the bifurcating phospholipase C pathway.

In contrast, Ca^{2+}-induced Ca^{2+} oscillations at low agonist concentration may partially isolate the activities of Ca^{2+} release from those of protein kinase C activation. The full range of oscillatory and sustained-plateau Ca^{2+} signals can thus be elicited from a single receptor. This complex Ca^{2+} signalling not only increases the flexibility with which cellular processes can be controlled, but also allows different G-protein-coupled receptors, using the same transmembrane signalling in the same cell, to achieve specificity.

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COMMUNICATION ARISING

Hospital waiting-lists

Do power laws imply self-regulation?

Negative feedback leading to self-regulatory behaviour is an important phenomenon that affects time-series fluctuations in a range of systems and is critical in forecasting and management, particularly when complex dynamics are possible. Smethurst and Williams[1] argue that the lengths of waiting-lists to see hospital consultants are self-regulating, on the grounds that the relative changes in the size of waiting-lists follow a power law, with large changes being relatively rare compared with small ones. Here we show that similar power laws can also be obtained from unregulated, random time series. The existence of a power law that governs fluctuations in time series is not sufficient to prove the existence of self-regulatory behaviour, and we argue that a more sophisticated analysis is required.

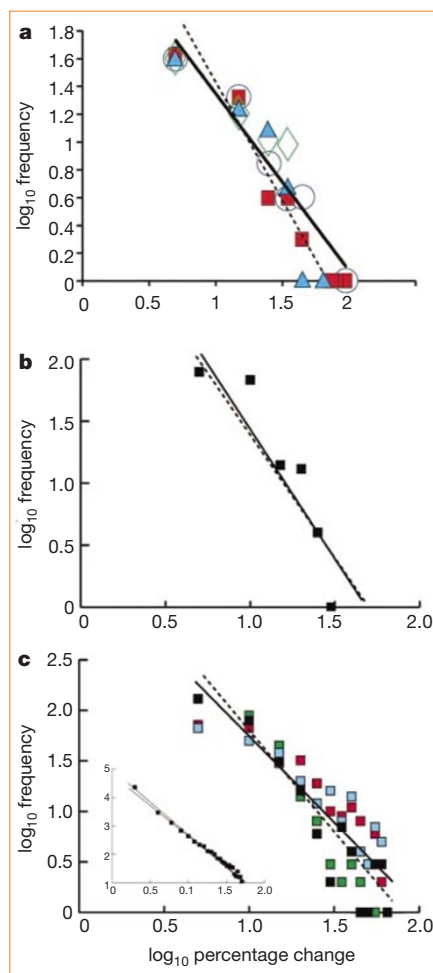Figure 1a shows a power law derived

Figure 1 Power-law behaviour in time series. **a–c,** Frequency distributions of relative changes in numbers (measured as $(N_{t+1} - N_t)/N_t$, where N is the number at current time t, or at one time period later, $t+1$) plotted on a double-logarithmic scale. **a,** Frequency distribution of the extent of length changes in hospital waiting-lists for consecutive months (different symbols signify different consultants); data from ref. 1. The frequency of large variations declines according to a power law (solid line, regression). **b,** Similar analysis of changes in the number of people at the bar of the Butcher's Arms public house in Headington, near Oxford. **c,** Similar analysis of data from discrete-time random walks. Results of random walks of length 300 time units are shown; different symbols denote separate replicates. Inset, asymptotic distribution, from a series of length 30,000 time units. These random walks (brownian motion) assume changes in numbers that are normally distributed (with zero mean); at any time t, the change in number is independent of the number at that time. Hence, this system shows no self-regulatory behaviour — in terms of a waiting-list or queue, this would imply that people join or leave at random, with no regard for the number of other people waiting. In **a–c,** dashed lines have a slope of -2, the expected value for a log-normal distribution of relative fluctuations.

from the data of Smethurst and Williams[1]. In their analysis, the rarity of large changes in the length of waiting-lists is used as evidence for negative feedback: people are more likely to join short rather than long queues, thereby buffering changes. Figure 1b reveals a similar relationship in the number of people waiting at the bar of a public house. The similarity of the plots for the two

systems could be taken as evidence of a general power law governing the behaviour of queues. However, the data in Fig. 1a, b have not been tested against a null model, and it is not clear what pattern would be expected in a system with no self-regulatory behaviour.

The appropriate null model for a system with no regulation is a random walk (brownian motion). If data are following a random walk (that is, if the time series is unregulated), the frequency distribution of relative changes will be expected to show power-law-like behaviour. This is because even in unregulated time series, relatively large fluctuations would be expected to be less common than relatively small ones.

To illustrate this point, Fig. 1c shows the results of applying Smethurst and Williams' analysis to randomly generated data from brownian-motion time series. These time series yield frequency distributions of relative changes that are strikingly similar to the plots in Fig. 1a, b, and which have a power-law slope that is indistinguishable from -2. This indicates that Smethurst and Williams' data are entirely consistent with models in which self-regulation does not occur. The existence of this power-law relationship cannot therefore be used to infer the operation of self-regulatory mechanisms.

Providing evidence for such negative feedback is difficult, as shown, for example, by the problems of detecting density-dependence in ecology[2,3]. We suggest three approaches to the problem of detecting negative feedback in hospital waiting-lists, on the basis of approaches taken by population ecologists. One is to adjust queue lengths experimentally and examine the responses[2]. The second is to plot the rate of change in queue length against the length of the queue, although this is subject to statistical problems[2,3]. The third is to use behaviour-based population modelling[4] to determine the range of trade-offs made by individuals — for example, specific trade-offs can be quantified between the expected waiting time for treatment and the probability of choosing private treatment. Knowledge of such responses could then be applied to reducing waiting times. By contrast, relationships of the type shown in Fig. 1 constitute a poor method of characterizing and forecasting such systems.

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