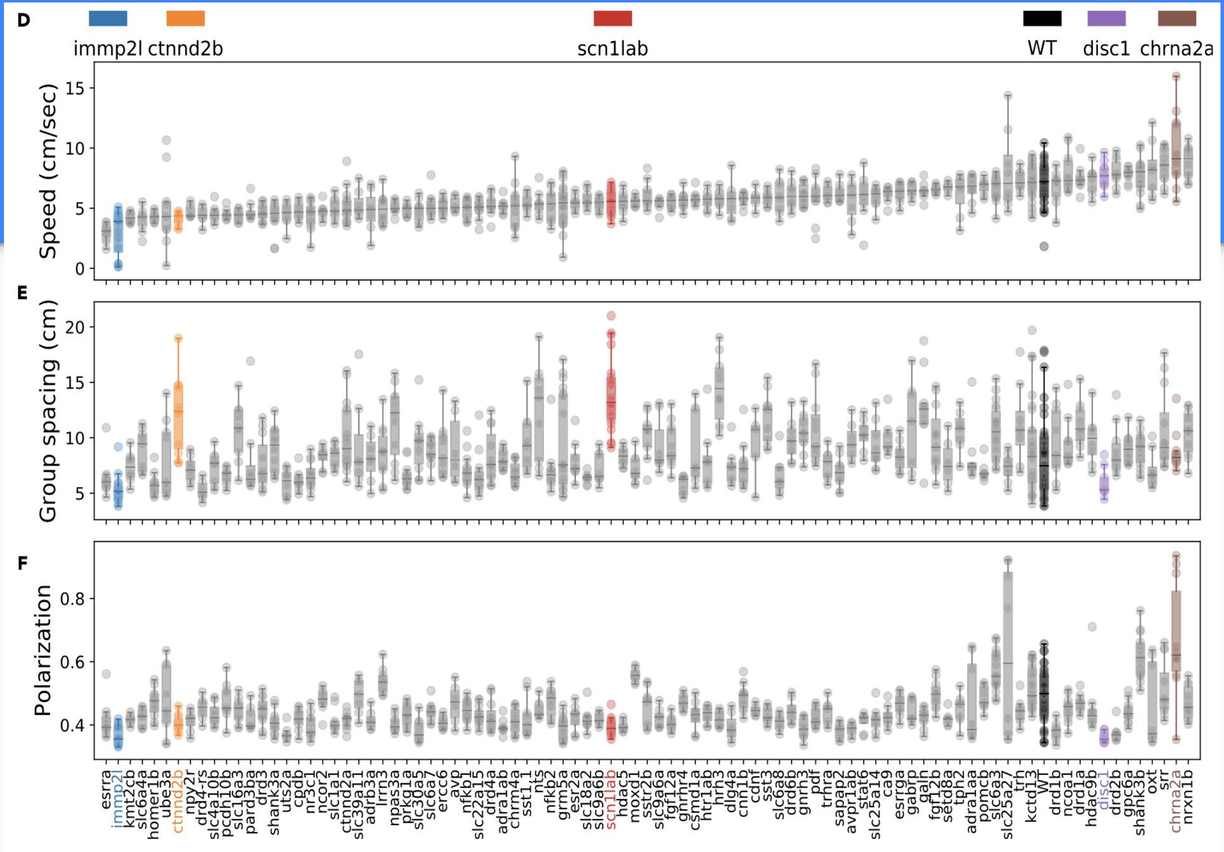


Figure 8

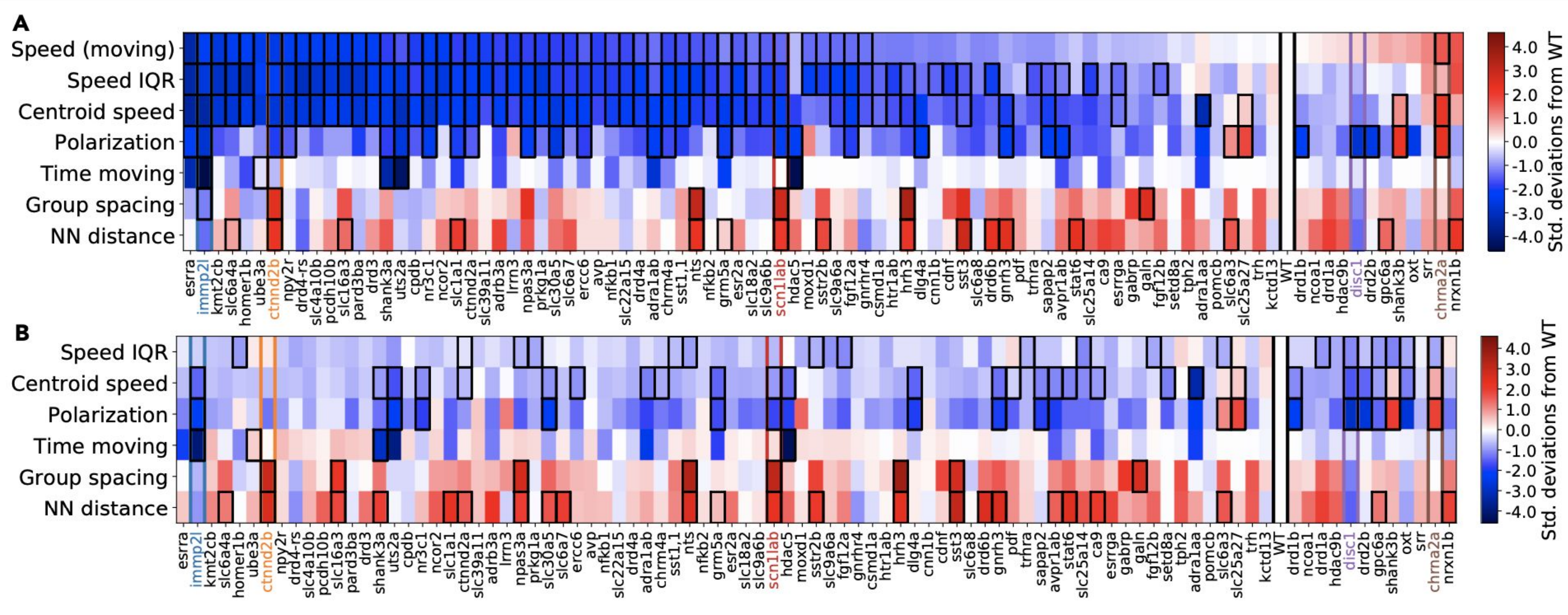


Figure 9

- WT - wild-type fish (unmutated)
- Centroid speed - center of the group's speed
- NN - nearest neighbor

Data Calculations

Polarization is calculated as in Tunstrøm et al. (2013):

$$P(t) = \frac{1}{N}\left|\sum_{i=1}^{N} \hat{v}_i(t)\right| = \sqrt{\langle \cos\theta_i(t)\rangle_i^2 + \langle \sin\theta_i(t)\rangle_i^2},$$

where $N = 6$ is the number of fish in the group, θ_i is the heading of fish i and $\hat{v}_i = (\cos\theta_i, \sin\theta_i)$ is the unit velocity vector of fish i.

- Centroid Speed
  - High - moving together in the same direction
  - Low - if they are not moving or are going opposite directions
- Nearest neighbor distance - selecting the closest neighbor for each fish at each time step, and taking the median of these values for a given trial
- Speed while moving - the median speed during frames where the fish was moving

Model of Individual Turning Decisions

$$z_i = \underbrace{\alpha F(s_i)\frac{1}{N}\sum_{j\neq i} G_{att}(r_j)H_{att}(\phi_j)}_{\text{attraction}} + \underbrace{\frac{1}{N}\sum_{j\neq i} G_{ali}(r_j)H_{ali}(\theta_j)}_{\text{alignment}}$$

$$P_i = 1/(1+e^{-wz_i}),$$

s_i - the speed of the focal individual
r_j - neighbor distance
Φ_j - angular position
Θ_j - relative heading
α - overall attraction-alignment ratio
$F(s_i)$ - speed dependent attraction-alignment ratio
$G_{att}(r_j)$, $G_{ali}(r_j)$ - neighbor interactions that depend on distance

N = 6 - the number of fish
P_i - the probability of turning left after a specified time delay
W - weight parameter
Positive values of z_i predict left-turns, and negative values predict right-turns
$H_{att}(\varphi_j)$ - relative angular position
$H_{ali}(\theta_j)$ - relative heading

Principal Component Analysis (PCA)

From points of data in a multidimensional space, a best fit line is made that has the minimal squared distance from the line to the points.

Then the next best fit line can be chosen perpendicular to the first.

This creates different components.

In this study, there are 3 components.

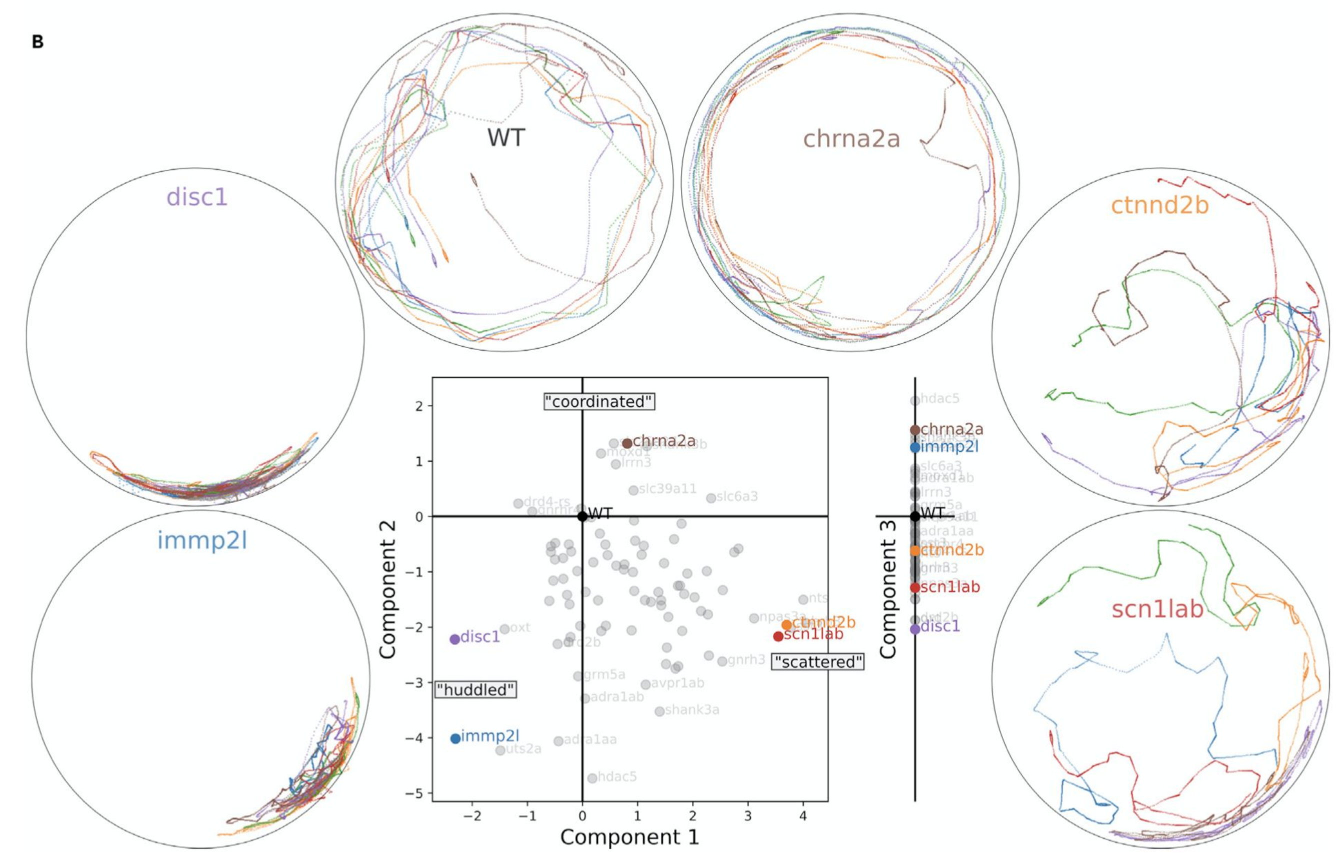

B
WT
chrna2a
disc1
ctnnd2b
immp2l
scn1lab
"coordinated"
"huddled"
"scattered"
Component 1
Component 2
Component 3

Figure 10

Conclusion

- This study uses quantitative behavioral metrics to show how genetics may direct patterns of collective behavior
- Patterns in the groups come from
  - Structure
  - Cohesion
  - Leadership
  - Dynamics
- Which lead to species fitness and adaptation to environmental changes (evolution)
- This study explores the relationship between genes, social interaction, and sensorimotor transformations
- In general, mutations that alter speed do change the behavior of the group in predictable ways
- But, mutations with effects on the group pattern and dynamics dissociated from the effects of speed

How can drones work in groups?

- I found that this research could possibly be applied to the autonomous flight of flocking drones
- These drones could use data about how animals move in groups to further push the envelope of dynamic flight technology
- This could result in flocks of drones that could accomplish complex tasks which were otherwise not accomplishable with only human controlled aircraft

Works Cited

- Genetic control of collective behavior
  - (article)https://news.harvard.edu/gazette/story/2020/03/study-connects-specific-genes-with-defective-social-behavior/
  - (scientific paper)https://www.cell.com/iscience/fulltext/S2589-0042(20)30126-7
  - Figure 1-7
- CRISPR Explained
  - https://www.youtube.com/watch?v=UKbrwPL3wXE
- Flocking algorithm for autonomous flying robots
  - https://iopscience.iop.org/article/10.1088/1748-3182/9/2/025012/meta