Signatures of self-organized criticality in spontaneous walking behavior of *Porcellio scaber*

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1 Introduction

Spontaneous behavior emerges without any specific external stimuli and has been well-studied in vertebrate animals, but research in invertebrates, particularly in arthropods, is limited. Isopods, one group of crustaceans found in various environments from deep ocean to land, have high spontaneous maneuverability [1]. This study focuses on spontaneous and exploratory locomotion of the woodlouse *Porcellio scaber* in isopods. Previous research on spontaneous locomotion in *Drosophila melanogaster* [2-4] has provided power-law-distributed behavioral data and its dynamical models have been proposed, but no such data or models exist for isopods.

Our research analyzes behavioral tracking data of walking isopods. The critical brain hypothesis, which posits that a brain operates in a critical state and shows multiple power-laws in power spectrum, duration, and size of behavioral events [5-7]. Although we do not directly collect neural data, the critical state as a whole animal can be examined by the multiple power-laws [8]. We first examined the power-spectra of 13 individuals and confirmed they showed 1/f noise (mean: -0.98; standard deviation: 0.18). Furthermore, we defined the size and duration of walking bouts, referred to as “avalanches", and evaluated if these behavioral avalanches follow a power-law pattern in space and time [9]. Thus the data show the signatures of critical dynamics from 13 animals with individual differences including the genetic, physiological, developmental backgrounds, implying that the signatures of criticality are self-organized [10].

2 Materials and Methods

2-1 Filming of locomotion patterns

In order to study the spontaneous walking movements of woodlice, we decided to create an experimental environment in which stimuli were eliminated as much as possible. Thus, woodlice were placed on a petri dish and allowed to walk freely without any stimulation for ~60 minutes, filmed from the dorsal side using the video recording function of an iPad. The petri dish was 120 mm in diameter and the iPad was set to 1080p HD/30 fps.

A total of 13 videos were filmed. Their body lengths varied from 6 mm to 15 mm. During filming, the experiment environment was set up so that light intensity did not vary depending on the location on the petri dish, and the petri dishes were washed after each experiment to minimize the effects of pheromones and other substances on the behavior.

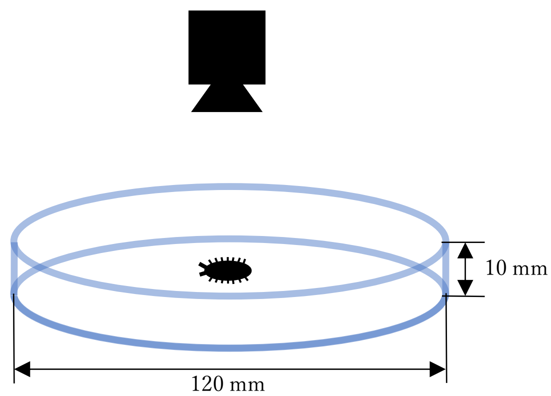

Figure. 1: Experimental setup.

2-2 Analysis procedures

As a pre-processing step in the analysis, we converted the videos to grayscale and its frame rate to 10 fps. Then, we used DeepLabCut [11], an automated tracking software, to record the central position of the body of each woodlice. The body positions were manually labeled for several images in the videos, and machine learning was performed using these manual labels as training data to automatically obtain the position for the remaining images in the videos. In this study, a total of 13 hours of video was tracked.

The acquired tracking data included points that were clearly outside the petri dish. Therefore, points that were outside the range of the petri dish were manually determined and eliminated as outliers in the tracking error. The missing data were linearly interpolated.

Velocity data was then obtained by calculating the difference in the position of the central co-ordinate from one previous video frame.

Fast Fourier transform was applied to the time series of velocity data obtained and the magnitude of the Fourier transform was squared to calculate the power spectrum.

3 Results

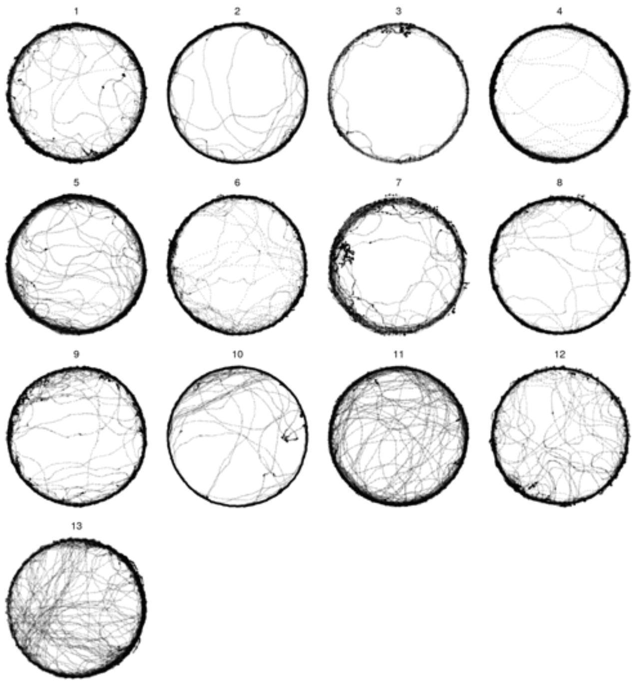

Figure. 2: Trajectory of locomotion.

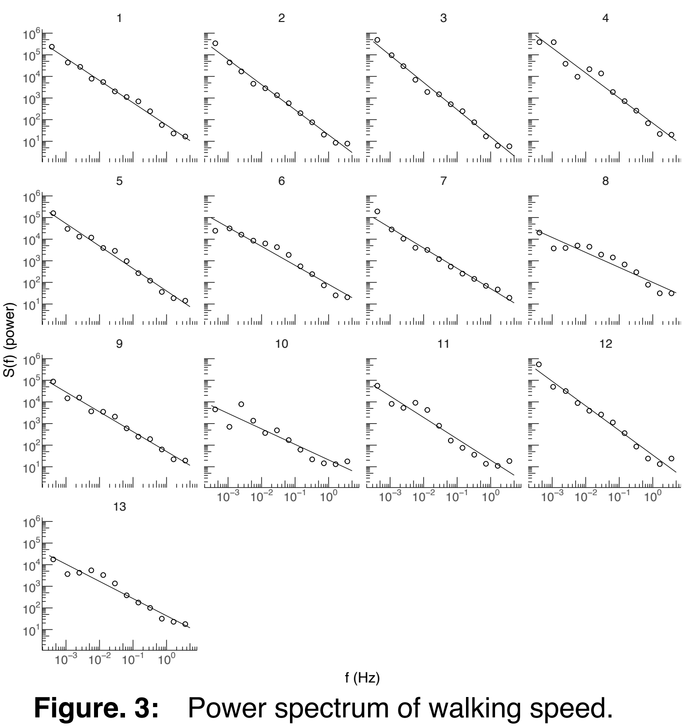

Figure. 3: Power spectrum of walking speed. Both axes are log scale.

Fig. 2 shows the tracked walking trajectories from the 13 individuals. The animals showed a variety of trajectories, but they tended to follow the wall of the dish. Although their body sizes are different and the trajectories were different, as shown in Fig. 3, all power-spectra showed power-laws in the time series of walking speed. The mean slope of the power-law fits was -0.98 and the standard deviation was 0.18, thus it is almost 1/f noise. Furthermore, the durations and sizes (distance) of walking bouts also showed power-laws.

4 Discussion

These multiple power-laws suggest a self-organized critical (SOC) phenomenon [10] in the gait of the woodlice.

Although equating spontaneity at the behavioral level with spontaneity in the nervous system is debatable, similar behavioral examples are known from studies in *Drosophila*, including larva crawling [2] and adult flight [4]. In the present study, the multiple power-laws, a signature of SOC, was newly observed in isopods. This implies that the physical principle SOC can be a principle to explain the spontaneous behavior of organisms. It is therefore considered to be a contribution to the fields of biology and neuroscience.

One issue for future research is that not all of the SOC criteria have been validated. In addition to the verification carried out in this study, future work is to verify if there is a universal form (scaling function) of the avalanche.

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