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Fluid dynamics and noise in bacterial cell-cell and cell-surface scattering

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Bacterial processes ranging from gene expression to motility and biofilm formation are constantly challenged by internal and external noise. While the importance of stochastic fluctuations has been appreciated for chemotaxis, it is currently believed that deterministic long-range fluid dynamical effects govern cell-cell and cell-surface scattering - the elementary events that lead to swarming and collective swimming in active suspensions and to the formation of biofilms. Here, we report the first direct measurements of the bacterial flow field generated by individual swimming Escherichia coli both far from and near to a solid surface. These experiments allowed us to examine the relative importance of fluid dynamics and rotational diffusion for bacteria. For cell-cell interactions it is shown that thermal and intrinsic stochasticity drown the effects of long-range fluid dynamics, implying that physical interactions between bacteria are determined by steric collisions and near-field lubrication forces. This dominance of short-range forces closely links collective motion in bacterial suspensions to self-organization in driven granular systems, assemblages of biofilaments, and animal flocks. For the scattering of bacteria with surfaces, long-range fluid dynamical interactions are also shown to be negligible before collisions; however, once the bacterium swims along the surface within a few microns after an aligning collision, hydrodynamic effects can contribute to the experimentally observed, long residence times. As these results are based on purely mechanical properties, they apply to a wide range of microorganisms.

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