Complex rheology of a pedestrian evacuation

Dariel Hernández-Delfin[1], Ander García[1,2], and Marco Ellero[1,3,4]
[1] BCAM, Basque Center for Applied Mathematics, 48009 Bilbao, Spain
[2] Department of Mathematics, University of the Basque Country UPV/EHU, Bilbao, 48080, Spain
[3] Zienkiewicz Center for Computational Engineering (ZCCE), Swansea University, United Kingdom
[4] IKERBASQUE, Basque Foundation for Science, 48013, Vizcaya, Spain

This study revisits the evacuation of pedestrians through a bottleneck from a rheological perspective. Pedestrian crowd dynamics exhibit complex behavior with the variation of the competitiveness of pedestrians forming part of the crowd. When pedestrians possess high competitiveness, the desire to escape rapidly leads to higher evacuation times. Besides the anecdotal experience, this is an outcome that has been previously corroborated through numerical[1] and experimental[2] investigations and has given the name of *faster-is-slower phenomenon* (FIS).

In the field of suspension rheology, a similar effect is obtained when non-Brownian suspensions are submitted to an external perturbation. Namely, the system's viscosity increases as the shear rate or shear stress upon the suspension increases. This effect is known as *shear thickening* and can occur smoothly or abruptly, being denoted as *continuous shear thickening* (CST) and *discontinuous shear thickening* (DST)[3], respectively. *Shear thickening* is explained on the basis of the transition that might emerge in the nature of the dominant forces, passing from frictionless (lubricated) interactions to frictional contacts. A similar transition experiences pedestrians systems when the competitiveness of pedestrians is increased, causing a system transition from purely-repulsive social long-range to frictional contact short-range forces.

Based on numerical simulations employing the Social Force Model (SFM)[4], we evaluate a pedestrian egress from a room across a constriction formed by the room door. The numerical setup employed here is a steady-state version of the geometry assessed by Helbing et al. in Ref. [1]. We find that the viscosity of the pedestrian flow depends on the desired velocity, showing discontinuous shear thickening close to the values where FIS is observed (see Fig. 1). The study find that both social force and shear force are necessary to trigger the frictionless-friction transition that leads to FIS. Contact forces alone cannot activate FIS, and social force interaction is necessary for avoiding contact at low speeds.

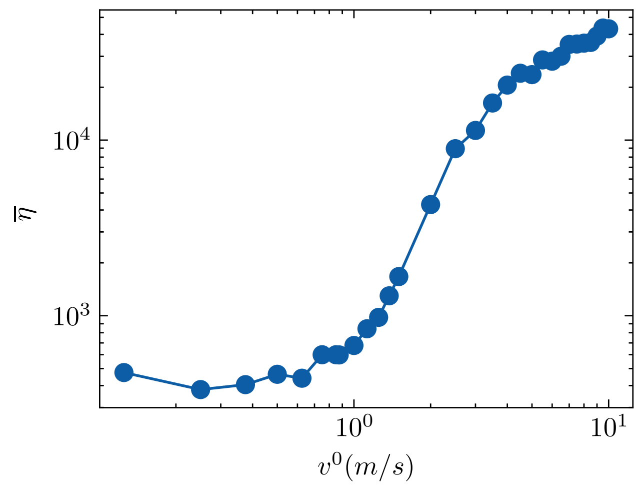

Fig. 1. Viscosity of the pedestrian flow as a function of the desired speed.

Suspension systems may be better for mimicking pedestrian dynamics than dry granular systems.

[1] Helbing, D., Farkas, I. & Vicsek, T. Simulating dynamical features of escape panic. *Nature*. **407**, 487-490 (2000)

[2] Garcimartín, A., Zuriguel, I., Pastor, J., Martín-Gómez, C. & Parisi, D. Experimental evidence of the "faster is slower" effect. *Transportation Research Procedia*. **2** pp. 760-767 (2014)

[3] Wyart, M. & Cates, M. Discontinuous shear thickening without inertia in dense non-Brownian suspensions. *Physical Review Letters*. **112**, 098302 (2014)

[4] Helbing, D. & Molnr, P. Social force model for pedestrian dynamics. *Physical Review E*. **51**, 4282 (1995)