Electronic Supplementary Information: Acoustic trap-and-release for rapid assessment of cell motility

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Relationship of ΔJ/CSA to MSD: Ideal Case and Practical Implementation

Ideal Case

The mean squared displacement of a collection of spreading cells is expressed as

$$\text{MSD} = \left\langle |\boldsymbol{x} - \boldsymbol{x_o}|^2 \right\rangle = \frac{1}{N}\sum_{n=1}^{N} |\boldsymbol{x_n} - \boldsymbol{x_{no}}|^2, \qquad \text{S.1}$$

where $\boldsymbol{x} = \boldsymbol{x_n}$ is the location of cell n at time t, $\boldsymbol{x_o} = \boldsymbol{x_{no}}$ is the initial location of the cell, and N is the total number of cells in the trap. To determine the ratio ΔJ/CSA, we first define the polar area moment of inertia, $\tilde{J}$, for the composite region of spreading cells with respect to a centroidal coordinate system at time t as

$$\tilde{J} = I_{min} + I_{max} = \int r^2 dA, \qquad \text{S.2}$$

where I_{min} and I_{max} are the principal second moments of area of the collective region, and r is the distance from an area element to the centroid of the region: $r = |\boldsymbol{x} - \boldsymbol{x_c}|$.

For a collection of discrete cells with areas $A_{cell,n}$, $\tilde{J}$ becomes

$$\tilde{J} = \sum_{n=1}^{N} |\boldsymbol{x_n} - \boldsymbol{x_c}|^2 A_{cell,n}, \qquad \text{S.3}$$

Where $\boldsymbol{x_n}$ is the location of cell n at time t and $\boldsymbol{x_c}$ is the location of the centroid of the cell collective at time t. Similarly, CSA can be expressed as

$$\text{CSA} = \sum_{n=1}^{N} A_{cell,n}. \qquad \text{S.4}$$

In an ideal trap-and-release experiment, a collection of identical cells would all start from the same point (the center of the trap) and swim radially outward, each with the same speed. If the initial location of every cell is the centroid (i.e., $\boldsymbol{x_{no}} = \boldsymbol{x_c}$) and each cell has the same area (i.e., $A_{cell,n} = A_{cell}$), the ratio of the polar moment of inertia (from Eq. S.3) to the cross-sectional area (from Eq. S.4) is exactly equal to the MSD:

$$\frac{\tilde{J}}{\text{CSA}} = \frac{\sum_{n=1}^{N} |\boldsymbol{x_n} - \boldsymbol{x_{no}}|^2}{N} = \text{MSD}. \qquad \text{S.5}$$

Practical Implementation

To account for small deviations from the ideal scenario described above, we report a slightly different metric: the change in total polar moment of inertia about the original centroid, ΔJ. First, *spreading is not perfectly axisymmetric*: the centroid of the cell collective shifts from its original position as the cells spread. The parallel axis theorem is

S.6

used to account for drift of the centroid. The total polar moment of inertia, J, with respect to the initial centroid of the cell collective at *t* = 0, is thus

$$J = \tilde{J} + d^2\text{CSA} = \tilde{J} + d^2\int dA,$$

where CSA is the cross-sectional area at the current time, t, and d is the distance between the current centroid and the centroid at t = 0: $d = |\boldsymbol{x_c} - \boldsymbol{x_{co}}|$. Second, *the cells do not all start at the same initial location* at t = 0, as they would in an ideal acoustic trap. To account for the finite initial radius of the cell cluster, the J value at t = 0, J_o, is subtracted from J to obtain ΔJ, defined as

$$\Delta J = J - J_o. \qquad \text{S.7}$$

The proposed metric of spreading, ΔJ/CSA, thus accounts for asymmetric spreading and imperfect trapping.

For completeness, we expand this metric for a collection of discrete cells:

$$\frac{\Delta J}{\text{CSA}} = \frac{\tilde{J} + d^2\text{CSA} - J_o}{\text{CSA}}. \qquad \text{S.8}$$

The term

$$d^2\text{CSA} = |\boldsymbol{x_c} - \boldsymbol{x_{co}}|^2 \sum_{n=1}^{N} A_{cell,n}, \qquad \text{S.9}$$

where $\boldsymbol{x_{co}}$ is the location of the centroid of the cell collective at time t = 0. Similarly, J_o becomes

$$J_o = \sum_{n=1}^{N} |\boldsymbol{x_{no}} - \boldsymbol{x_{co}}|^2 A_{cell,no}, \qquad \text{S.10}$$

where $\boldsymbol{x_{no}}$ is the initial location of each cell, and $A_{cell,no}$ is the initial area of each cell. Substituting expressions for $\tilde{J}$, J_o, and CSA into Eq. S.8, we obtain

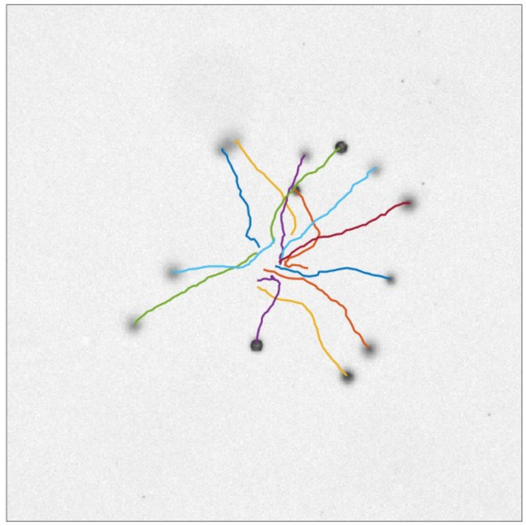
$$\frac{\Delta J}{\text{CSA}} = \frac{\sum_{n=1}^{N} |\boldsymbol{x_n} - \boldsymbol{x_c}|^2 A_{cell,n} + |\boldsymbol{x_c} - \boldsymbol{x_{co}}|^2 \sum_{n=1}^{N} A_{cell,n} - \sum_{n=1}^{N} |\boldsymbol{x_{no}} - \boldsymbol{x_{co}}|^2 A_{cell,no}}{\sum_{n=1}^{N} A_{cell,n}}. \qquad \text{S.11}$$

If all cells are of constant, uniform apparent size, $A_{cell,n}$ = $A_{cell,no}$ = A_{cell}, then

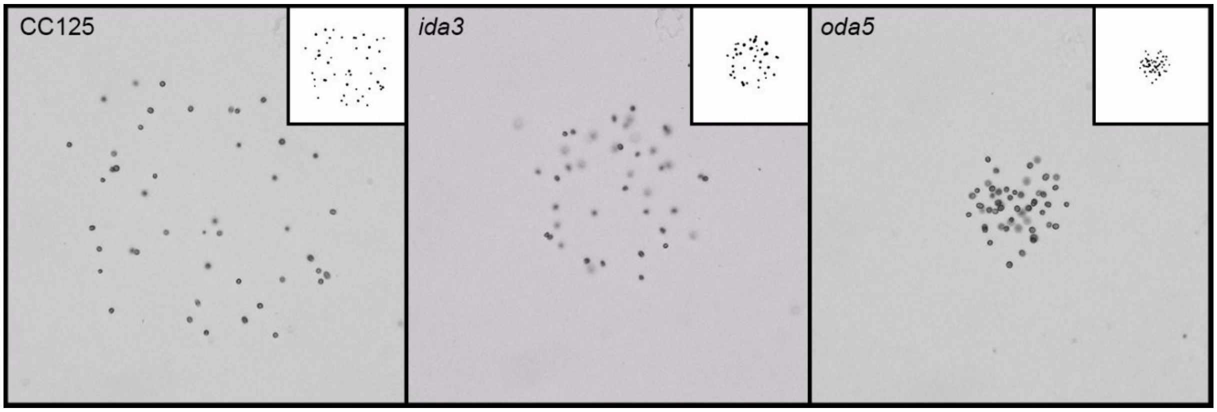
$$\frac{\Delta J}{\text{CSA}} = \frac{\sum_{n=1}^{N} |\boldsymbol{x_n} - \boldsymbol{x_c}|^2 + N|\boldsymbol{x_c} - \boldsymbol{x_{co}}|^2 - \sum_{n=1}^{N} |\boldsymbol{x_{no}} - \boldsymbol{x_{co}}|^2}{N}. \qquad \text{S.12}$$

Considering again the ideal case, if there is no drift (perfect radial spreading), the centroid is fixed: $\boldsymbol{x_c} = \boldsymbol{x_{co}}$; also, for a perfect acoustic trap, all cells are initially confined to the trap center: $\boldsymbol{x_{no}} = \boldsymbol{x_{co}}$. Under these ideal conditions,

$$\frac{\Delta J}{\mathrm{CSA}} = \frac{\sum_{n=1}^{N} |\boldsymbol{x_n} - \boldsymbol{x_{no}}|^2}{N} = \mathrm{MSD}. \qquad \text{S.13}$$



Movie S1. Low-population release of wild-type (CC-125) *C. reinhardtii* cells from the acoustic trap overlaid with manually-traced trajectories for the ballistic swimming regime (t = 0.75 s).



Movie S2. Large-population comparison of swimming after release for the three *C. reinhardtii* strains studied in this manuscript. The wild-type (CC-125, left panel) cells exhibit the most ballistic swimming behavior and take the least time to disperse. Mutant cells with impaired motility, *ida3* (middle panel) and *oda5* (right panel), take longer times to spread.