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An experimental study of the impact of an obstacle on the escape efficiency by using mice under high competition

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HIGHLIGHTS

- Mice were driven to pass through an exit, with or without an obstacle before it.
- The impact of the obstacle on the efficiency of evacuation was studied.
- An obstacle can either reduce or increases the evacuation time.
- The time intervals of two consecutive mice and the burst sizes are studied.

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ABSTRACT

Crowd dynamics is an area of interest for scientists as a series of accidents caused by crowd within the last decades. Interestingly, some previous experiments and simulations have suggested that the presence of an obstacle in front of an outlet may improve the flow rate. A number of experiments were conducted to drive the mice to pass through an exit, with or without an obstacle before it. The impact of the obstacle on the efficiency of evacuation was studied under two typical geometry conditions, i.e., The setting I and the setting II. The setting I is an area of 1.5 m wide and 80 cm long and the setting II is a laterally confined space compared with Setting I. For evacuation at Setting I, a benchmarking study without the obstacle was conducted and the average evacuation time per mouse is 4.7 s ± 0.44 s. Further study was conducted by placing a 3.2 cm-obstacle at varying distances of 3 cm–6 cm and the quickest evacuation time per mouse is reduced to 3 s ± 0.09 s, around reduce by 36% compared with no obstacle condition. The presence of an obstacle before an exit improves the flow rate, which is consistent with the previous finding in silo flow and crowd flow. For evacuation at Setting II, similarly, a benchmarking study without obstacle was conducted and the average evacuation time per mouse is 3.9 s ± 0.36 s. When the 3.2 cm-obstacle was placed at varying distances from 4 cm to 10 cm, the average evacuation time per mouse increases to 4.9 s ± 0.28 s, around 26% higher than no obstacle condition. Further experiments were conducted at Setting II by using a 2 cm-diameter at varying distances from 4 cm to 8 cm and the presence of 2-cm obstacle still

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increases the evacuation time. The study reveals that the presence of an obstacle in front of an exit can improve or deteriorate the evacuation efficiency depending on the surrounded geometry. The time intervals of two consecutive mice and the burst sizes are also studied.

1. Introduction

When large amount of people gathering together, the over-congested crowd may trigger potential disaster under emergency situations if crowd management is not appropriately implemented. Crowd disasters happen in different areas across the globe almost every year and approximately take 2000 lives per year on average [1,2]. For example, in 1990, 1426 people were killed in crowd crush during the annual pilgrimage in Mecca, Saudi Arabia. On 24th July 2010, 21 people were crushed to death at Love Parade in Duisburg, Germany. On 1st January 2013, 62 people were stampeded to death at New Year's Eve fireworks display in Ivory Coast. On 13th October 2013, 115 pilgrims had been killed in a stampede on a bridge at a Hindu festival in central India sparked by a rumor that the bridge was about to collapse. On 1st January 2015, 35 people were stampeded to death in the Bund Shanghai, PRC.

Pedestrian flow attracted the attention of physicists and sociologists in recent years. One of interesting observations in the study of crowd flow is that the presence of an obstacle in front of the outlet could improve the flow rate, Helbing et al. [3] proposed social force model to simulate the people through an exit under panic condition. Frank and Dorso [4] also used the social force model and found the pillar-like obstacle could reduce the evacuation time and the authors suggested that the size of the obstacle should be typically of the order of a pedestrian and its position should be generally at a distance of 2 or 3 pedestrian sizes. Yanagisawa et al. [5] studied the effect of a 20 cm-obstacle in front of a 50 cm-wide exit in a controlled experiment and the flow rate was improved by around 4%.

Silo/hopper is typical industrial equipment that gravity-particles discharge through an outlet. Groups of particles through a bottleneck lead to the spontaneous development of clogs. Recent experiment [6,7] in silo flow showed that the presence of an obstacle above the outlet can significantly reduce the clogging probability of granular matter pouring from a silo and the physical mechanism behind the clogging reduction is assumed to be a pressure decrease in the region of arch formation. The placement of obstacles in front of the exit could reduce the pressure on the wall, thus improves the flow rate through the exit. However, the presence of obstacle does not improve the flow rate much. Numerical simulations of gravity-driven granular flow through an hourglass hopper was conducted [8] and it was found that the flow rate across a bottleneck actually increases if an optimized obstacle is placed before it. A number of full-scale experiments [9] by using different inserts in front the outlet were conducted to study their impact on the mass flow and the results suggested that the minimum horizontal distance between the silo hopper and inserts should be twice larger than the silo outlet diameter.

It is believed that gravity-driven particles and self-driven people have many characteristics in common, e.g., the flow-rate through an outlet is both determined by the size of outlet and the size of particles. An experimental study of high competitive evacuation with human is almost impossible as the ethical and legal issues. So, the researchers used a number of alternative creatures. Soria et al. [10] carried out experiments with ants, and the minimum evacuation time was observed with intermediate concentrations of citronella, which was compatible with the "faster is slower" effect. Parisi et al. [11] further analyzed the experimental data and stated that the "faster-is-slower" effect observed in ants by Soria et al. [10] is clearly of a different nature to that predicted by the social force model. Shiwakoti [12–14] conducted a series of experiments with Argentine ants under panic conditions to study the effect of with and without a partial obstruction near the exit in a circular chamber. Saloma et al. [15] studied the mice escaping out of water pool and found that for a critical sampling rate the escape behavior exhibits the predicted features even at short observation times. The mice escaped via an exit in bursts of different sizes that obey exponential and (truncated) power-law distributions depending on exit width. Saloma et al. [16] further studied mice escaped from an enclosed water pool to a dry platform via any of two possible exits. Lin et al. [17] studied the mice evacuation under panic in a container to experimental verify the faster-is-slower effect. Garcimartín [18] and Zuriguel [19] presented an experimental study of a flock of sheep passing through a narrow door. Video monitoring of daily routines in a farm was collected by measuring the time lapses between the passages of consecutive sheep, some features of the flow regime can be assessed and they evaluated the effect of increasing the door size and the performance of an obstacle placed in front of it. Nagai et al. [20] studied evacuation processes of walkers (pedestrians) and crawlers are investigated by experiment and simulation. Zuriguel et al. [19] studied three distinct grains flowing through an opening, including sheep herds, pedestrian crowds, assemblies of grains, and proposed that the probability distribution of time lapses between the passages of consecutive bodies exhibits a power-law tail with an exponent that depends on the system condition.

In this paper, a series of experiments with mice were conducted at a bi-dimensional space to further verify the impact of obstacle on the efficiency of evacuation. This paper is structured as follows: the experimental setting is presented in subsequent section, and the experimental results are included in Section 3. The conclusions are drawn in Section 4.