Spontaneous emergence of counterclockwise vortex motion in assemblies of pedestrians roaming within an enclosure

Iñaki Echeverría-Huarte[1], Alexandre Nicolás[2], Raúl Cruz Hidalgo[1], Angel Garcimartín[1] and Iker Zuriguel[1]
[1]Departamento de Física y Mat. Apl., Facultad de Ciencias, Universidad de Navarra, E-31080 Pamplona, Spain
[2]Institut Lumière Matière, CNRS Universitè Claude Bernard Lyon 1 & Universitè de Lyon, F-69622, Villeurbanne, France.

Over the last few years, the study of active matter has brought to light surprising results concerning the emergence of collective patterns. Among them, a particularly interesting one is the formation of vortices, present from macroscopic scales (fish schools [1]) to microscopic ones (colloids [2] or bacteria [3]). Although the basics for the origin of these structures have been studied in detail, little attention has been paid so far to the direction of rotation. This manuscript addresses this issue by presenting experimental results of a crowd roaming within an enclosure: A vortex-like structure spontaneously emerges and, even more strikingly, the vortex always rotates counterclockwise (see Figs.1a-b).

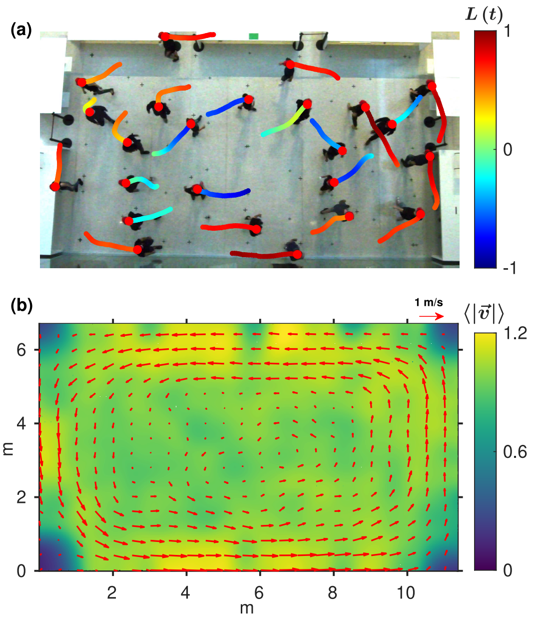

Fig. 1. In (a), snapshot of an experiment with 24 pedestrians. The tails show the instantaneous angular momentum $L_i(t)$ for each agent over the last 1.5 seconds. They have been coloured according to the colorbar on the right. In (b), average velocity modulus field $\langle|\vec{v}|\rangle$ for the same experiment (in m/s). The value of $\langle\vec{v}\rangle$ is indicated by red arrows (as reference, the one on the top right corresponds to 1 m/s).

In order to quantify the collective rotation of the system, we use the normalized angular momemtum:

$$L(t) = \frac{1}{N}\sum_{i=1}^{N}\frac{\vec{r}_i(t)\times\vec{v}_i(t)}{|\vec{r}_i(t)|} \quad (1)$$

where N is the total number of people within the stage, $\vec{v}_i$ the velocity of pedestrian i, and $\vec{r}_i$ its position (with the origin at the centre of the arena). The analysis of this descriptor will eventually confirm that, regardless of the experimental condition, the symmetry-breaking is always present in the system (Fig.1a).

Finally, for the purpose of revealing the physical origin of this unexpected phenomenon, we put forward a minimal numerical model of self-propelled particles. Thus, the motion of each agent will be determined by a self-propulsion force with no preferential direction of motion and two repulsive forces; one against particles and the other between the agents and the walls (the latter with a dissipative term inspired by the observation of higher densities near the walls).

After replicating the same experimental conditions, we demonstrate the fundamental role that both, the density of agents and their dissipative interaction with the walls, play in the formation of vortices (blue dots in Fig.2). Additionally, for the particular case of pedestrians, we justify that the symmetry-breaking presented in the system could be triggered by the turning preference of right-handed people (the majority in our experiment) to turn leftwards when facing a wall. Incorporating this new feature in the particles' movement by means of a new turning force, the main experimental results are reproduced, particularly the permanent rotation of the system in the counterclockwise direction (orange dots in Fig.2).

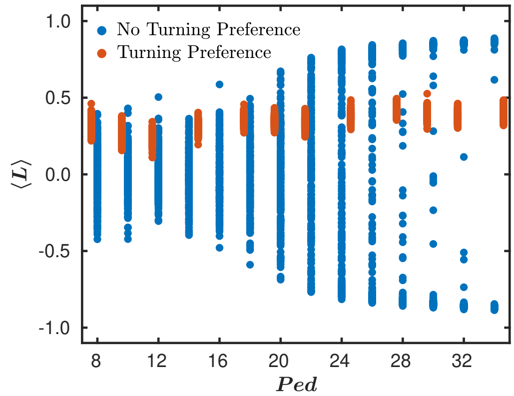

Fig. 2. Bifurcation diagram of the temporal average of $L(t)$ obtained for different number of simulated pedestrians inside the arena. Blue dots correspond to simulations where the turning preference mechanism is not included. In orange, the turning preference is activated. Both models include a dissipative interaction with the walls.

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