

Self-organization in the Concert Hall: the Dynamics of Rhythmic Applause

The appreciation of the audience for a good performance is expressed by the strength and the nature of the applause, often turning the initial thunder into synchronized clapping (SC), familiar to many who frequent concert halls. Synchronized clapping has a well defined scenario: the initial strong incoherent clapping is followed by a relatively sudden synchronization process, after which everybody claps simultaneously and periodically. This synchronization can disappear and reappear several times during the applause. The phenomenon is a wonderful expression of social self-organization, providing a human scale example of the synchronization processes observed in numerous systems in nature, ranging from the synchronized flashing of the south-east Asian fireflies to oscillating chemical reactions [1–3].

Here we investigate the mechanism and the development of SC by performing a series of measurements, focusing on both the collective aspects of the self-organization process as well as the behavior of the individuals in the audience. First, we recorded the applause after several theater and opera performances, capturing the emergence and the disappearance of synchronization recorded by a microphone placed at the ceiling of the hall (Fig 1a). After a few seconds of random clapping a periodic signal develops (a signature of SC), a transition captured by the order parameter (Fig. 1c), which increases as the periodic signal develops, and decreases as it disappears. While the synchronization process increases the strength of the signal at the moment of the clapping, it leads to a decrease in the average noise intensity in the room (see Fig. 1d). This is rather surprising, since one would expect that the driving force for synchronization could be the desire of the audience to express its enthusiasm by increasing the average noise intensity. The origin of this apparent anomalous behavior can be understood by correlating the global signal with the behavior of an individual in the audience. For this we recorded the local sound intensity in the vicinity of a group of individuals (Fig. 1b). In the incoherent phase the local signal shows a periodic character with a short period corresponding to the clapping of an individual in the audience. However, the

period suddenly increases as SC develops. The process can be quantified by measuring the clapping period, defined as the distance between the consecutive local maxima in Fig. 1b. As Fig. 1e shows, the clapping period suddenly doubles at the beginning of the synchronized phase, and slowly decreases as synchronization is lost. Consequently, by synchronizing the clapping the audience has succeeded in increasing the instantaneous noise intensity, but the average noise intensity has decreased (Fig. 1d) since there is less clapping in unit time. An increase in the average noise intensity is possible only by decreasing the period of clapping, a process that can be clearly observed in Fig. 1e. However, this gradually brings the synchronized clapping back to the fast clapping observed in the early asynchronous phase, and synchronization disappears. Apparently, the conflicting desire of the audience to simultaneously increase the average noise intensity and to maintain synchronization leads to the sequence of appearing and disappearing synchronized regimes.

To better understand the origin of the period doubling process seen in Fig. 1e, we investigated the internal frequency of several individuals by controlled clapping experiments. Students were asked to clap in the manner they usually do right after a good performance (Mode I clapping), after which they were asked to clap in the manner they would during the rhythmic applause (Mode II clapping). As Fig. 1f shows, we find that the frequencies of the Mode I and Mode II clapping are clearly separated such that the average period doubles from Mode I to Mode II clapping, and the width of the frequency distribution of the Mode II clapping is considerably smaller. Furthermore, we find that the relative dispersion of the distribution also decreases. The separation of the frequencies and the period doubling is reproducible for a single individual as well (Fig. 1g).

The above results indicate that after an initial asynchronous phase, characterized by high frequency clapping (Mode I), the individuals synchronize by eliminating every second beat from their clapping, suddenly shifting to a double period (Mode II) clapping, where dispersion is smaller. As shown by Kuramoto, for a group of globally coupled oscillators the necessary condition for synchronization is that dispersion has to be smaller than a critical value, thus decreasing the dispersion improves synchronization [4]. This correlation between

synchronization and the width of the distribution could apply to SC as well: as Mode II clapping with small dispersion appears, synchronization is possible, but as the period gradually decreases, it brings a gradual slip back to the incoherent Mode I clapping with larger dispersion. This is due to the frustration in the system: the audience cannot achieve both optimal synchronization and maximal noise intensity within the same clapping mode.

Our measurements indicate that the dynamics of SC has a number of unique features, not yet observed in physical or biological systems. Modeling this phenomena would likely involve a combination of system specific concepts, incorporating ideas from the integrate and fire [2,3,5] and the Kuramoto [4] models of synchronization. Consequently, the results presented here have the potential to go beyond the description of this fascinating social self-organization, offering hints that could be useful in describing synchronization in other complex systems as well.

Z. Nédá*, **E. Ravasz***, **Y. Brechet[&]**, **T. Vicsek****, A.-L. Barabási***,

* Babeş-Bolyai University, Department of Theoretical Physics, str. Kogălniceanu 1, RO-3400, Cluj-Napoca, Romania

[&] ENSEEG-LTPCM, INP-Grenoble Saint-Martin D’Heres, CEDEX, France

** Department of Biological Physics, Eötvös-Loránd University, Budapest, Hungary

*** Department of Physics, University of Notre Dame, IN 46556, USA

E-mail: zneda@hera.ubbcluj.ro

REFERENCES

- [1] Strogatz, S.H. and Stewart, I., *Scientific American* December, 102-109 (1993)
- [2] Bottani, S., *Phys. Rev. E* **54**, 2334-2350 (1997)
- [3] Glass, L. and Mackey, M.C., *From Clocks to Chaos: The Rhythms of Life* (Princeton University Press, 1988)
- [4] Kuramoto, Y. and Nishikawa, I., *J. Stat. Phys.* **49**, 569-605 (1987)
- [5] Mirollo, R. and Strogatz, S.H., *SIAM J. Appl. Math.* **50**, 1645-1662 (1990)

FIGURES

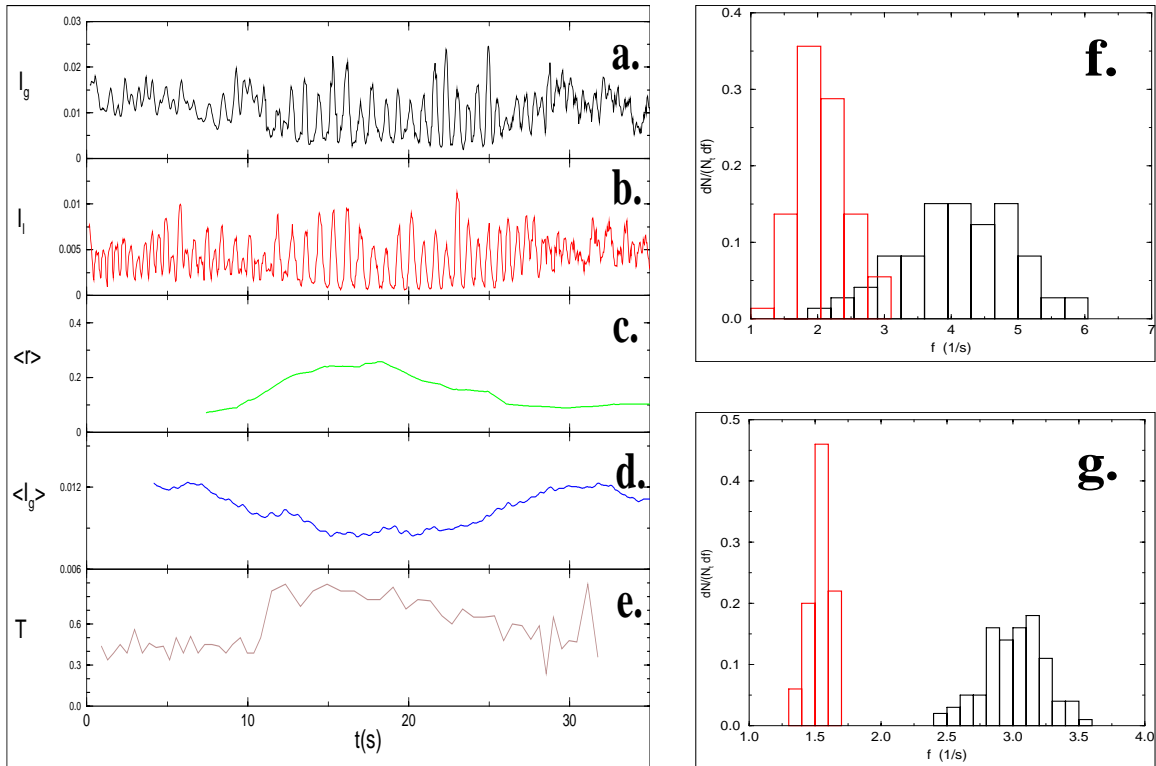


FIG. 1. Emergence of synchronization in clapping. (a) Global noise intensity as a function

of time. The digitized data was squared and a moving average was performed over a window of size $0.2s$, much smaller than the clapping period. The figure shows one of the fifty characteristic regions with the appearance and disappearance of the synchronized clapping. (b) Local noise intensity, measured by a microphone in the vicinity of a spectator. (c) Order parameter, r , defined as the maximum of the normalized correlation between the signal $c(t)$ and a harmonic function, $r = \max_{(T, \phi)} \int_{t-T}^{t+T} c(t) \sin(2\pi/T + \phi) dt / \int_{t-T}^{t+T} c(t) dt$, where ϕ and T span all possible values. (d) Average noise intensity, obtained by taking a moving average over a $3s$ window of the global noise intensity shown in (a). (e) The clapping period, defined as the intervals between the clearly distinguishable maxima. (f) The normalized histogram of clapping frequencies measured for 73 high school students for Mode I (black) and Mode II (red) clapping. (g) Normalized histogram for Mode I and II clapping obtained for a single student, sampled 100 times over a one week period.