VR-based Experimental Study on Interactions and Behaviors of Luggage-Carrying Pedestrians in High-Speed Railway Stations

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Abstract This study investigates behaviors of luggage-carrying pedestrians using VR experiments. Various scenarios were designed with NPC crowds differing in density, speed, and luggage-carrying side to examine their effects on pedestrian movement. Participants' trajectories, overtaking frequency, directional preference and lateral path deviation during overtaking are analyzed to characterize overtaking behaviors. The real-time interpersonal distances are recorded to quantify interactions among luggage-carrying pedestrians. The results provide insights to optimize the corridor designing and improve the efficiency and safety of passenger flow.

Keywords Virtual Reality, Luggage-carrying Pedestrian, Overtaking Behavior, Pedestrian Dynamics

Instruction

Existing studies on pedestrian dynamics widely recognize luggage-carrying as a critical factor [1, 2, 3, 4], yet predominantly focus on the quantitative impacts of luggage quantity (e.g., with/without luggage and proportion of luggage carriers in crowds). Prior research has overlooked the effects of luggage positional configurations (e.g., left/right-side carrying), limiting practical insights into how these attributes shape pedestrian interaction patterns. Most existing studies on luggage-carrying pedestrians are about group dynamics characteristics, including change in crowd velocity and density [1, 4], evacuation timelines [4, 5], crowd trajectory [1, 4, 5] and spatial distancing [1, 4]. All of these studies were conducted as real-world experiments with human participants. Notably, both real-world and VR experiments have scarcely explored overtaking behavior among luggage-carrying pedestrians. Building on this gap, this study sets up a simulated VR experimental environment and systematically analyzes the interaction mechanisms of luggage-carrying pedestrians in heterogeneous crowds. Specifically, it investigates how pedestrian density, speed disparities and luggage-carrying positional configurations, individually and collectively influence behavioral strategies (e.g., overtaking behavior, interpersonal distance).

Index	Crowd density	Movement mode	Luggage-carrying side
L-W-L	Low: ⩾3 m^2/person	Walk	Left
L-W-R			Right
L-R-L		Run	Left
L-R-R			Right
M-W-L	Medium: 2 m^2/person	Walk	Left
M-W-R			Right
M-R-L		Run	Left
M-R-R			Right
H-W-L	High: ⩽1 m^2/person	Walk	Left
H-W-R			Right
H-R-L		Run	Left
H-R-R			Right

Figure 1: Details of each scenario.

A controlled VR experimental platform was developed using Unity to simulate a straight corridor based on a high-speed railway station exit passage. During the experiment, NPC crowds with varying attributes walk unidirectionally in the simulated corridor, and participants are required to "walk" in the

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same direction among the NPC crowds according to their own will. We adjusted three key variables: crowd density (low, medium, high), movement mode (walking or running), and luggage-carrying side (left or right). Details of scenarios are shown in Figure 1. Two example scenarios are shown in Figure 2 and Figure 3. Additionally, all participants physically hold luggage throughout the experiment (Figure 4). Participants' trajectories, distances to NPCs and NPCs' luggage were recorded. The results of adjusted scenarios with luggage-carrying NPCs were also compared to baseline groups that had identical density and movement mode but no luggage. These data are analyzed to address following core questions: How the experimental variables influence both overtaking behavior and interpersonal distance. Specifically, overtaking frequency, directional preference and lateral path deviation during overtaking are analyzed, while interpersonal spacing dynamics (e.g., minimum distances and proximity trends) are quantified under varying experimental conditions.

Figure 2: Scenario H-W-R.

Figure 3: Scenario L-R-L.

Figure 4: A participant using immersive VR during the experiment.

Results will focus on the quantitative analysis of overtaking behavior and interpersonal spacing under varied experimental conditions. Specifically, the study will measure metrics such as overtaking frequency, lateral trajectory deviation, and minimum interpersonal distances as functions of crowd density, movement mode, and luggage-carrying configuration. Furthermore, these findings are expected to inform practical recommendations for transportation hub design—such as optimizing corridor widths and luggage-handling areas—to enhance both passenger flow efficiency and safety.

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