Mixed-Age Pedestrian Dynamics and Obstacle Avoidance Behaviors: An Experimental Analysis

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A mixed-age walking experiment was conducted to investigate the pedestrian dynamics of elderly and young participants under a notified evacuation without a visible disaster. The study analyzed walking speeds and fundamental diagrams and proposed a quantitative method for assessing pedestrian urgency. Furthermore, obstacle avoidance behaviors were examined and compared across different obstacle conditions, highlighting age-related differences in pedestrian movement.

Keywords: Elderly, Emergency, Urgency, Obstacles

Instruction

The global population is undergoing a significant demographic transition toward aging, with China being one of the most affected countries. Existing research on evacuation dynamics has predominantly relied on data from younger individuals. However, the presence of elderly individuals can significantly influence crowd movement patterns, potentially altering evacuation efficiency. Therefore, understanding of the impact of elderly individuals on group evacuation under emergency conditions is essential for improving evacuation strategies and ensuring the safety of aging populations.

A walking experiment was conducted on a university campus in China to examine pedestrian dynamics involving elderly individuals. It included 12 elderly participants (⩾60 years old) and 36 young adults (20–30 years old). Participants walked under a hypothetical emergency scenario, instructed to move as quickly as possible without running or pushing, simulating a notified evacuation without a visible disaster. The experiment varied corridor widths, elderly-to-young participant ratios, and obstacle placements. The scenarios included a straight corridor, a circular corridor, and intersecting straight corridors. All experiments were conducted under controlled conditions. Figure 1 presents the experimental setup and some of the results.

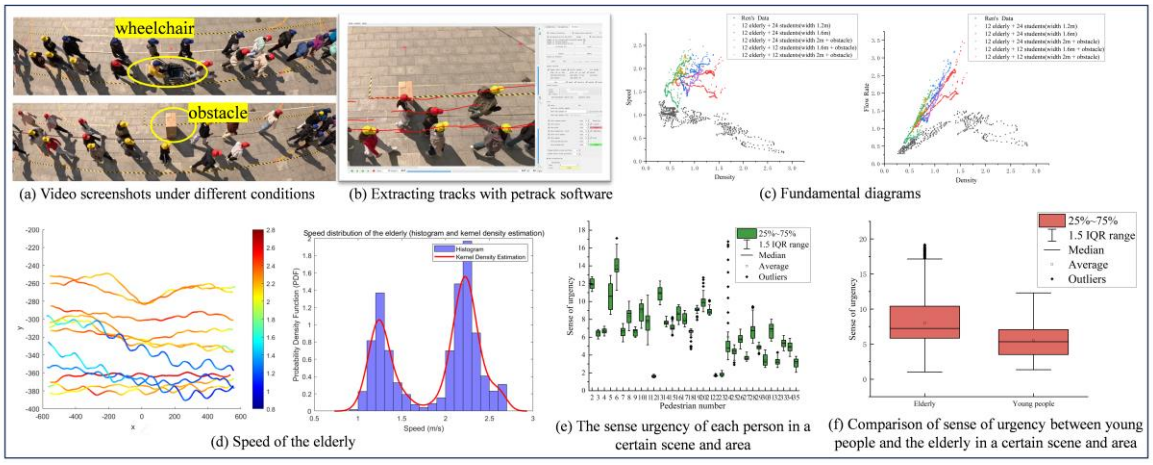

Figure 1: Experimental setup and some of the results.

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After importing the top-view camera footage into the Petrack software [1], external and internal calibrations were performed to obtain each participant's position coordinates over time. The instantaneous velocities of elderly and young groups were calculated. The t-test results for velocity differences between elderly and young participants indicate a significant difference. A bimodal distribution of walking speeds was observed within both age groups. Video analysis revealed that female participants exhibited greater enthusiasm for walking at higher speeds, suggesting that gender contributed to the bimodal distribution. Notably, female participants, particularly elderly women, demonstrated the highest level of motivation in reaching the goal.

The Voronoi-based Thiessen polygon method [2] was used to calculate the average velocity, density, and flow rate in different regions (front, middle, and rear) of the straight corridor. The results indicate a gradual decrease in average velocity within the designated regions as the queue progresses. Additionally, we examined the fundamental diagram of the middle region, where pedestrian flow remains stable. Due to the limited number of participants, data points could not be obtained for the entire density range. Compared to previous studies [3], our data consistently exhibited higher values. This can be attributed to the predominantly low-density conditions in our experiment, where participants exhibited a conscious tendency to accelerate, as confirmed by our post-experiment questionnaire. Further comparisons across different conditions revealed that increasing corridor width led to lower density and a broader speed range. Additionally, increasing the proportion of elderly participants (reducing the number of students) resulted in a more continuous walking flow, eliminating the sudden drops in density caused by individual pedestrian slowing down.

During emergency evacuations, pedestrians tend to reduce their interpersonal distance and increase their walking speed [4] to reach a safe area more quickly. However, their perceived urgency varies. Asja's study suggests that at low densities, pedestrians walk at their preferred velocity with minimal interaction with others, a state referred to as the free regime [5]. In our experiment, pedestrian densities remained within this free state range. Therefore, in emergency scenarios, the relationship between a pedestrian's preferred velocity and the space maintained with others within their visible range can reflect their perceived urgency. To quantify this, we calculated the visible area using the K-nearest neighbors (KNN) method and measured psychological urgency using the dynamic pressure concept from fluid mechanics.

$$p = \rho_i v_i^2 \tag{1}$$

$$\rho_i = \frac{1}{S_i} \tag{2}$$

v_i represents the instantaneous velocity of a pedestrian i and S_i denotes the visible nearest-neighbor area. Under low-density conditions, the space maintained by pedestrians is largely subjective. The calculated dynamic pressure can serve as an indicator of perceived urgency. A pedestrian moving at a higher speed while maintaining a smaller interpersonal distance is likely experiencing a greater sense of urgency. The results indicate that in a notified evacuation without a visible disaster, elderly individuals exhibit a stronger sense of urgency than younger ones. Additionally, women of all ages demonstrate a higher urgency level than men. Furthermore, the front of the crowd experience significantly higher urgency than those at the back. Therefore, in a notified evacuation without a visible disaster, guiding personnel should prioritize raising evacuation awareness among pedestrians in the latter half of the crowd.

The experiment included various types of obstacles in different states. By extracting pedestrian trajectories and computing trajectory slope curves, we applied Fast Fourier Transform (FFT) to perform discrete Fourier analysis. By combining low and high frequency components, we corrected trajectory deviations caused by lateral body sway. Additionally, through segmented fitting of high-frequency components, we extracted key gait parameters. We analyzed and compared pedestrian avoidance behaviors for dynamic, static, same-direction, and opposite-direction obstacles, summarizing the differences between elderly and young participants. This study can provide fundamental parameters for pedestrian modeling in notified evacuations without visible disasters and have important implications for the design of elderly-friendly buildings.

Bibliography

[1] Boltes, M., & Seyfried, A. . (2013). Collecting pedestrian trajectories. Neurocomputing, 100(JAN.16), 127-133.

[2] Steffen, B., & Seyfried, A. . (2010). Methods for measuring pedestrian density, flow, speed and direction with minimal scatter. Physica A: Statistical Mechanics and its Applications, 389(9), 1902-1910.

[3] Ren, X., Zhang, J., Song, W., & Cao, S. . (2019). The fundamental diagrams of elderly pedestrian flow in straight corridors under different densities. Journal of Statistical Mechanics Theory and Experiment, 2019(2).

[4] Helbing, D., Farkas, I., & Vicsek, T. . (2000). Simulating dynamical features of escape panic. Nature, 407(6803), 487-90.

[5] Jelić, A., Appert-Rolland, C., Lemercier, S., & Pettré, J. (2012). Properties of pedestrians walking in line: Fundamental diagrams. Physical Review E—Statistical, Nonlinear, and Soft Matter Physics, 85(3), 036111.