Quantifying Contact Pressure in High Competitive Pedestrian Evacuations

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Abstract Understanding how crowds behave during evacuations is key to ensuring safety. Yet, while density and flow have been extensively studied, direct measurements of contact pressure remain scarce. Here, we employed a dynamic pressure mapping sensor to capture real-time pressure at the exit door during high-competitive evacuations. The results reveal that pressure at the doorjamb can be nearly an order of magnitude higher than on the wall, and that strategically placed obstacles help reduce these peaks and ease pressure surges caused by clogs.

Keywords Contact Pressure, Evacuation Safety, Pedestrian Dynamics.

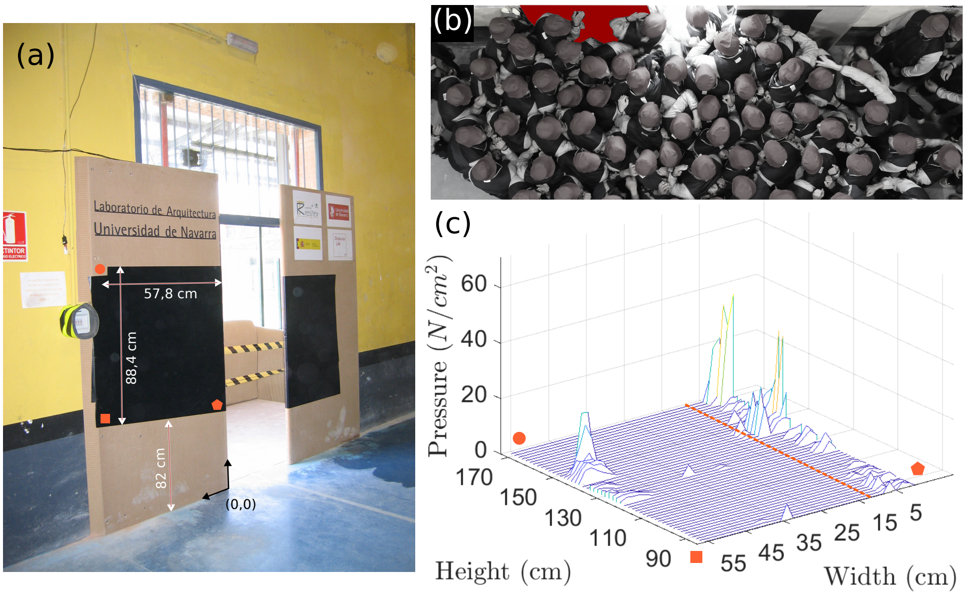

Figure 1: **(a)** Photograph of the door equipped with a dynamic pressure mapping sensor, with the sensor area featuring a black adhesive lining on the left. **(b)** Top view of a high-competitive evacuation experiment. The location of the pressure sensor is highlighted in red. **(c)** An instantaneous pressure field captured during a high-competitive evacuation. The dashed line divides the analyzed area into the doorjamb region (on the right) and the wall region (on the left), while the symbols mark three key spatial reference points.

Over the past two decades, research in pedestrian dynamics has primarily focused on metrics such as density and flow rates to gauge safety during evacuations. Seminal works by Helbing *et al.* [1] introduced phenomena like the "faster is slower" effect and the potential use of obstacles to modulate crowd movement. Despite these advances, the direct measurement of contact pressure (a critical parameter linked to life-threatening compressive asphyxia) has received limited quantitative attention. A recent literature review on contacting force measurement methods for pedestrian crowds [2] underscores that current techniques often lack sufficient spatial resolution, temporal accuracy, and integration with dynamic models. These shortcomings hinder our ability to capture the transient, localized force peaks that precipitate crowd disasters. Here, we addressed this gap by conducting controlled evacuation drills with 180 soldiers under high competitive conditions [3]. A dynamic pressure mapping sensor was installed along the exit door of

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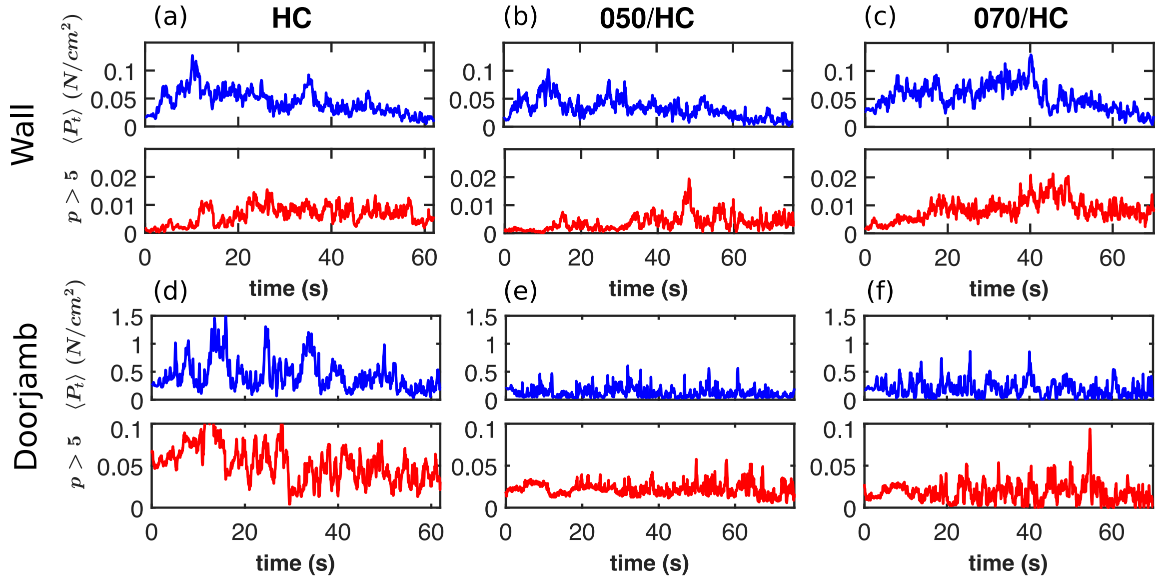

Figure 2: Temporal evolution of the mean pressure (blue) and the probability of detecting sensor pressure values above 5 $\mathrm{N/cm^2}$ (red) under three diferent experimental conditions: High competitiveness without obstacle (HC), HC with an obstacle at 50 cm, and HC with an obstacle at 70 cm. The obstacle was centered in front of the door. At each time, the mean pressure $\langle P_t \rangle$ is computed as the average across all sensor units in the two distinct regions—the wall (a-c) and the doorjamb (d-f). The probability (p) of detecting high-pressure values is calculated as the fraction of sensor units registering pressures above 5 $\mathrm{N/cm^2}$ divided by the total number of units in each region.

the room (Fig. 1a) to capture real-time contact pressures during the evacuation (Fig. 1b). Our experiments reveal that the pressure does not distribute uniformly across the sensor (as seen in Fig. 1c), where clear spatial heterogeneities are evident. This observation prompted us to define two distinct zones for the analysis: the wall zone and the door edge (doorjamb).

Detailed analysis shows that the pressure levels in these two zones differ markedly. In particular, the mean pressure $\langle P_t \rangle$ along the wall (panels a-c in Fig. 2, shown as blue lines) is nearly an order of magnitude lower than that at the doorjamb (panels d-f). This is clearly underscored by the change in the y-axis scale between the plots representing these two regions. Moreover, the probability (p) of recording high-pressure values (exceeding 5 $\mathrm{N/cm^2}$, indicated in red) is considerably higher at the door edge than along the wall (notice again the change in the scale), suggesting that the doorjamb region is more susceptible to pressure surges that can lead to clogs and, ultimately, crowd disasters.

Furthermore, our study demonstrates the impact of strategically positioning an obstacle in front of the exit. When placed approximately 50 cm from the door (second column of Fig.2), the obstacle serves as an effective buffer, mitigating the pressure peaks. This intervention results in a substantial reduction in $\langle P_t \rangle$ and a decreased likelihood of high-pressure events compared to the no-obstacle scenario (first column of Fig.2). Notably, the effect is most pronounced in the doorjamb region, where the obstacle alleviates the pressure surges associated with clogs and congestion. In contrast, when the obstacle is positioned at 70 cm (third column of Fig. 2), its mitigating effect, although present, is less pronounced than at the optimal 50 cm placement.

These findings not only validate previous hypotheses regarding the benefits of obstacle placement in crowd management [1] but also underscore the importance of integrating high-resolution, dynamic pressure measurements into pedestrian dynamics models to better predict and prevent crowd disasters.

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