Supplemental Material

Swimming statistics of cargo-loaded single bacteria

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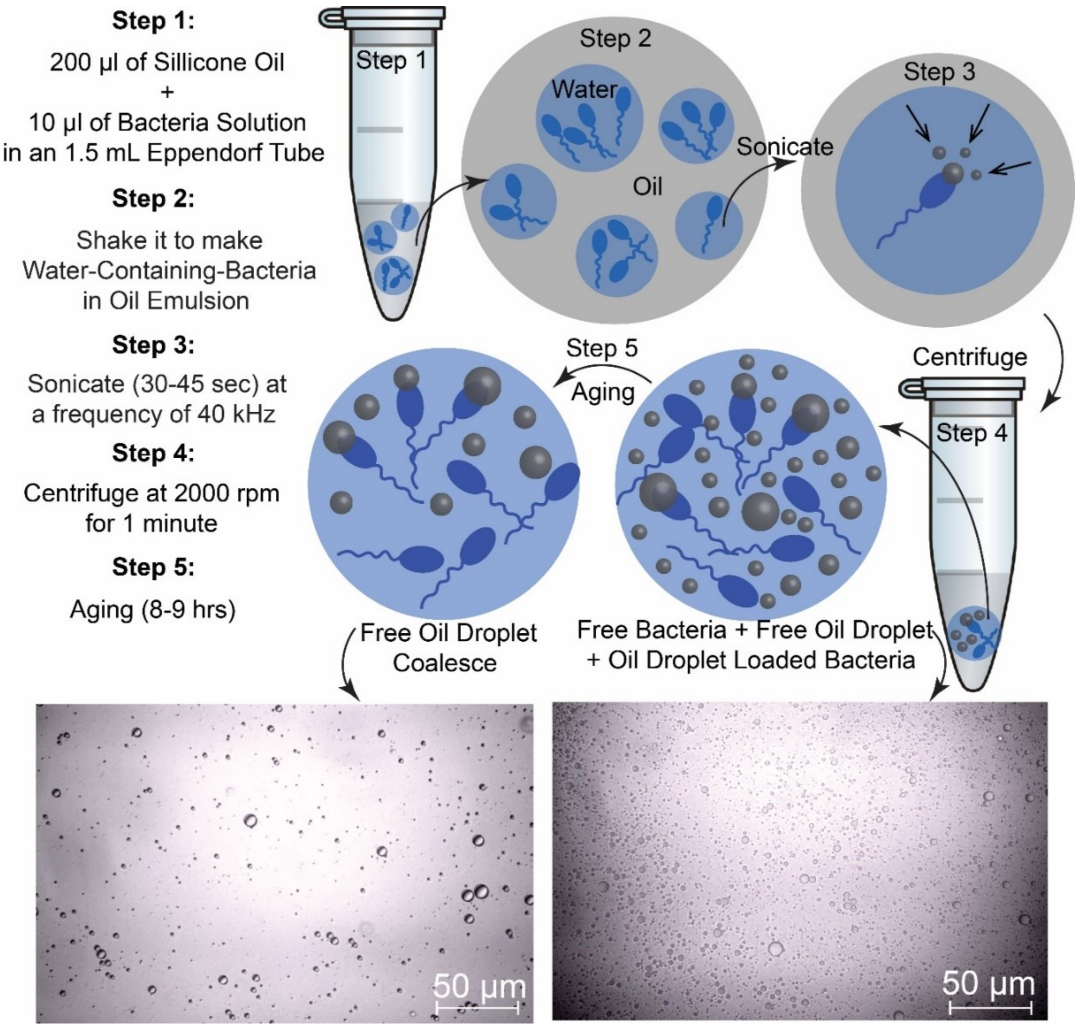
1. Infographic on oil-droplet attachment process: The aging step (Step 5) is of particular importance as it provides enough time for the free oil-droplets to coalesce, resulting in fewer obstructions in the tracks of oil-droplet loaded bacteria.



2. Raw Scanning Electron Microscopy image of bacteria

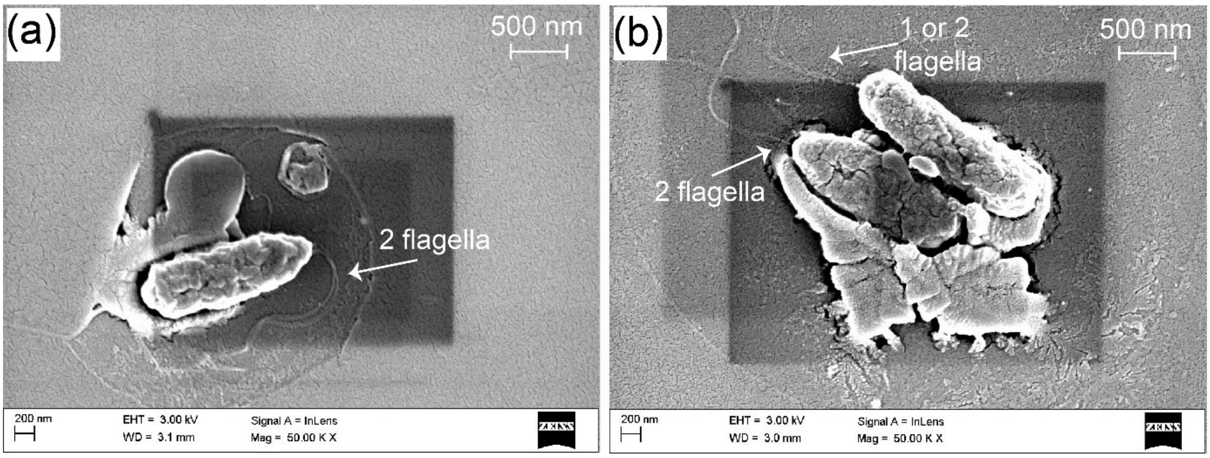


Fig. S1 Raw SEM image showing 2 flagella protruding from two different bacteria. As we have observed several meandering tracks, it may be that this strain is a mixture of bi-flagellated and mono-flagellated species.

3. Modified Purcell's model for cargo loaded bacteria

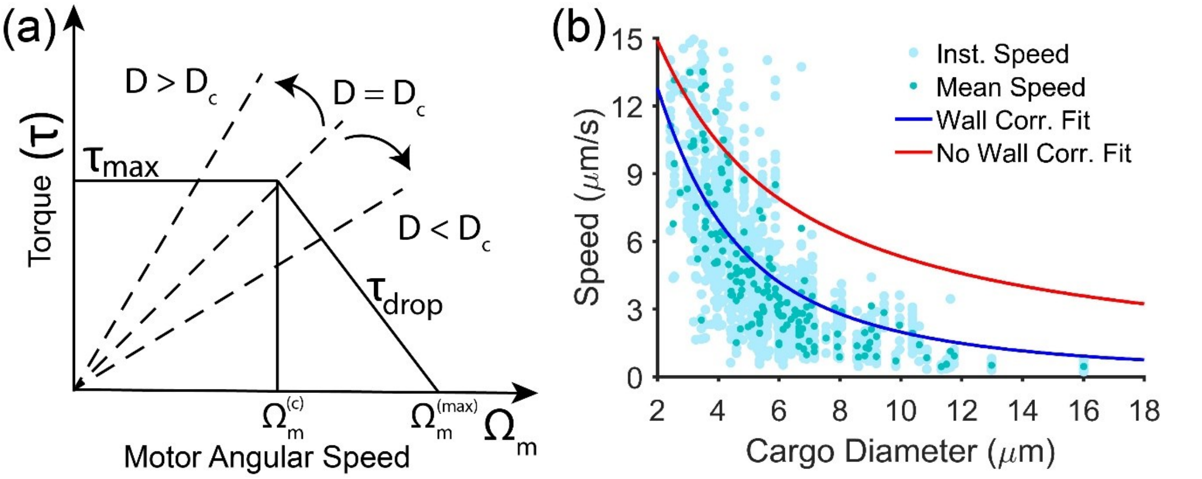


Fig. S2: (a) A schematic of the torque speed response curve of the bacterial motor. (b) Speed of oil-droplet loaded bacteria vs. cargo diameter. We have included the swimming speed of several smaller trajectories in addition to the longer trajectories presented in the manuscript.

For detailed derivation, please refer to the Reference 7. A_o, D_o are the translation and rotational drag coefficients and V, Ω are the translation and angular speed of bacterial body. Similarly, A, D are the translational and rotational drag coefficients and V, ω is the translation and angular speed of flagella. When a bacterium is loaded with cargo on its cell body, the drag coefficients A_0 and D_0 can be written as:

$A_0 = \alpha A^{cell-body}_0 + A^{cargo}_0$ and $D_0 = \alpha D^{cell-body}_0 + D^{cargo}_0$

where, A^{cargo}_0 and D^{cargo}_0 for a spherical cargo of radius r is given by $6\pi\eta r$ and $8\pi\eta r^3$ respectively, and η is the viscosity of the fluid medium. The factor α is to account for the partial occlusion of the cell body by the cargo. We take α to be 0.5, although the results are not very sensitive to the precise value of α. In our experiments, bacteria swim close to the top wall of the reservoir resulting in increased drag which is not accounted in the above equations. We incorporated this wall effect by correcting the drag coefficients as [1]:

$$A_o = A_\infty \left(\frac{1 + 9/16(A_\infty)}{6\pi\eta d_{wall}} \right) \text{ and } D_o = D_\infty \left(\frac{1 + 1/8(D_\infty)}{8\pi\eta d_{wall}^3} \right)$$

where A_∞ and D_∞ are translation and rotational drag coefficients far from the wall, i.e. and $d_{wall} = 1.5\ \mu m$ is the 'best fit' average distance of the cargo loaded bacteria from the wall of the fluidic chamber.

If the slope D is less than a critical value $D_c = \tau_{max}/\Omega^{(c)}_m$ then the load line will never intersect the flat region of the TS, i.e. the maximum available torque will not be accessible to the bacterium (Fig. S2 (a)).

$$V_{flat} = \frac{B}{A + A_o} \cdot \frac{\tau_{max}}{D} \text{ when } DD_0/(D + D_0) > D_c$$

$$\text{and } V_{slope} = \frac{B}{A + A_o} \left(\frac{1}{1 + \frac{D}{D_o} + \frac{kD}{D_c}} \right) \Omega^{(max)}_m \text{ when } DD_0/(D + D_0) < D_c$$

where $k = (\Omega^{(max)}_m - \Omega^{(c)}_m)/\Omega^{(c)}_m$, $A = 1.48 \times 10^{-8}\ N \cdot s/m$, $B = 7.9 \times 10^{-16}\ N \cdot s$, $D = 7 \times 10^{-22}\ N \cdot s \cdot m$, $A^{cell-body}_o = 1.4 \times 10^{-8}\ N \cdot s/m$, $D^{cell-body}_o = 4.2 \times 10^{-21}\ N \cdot s \cdot m$, $\Omega^{(max)}_m = 900\ rad/s$. These parameters were taken from experimental measurements of the propulsion matrix for, *E. coli* [2]. The TS characteristics of E. coli have also been measured, from which we take $\tau_{max} = 1260\ pN.nm$ [3,4] and $k = 0.5$ [5,6]. In order to check the viability of the cargo loaded bacteria, we compared the experimentally obtained speed from the one obtained from the modified Purcell's model. The swimming speed can be predicted with good accuracy by using the modified form, as shown in Fig. S2(b)[7].

4. Free and oil-droplet loaded bacteria tracks

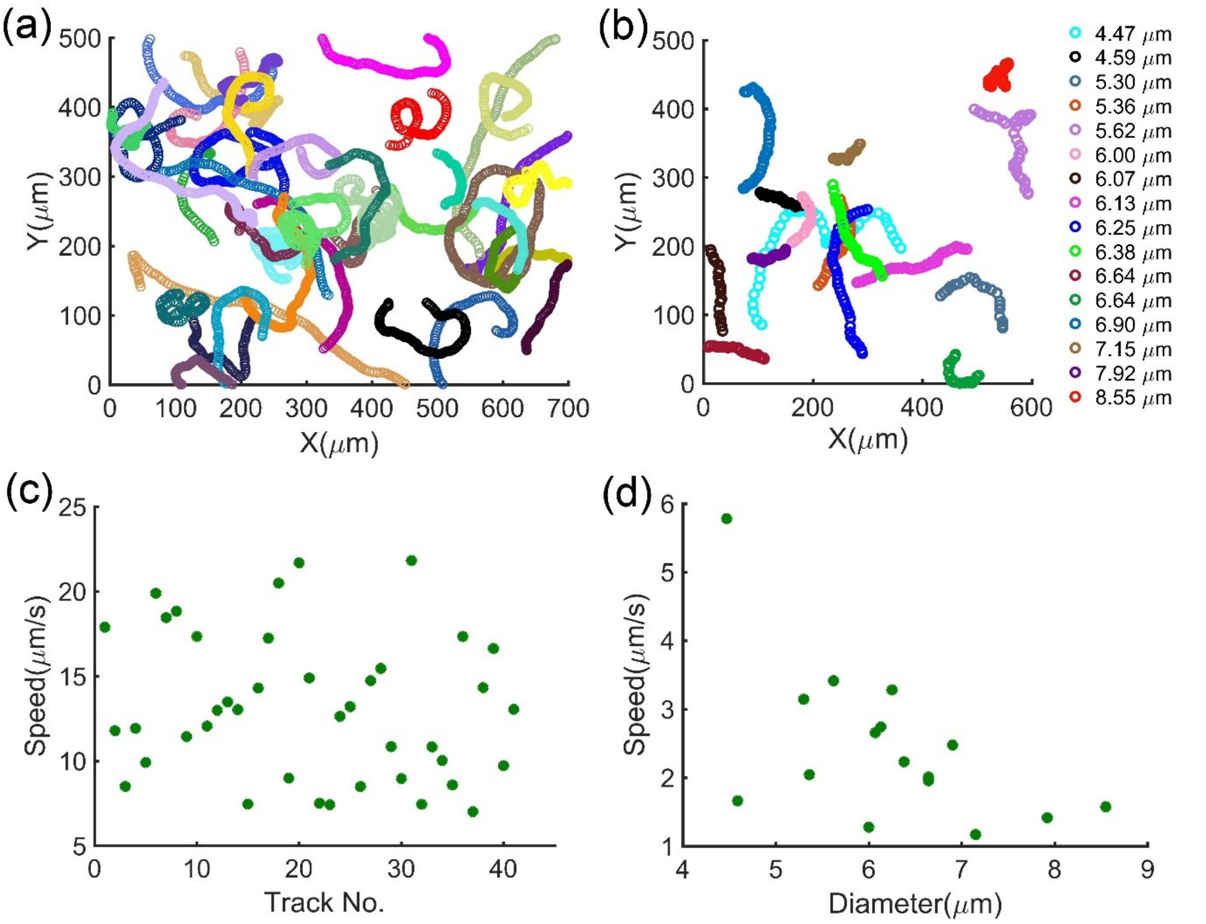


Fig. S3 (a) Bacteria tracks: 35 tracks are up to 25 sec long and 5 tracks are up to 40 sec long (b) Oil-droplet loaded bacteria track: 8 tracks are up to 50 sec long and another 8 tracks are up to 80 sec. (c) Average speed of bacteria tracks. (d) Average speed of oil-droplet loaded bacteria tracks.

5. $\alpha = \langle Cos(\theta_d) \rangle$ for bacteria and oil-droplet loaded bacteria tracks

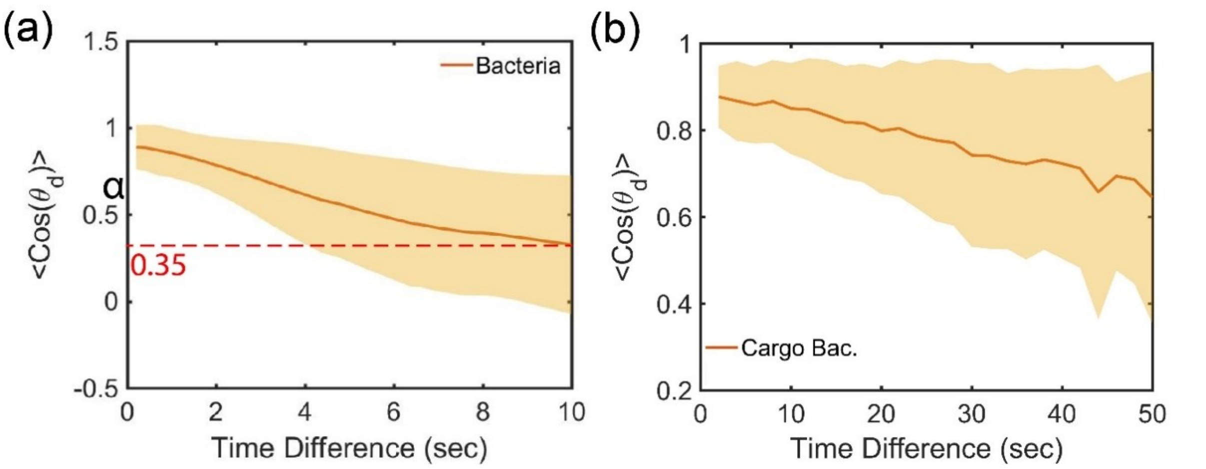


Fig. S4: (a) $\alpha = 0.35$ for bacteria tracks after 10 sec. (b) α for oil-droplet loaded bacteria tracks.

6. Description of the Supplementary Videos

Video 1 shows following four types of motile species:

a) Several motile bacteria throughout the movie; corresponds to Track No. 4-17 in Video 2.

b) Oil-droplet loaded bacteria ($0 - 4\ sec$); corresponds to Track No. 1 in Video 2.

c) Oil-droplet attached sideways to bacteria ($5 - 30\ sec$); corresponds to Track No. 2 in Video 2.

d) Oil-droplet attached to a large oil-droplet which is unable to move (30 sec onwards); corresponds to Track No. 3 in Video 2.

Reference

1 J. Happel and H. Brenner, *Low Reynolds number hydrodynamics*, Springer Netherlands, Dordrecht, 1981, Vol. 1.

2 S. Chattopadhyay, R. Moldovan, C. Yeung and X. L. Wu, *Proc. Natl. Acad. Sci. U. S. A.*, 2006, **103**, 13712–13717.

3 S. W. Reid, M. C. Leake, J. H. Chandler, C. -J. Lo, J. P. Armitage and R. M. Berry, *Proc. Natl. Acad. Sci. U. S. A.*, 2006, **103**, 8066–8071.

4 Y. Sowa and R. M. Berry, *Q. Rev. Biophys.*, 2008, **41**, 103–132.

5 G. Li and J. X. Tang, *Biophys. J.*, 2006, **91**, 2726–2734.

6 Y. Inoue, C. -J. Lo, H. Fukuoka, H. Takahashi, Y. Sowa, T. Pilizota, G. H. Wadhams, M. Homma, R. M. Berry and A. Ishijima, *J. Mol. Biol.*, 2008, **376**, 1251–1259.

7 P. Prakash, A. Z. Abdulla, V. Singh and M. Varma, *Phys. Rev. E*, 2019, **100**, 062609.