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Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see Authors & Referees and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed
☐	☒ The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒ The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒ A description of all covariates tested
☐	☒ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒ For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☐	☒ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☐	☒ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒ Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Imaging tools including high-speed camera (Phantom v2012) was used with Imaging software PCC (2.1).
Data analysis	Tracer trajectories and velocities were obtained with "TrackMate" PTV software (Tinevez, J.-Y. et al. Trackmate: An open and extensible platform for single-particle tracking. Methods 115, 80–90 (2017). The description of all the other data analysis techniques is provided in the paper. FlowTrace (https://github.com/williamgilpin/flowtrace_python) used for visualization. Matlab 2018 used for analysis.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

No restrictions exists on data availability. The key datasets for all the plots and simulations including videos are included in the submission.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☒ Life sciences ☐ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

Sample size	Sample size of number of cells used and number of times experiments are repeated for each figures is provided in main figures and supplementary figures. The associated statistical tests are provided in the supplementary materials. Details: Fig 1B: This SEM experiment was independently re- peated Ne = 21 times with different organisms, giving similar results. Fig 1C: This contraction kinematics experiment was independently repeated Ne = 48 times with different or- ganisms, giving similar results. Note that these are spon- taneous contractions that were not triggered electrically. Fig 1E: This contraction kinematics experiment was independently repeated Ne = 216 times with different organisms, at 8 different pulse strengths. See §IIB for more details. Fig 2C-D: This particle image velocimetry (PIV) ex- periment was independently repeated Ne = 46 times with different organisms, with tracer particles of different di- ameters, D = 0.75, 1, 2, 6µm, all showing similar results. See §III A for more details. Fig 2E: This particle tracking velocimetry (PTV) ex- periment uses an ensemble of Nt = 171 tracer particles to determine the averaged flow velocity over time. See §III A for more details. The low-viscosity were repeated Ne = 46 times with similar results, and Ne = 17 for the high-viscosity control experiments. Fig 2F: This mixing simulation uses an ensemble of Nt = 500 tracer particles, and was repeated indepen- dently for the high and low viscosity cases. See §III E for more details. Fig 3B-E: This rheosensing experiment comprised of No = 115 different organisms. See §IV A for more details. This experiment was independently repeated Ne = 17 times with similar results. Fig 3E: Box-whisker chart definition: Whiskers show the upper and lower fences (outliers), the box edges show the 25% and 75% quantiles, and the middle line is the median. Fig 4A: Shown is one hydrodynamic trigger wave ex- periment with No = 97 organisms. This hydrody- namic trigger wave experiment was independently re- peated Ne = 41 times giving similar results. See §VB for more details. Fig 4B: This phase diagram shows simulations (blue) for an ensemble of Ne = 100 independent colonies, each with No ~ 103 organisms depending on the density [see §V E]. The trigger wave velocity experiment (pink) used No = 97 organisms, and was repeated Ne = 41 times with similar results. Fig 4D,E: This pairwise contraction experiment was independently repeated Ne = 57 times with different or- ganisms. See §V C for more details. Fig S1B: Shown is the median behaviour of No > 20 organisms for each data point, which is repeated in Ne = 20 × 25 independent experiments with new organisms for different pulse strengths and duration. Fig S1C,D: This contraction kinematics experiment was independently repeated with Ne = 28, 38, 47, 26, 30, 18, 19, 10 organisms at applied voltages 10, 15, 20, 25, 30, 35, 40, 45V, respectively. See §IIB for more de- tails. Fig S2,4,5: These flow measurement experiments were independently repeated Ne = 46 times with different or- ganisms, giving similar results. Fig S8: These hydrodynamic trigger wave simulations were repeated for an ensemble of Ne = 100 independent colonies, each with No ~ 103 organisms depending on the density [see §V G].
Data exclusions	No data has been excluded.
Replication	Extensive efforts were taken throughout data collection process to ensure replication and reproducibility. The list above on sample size goes through step by step on choices made on samples. With large sample sizes and no data excluded; replication is documented in figures plotted already. Furthermore, we replicated experiments at two different locations in two labs - one in primary lab at Stanford and a few experiments were also recreated and replicated in a former postdoc's lab in Georgia Tech.
Randomization	Single cells were randomly picked from cultures and randomly chosen for imaging. For studies involving length related correlations, data was collected on a randomly sampled group of cells and sorted as a function of cell length.
Blinding	Blinding was not relevant for our study since no a-prior grouping was done on cells used in the experiments.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology
☐	☒ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Animals and other organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research

Laboratory animals	The study involves single cell ciliates Spirostomum ambiguum; which were obtained from Carolina Biological and cultured in the lab.
Wild animals	The study did not involve wild animals.
Field-collected samples	The study did not involve field collected samples.
Ethics oversight	The study did not require any ethics approval or guidance.

Note that full information on the approval of the study protocol must also be provided in the manuscript.