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rok	1994.
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DÄNIKEN, E. von. *Prorok minulosti.* Přel. R. Řežábek. 1. vyd. Praha : Naše vojsko, 1994. 220 s. Fakta a svědectví. Sv. 119. Přel. z: Prophet der Vergangenheit.

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Rok, číslo svazku, lokace části	duben 1995, č. 4, s. 25-29

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1 CARROLL, Lewis. *Alice's Adventures in Wonderland* [online]. Texinfo ed. 2.1. [Dortmund (Německo)]: WindSpiel, November 1994 [cit. 10. února 1995]. Dostupné na World Wide Web: <http://www.germany.eu.net/books/carroll/alice/html>. Dostupné také v PostScript a ASCII verzích na Internetu: <ftp://ftp.Germany.EU.net/pub/books/carroll/>.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ijmm.2010.10.005.

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they could also display optical properties and emit electromagnetic radiation, a process known as electroluminescence [79]. This raises the question of how specific physical signals really are. Because the unifying property of all physical signals is the energy they carry, energy could be the specific information transmitted from cell to cell. After all, life is the interaction of matter and energy. Physical signaling could be an ancestral language of all living forms and, perhaps, a key code to decipher if we want to understand the microbial conversations that have for so long remained inaudible.

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Opinion

Cell PRESS

When microbial conversations get physical

Gemma Reguera

Department of Microbiology and Molecular Genetics, Michigan State University, 6190 Biomedical & Physical Science Building, East Lansing, MI 48824, USA

It is widely accepted that microorganisms are social beings. Whereas communication via chemical signals (e.g. quorum sensing) has been the focus of most investigations, the use of physical signals for microbial cell–cell communication has received only limited attention. In this Opinion article, I postulate that physical modes of microbial communication could be widespread in nature. This is based on experimental evidence on the microbial emission and response to three physical signals: sound waves, electromagnetic radiation and electric currents. These signals propagate rapidly, and even at very low intensities, they provide useful mechanisms when a rapid response is required. I also make some suggestions for promising future research avenues that could provide novel and unsuspected insights into the physical nature of microbial signaling networks.

Can microbial conversations get physical?

Communication is by definition a process of information (signal) exchange between a sender and a receiver through a common medium. Quorum sensing enables microorganisms to communicate chemically by responding coordinately to the accumulation of extracellular chemical signals (autoinducers) and reprogramming gene expression as a function of cell density [1]. Experimental evidence also indicates that microorganisms can generate and respond to physical signals such as sound waves, electromagnetic radiation and electric currents [2–6]. However, the technical challenges associated with probing microbial physical signaling networks at the intensities and time scales required have long limited this field of research. As a result, the role of physical signals as information carriers has received only limited attention. I also provide my opinion about the limitations of these studies, the outstanding questions and what I consider are the most promising directions to advance this field of research. Unlike chemical signals, physical signals are subjected less to diffusion constraints, and can propagate through a wide range of media, including cells, which I propose can enable faster cellular responses. I also present evidence that links physical signaling to the metabolic status of the emitting and recipient cells, and speculate about the possibility that the energy carried in these signals is the real 'language' used in physical modes of microbial communication. In this Opinion paper, I hope to stimulate research into this controversial, yet exciting, field of research that has only been marginally explored.

'If microorganisms could talk…': cell–cell communication via sound waves

The suggestion that cells have the ability to communicate with sounds was based on the observation that sound waves stimulated the growth of *Bacillus carboniphilus* under stress conditions [2]. Although the bacteria were unable to grow in high salt concentrations or at high temperature [7], their growth was stimulated by neighboring cells of the same or different species grown on a separate plate stacked on top, and regardless of the presence of a separating 2 mm iron barrier to prevent the exchange of volatile substances [8]. Growth under non-permissive conditions was also stimulated by specific sound frequencies applied with an external speaker [2] and by including in the growth medium carbon materials, such as graphite or activated charcoal, known to convert external electromagnetic radiation into sound [9]. These results suggested that the growth-stimulating signal was physical and, possibly, sonic in nature. Interestingly, al-

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