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Implications for improving evacuation safety in primary school corridors: a video-based analysis on evacuees' speed and density

Engineering, Construction and Architectural Management

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Abstract

Purpose – This study aims to enhance evacuation safety and efficiency measures in primary school corridors by considering the impact of adult guidance and evacuation graphical signs on evacuation speed and density by considering different visibility conditions and corridor design.

Design/methodology/approach – The experiment setup involved ten carefully designed drills exploring the evacuation behavior of 6–7-year-old students in a primary school, varying factors such as adult guidance, smoke conditions and graphical evacuation signs. Kinovea software was employed for data extraction to transform video footage into frames, facilitating meticulous manual tallies of children's movements in designated sub-areas during the drills. The research utilized statistical tests, a generalized linear model and curve-fitting techniques to analyze the extracted data.

Findings – The findings highlight the vital role of adult guidance in expediting evacuations, emphasizing the importance of trained personnel during emergencies. Additionally, graphical evacuation signs were identified as powerful tools for enhancing evacuation speed during low visibility, as they provide clear visual cues to guide evacuees effectively. Signage and adult guidance are beneficial when the classrooms' gates opening to the

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Ethical statement: The Office of Humanities of Social Sciences, Chengdu University of Technology, reviewed and approved this research proposal under the project title "Implications for Improving Evacuation Safety in Primary School Corridors." All participant-related data have been deidentified, and anonymity has been preserved.

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passage are far from each other. In contrast, in areas with close and multiple exits, guidance strategies, especially those involving adults, are more effective in reducing population density during evacuations.

Originality/value – These findings have practical implications for improving emergency preparedness, guiding the design of primary school corridors and informing evacuation protocols. School administrators, architects and emergency planners can utilize these findings to inform the development of safety protocols, enhance evacuation guidance strategies and improve the design of primary school corridors. Further research can expand on these findings by exploring their applicability in diverse educational settings and evaluating the real-world implementation of evacuation measures.

Keywords Evacuation speed, Evacuation density, Primary school, Emergency preparedness, Adult guidance, Evacuation signage

Paper type Research paper

1. Introduction

The onset of disasters or emergencies not only poses a threat to human lives but also carries the risk of self-inflicted harm through human responses to such situations. Accidents such as the Station Night Club in Fire Rhode Island, the USA, 2003, caused the loss of 100 lives and injuries due to overcrowding and panicked behavior of public evacuating through insufficient exits (Grosshandler *et al.*, 2005). Therefore, studying evacuation behavior among individuals is fundamental to ensuring safety and preparedness in emergencies. Evacuation involves three stages: pre-decision (from threat awareness to deciding on evacuation), protective action (from the decision to actual movement), and travel (from initiation of movement to reaching safety) (Kuligowski, 2008). These studies have analyzed the individuals' emergency behavior by assessing their stay/ evacuation decisions and the reasons behind it (Lazo *et al.*, 2015; Yang *et al.*, 2019; Kakimoto and Yoshida, 2022; Xenidis and Kaltsidi, 2022), route selection during an evacuation (Ding and Sun, 2020; Chen *et al.*, 2022; Najmanová and Ronchi, 2023), and public emergency behavior (Pan *et al.*, 2007; Elzie *et al.*, 2016; Koshiba and Nakayama, 2021; Liu and Mao, 2022). Previous studies examined the effectiveness of graphical evacuation signs in guiding evacuees by examining the signs' design (Ding, 2020; Shi *et al.*, 2022a, b). A global online survey evaluated the effectiveness of an innovative graphical signage system, as conducted by Xie and Galea (2022). Testing a novel system with flashing green LEDs demonstrated improved evacuation efficiency compared to conventional signage (Filippidis *et al.*, 2021). On the macroscopic scale, applying the 3D LiDARD database and Google Maps benefited a tsunami-prone area by efficiently placing and designing the evacuation graphical signs (Lonergan *et al.*, 2015). Several studies have also addressed the meditating role of emergency guides/ calming agents in guiding a panicked population. Therefore, the scholars attempted to provide practical suggestions for better training capable guides, and previous studies presented scientific models to optimize the number and place of evacuation leaders and guides (Dong *et al.*, 2022; von Schantz and Ehtamo, 2022).

On the other hand, age is crucial in influencing evacuation dynamics (Hamilton *et al.*, 2020; Yao and Lu, 2020; Najmanová and Ronchi, 2023; Yao *et al.*, 2023). Existing research often centers on adult evacuation behavior, assuming independent navigation to safety. In addition, due to the children's low capability in dealing with emergencies (Save the Children. Foundation for Sustainable Parks and Recreation, 2015; Jin and Zhao, 2021), children's evacuation safety requires further attention. Past incidents, such as the 2001 fire at the Artistic Kindergarten in Nanchang, China, highlight that immediate dangers like flames do not solely cause fatalities during emergencies but can result from stampedes during evacuation (China News, 2001), emphasizing the significance of safety measures and building geometry, particularly in structures occupied by children. Previous studies established differences in walking speeds between children and adults (Larusdottir and Dederichs, 2011; Yao *et al.*, 2023). However, at the same population density, children can run faster than adults (Fang *et al.*, 2019). Noteworthy experiments in daycare centers have unveiled higher population density and flow rates among children than adults (Larusdottir, 2014), especially at exits/ entrances (Yao *et al.*, 2023). Through the research sets conducted by Ano in Brazil, the research team also found the path selection difference between children and adults descending the staircase (Valentim and Ono, 2017; Ono *et al.*, 2021). The investigations on the children and adults' movement dynamics proved that children's flow rate–density relationship cannot be appropriately described by the SFPE guidelines established for the unique homogeneous adult population (Larusdottir and Dederichs, 2011; Yao *et al.*, 2023). Experiments involving 4-6-year-old children underscored the profound impact of population density on individual speed (Yao *et al.*, 2023). Studies on Chinese kindergarten children investigated the influence of bottleneck width and hand-holding behavior on evacuation speed and trajectory. The research indicated that widening bottlenecks did not consistently reduce evacuation times, and hand-holding behavior negatively affected evacuation efficiency (Zhang *et al.*, 2018; Xue *et al.*, 2021). The discoveries mentioned above once more highlighted the need to employ a dataset tailored explicitly to children for the adequate safety management of facilities centered around children.

Researchers have devoted great attention to studying children's movement characteristics in staircases, where the density of children is supposed to change (Valentim *et al.*, 2015). Not only does the staircase flight and landing width significantly influence the children's evacuation speed and time (Ono *et al.*, 2021, 2023), but also the staircase position toward the corridor and the corner design of the corridor reaching the staircase affect the evacuation efficiency (Zhou *et al.*, 2020). Recent research, including a study by Ono *et al.* (2023), determined that walking speed is more significantly influenced by staircase geometry and individual behavior than by children's age and body dimensions. Studies comparing children's walking speeds during everyday life and evacuation drills underscored the impact of drills and emergencies on children's speed (Valentim *et al.*, 2015). Consistent results were reported by Gu *et al.* (2016), who analyzed actual CCTV footage of students' movements both during earthquakes and under normal circumstances. Moreover, factors such as congestion, group dynamics, backtracking tendencies, obstacles, and proximity to exits wield a substantial influence on children's decision-making in route selection (Chen *et al.*, 2018, 2019).

Various studies have focused on the impact of adult guidance on evacuation efficiency and students' route choices, but conflicting findings exist regarding this issue. Studies on preschool children and primary schools reveal that evacuation behavior in these settings primarily depends on adults, such as teachers, and established school routines (Najmanová and Ronchi, 2023; Klüpfel *et al.*, 2003). In contrast, (Chen *et al.*, 2022) found that emergency severity substantially impacts evacuation decisions for children aged 9–11 more than teacher guidance. Another study with preschool children showed no significant link between evacuation speed and the presence of adult guidance (Najmanová and Ronchi, 2017). In general, as children age, their reliance on adult assistance during evacuation decreases, shifting notably between ages 6–8 and those above 9, who initiate evacuation independently (Larusdottir and Dederichs, 2011; Larusdottir, 2014).

Despite some research on the impact of calming authorities/ guides on the evacuation process of children, studies on the influence of graphical evacuation signs on the evacuation behavior of this age group are scarce. Moreover, although several studies illustrated the negative impact of low visibility on evacuation speed (Wu *et al.*, 2018; Liu *et al.*, 2019; Xie *et al.*, 2020), studies on the effect of poor visual situations on children's evacuation behavior are lacking in the main literature research. This study addresses previous research gaps by examining the impact of evacuation signs and adult guidance on children's evacuation efficiency, evacuation speed and population density. (Please note that the analysis of evacuation time and route selection behavior is the focus of another study). Hypotheses were formulated, testing the influence of guides and signs on speed and congestion and considering the impact of low visibility. Ten drills with varied scenarios were conducted, capturing the exercises through strategically placed CCTV cameras. Extracted data underwent thorough statistical analysis to answer the research questions. The subsequent sections provide an extensive overview of the experimental configuration and data handling in Section 2, with

Section 3 presenting the empirical outcomes. The paper summarizes the principal discoveries and acknowledges the study's constraints in Section 4 and 5, respectively.

2. Experiment, data collection, and analysis methodology

2.1 Preparation and training

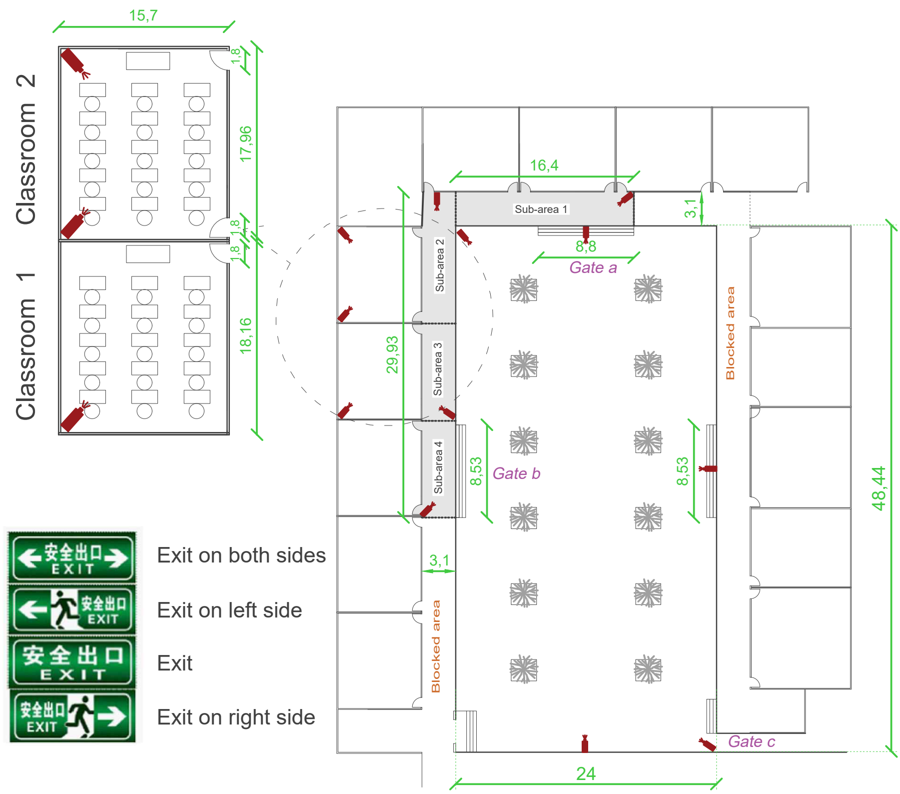
On April 23, 2023, 783 participants aged 6 to 7 from grades 1 and 2 at the Affiliated Primary School of Chengdu University of Technology in Chengdu, China, participated in evacuation drills. With prior announcements and proactive measures, the drills were conducted on the school's first floor in two chosen classrooms to ensure participant safety. The participants had some familiarity with the evacuation drills as the school conducts one evacuation drill annually as in Chengdu city, evacuation drills are mandatory; however, the preparedness of staff and students is evaluated individually by each school [1]. The research team conducted meetings and training sessions for teachers and staff to explain the research goals, provide guidance, and ensure smooth experiment execution. The research team asked the teachers to position themselves in clearly marked areas between the classroom's gates during the experiments conducted with adults' guidance in the corridors. They were also required to uniformly instruct the pupils by raising their right hand and issuing clear instructions such as "Leave the corridor quickly" and "Go to the playground quickly". The teachers were explicitly prohibited from coercing the students to choose specific exits.

Following training, teachers were responsible for clearly explaining evacuation rules to students, ensuring comprehensive understanding. Teachers were equipped with clear instructions and graphical guidelines to easily convey drill rules and the meaning of evacuation signs to students. The students' training took place before the drills, during which the research team meticulously observed the clarity and accuracy of the guidelines provided by the teachers. Teachers instructed students to remain seated and engage in normal class activities before an evacuation alert. Upon hearing the evacuation alarm, students formed lines and exited classrooms toward the designated playground through the nearest available exits. While running was permitted, students were strictly advised against pushing or hitting others. The training emphasized remaining calm and following instructions from teachers or evacuation signs to exit through the nearest gate. Without signs and guidance, pupils were instructed to promptly leave the area and proceed to the playground. Non-participating students were instructed to stay in their classrooms without disrupting the drills. Eight research team members strategically placed at fixed corners of the evacuation site observed the drills to ensure pupil safety, intervening only in unforeseen incidents or accidents to avoid interference with evacuation procedures.

To direct evacuees towards the designated playground exits leading to other areas were temporarily obstructed, with strict monitoring by the research team to prevent the use of these blocked routes. The school's corridors were divided into four sub-areas, each equipped with at least one full-HD CCTV camera for comprehensive monitoring. The students were acquainted with the school layout due to studying there for several months. They were also familiar with the escape routes in the classrooms, as each classroom within the chosen school was equipped with two entry points leading to the corridors. However, as part of the research design, one of the exits in classroom 1 was intentionally blocked off for the experiments [2]. Consequently, in sub-area 2, only one entrance was available, with a distance of 10.16 meters to the nearest exit in sub-area 3. In contrast, sub-area 3 featured classroom entrances that were in close proximity, separated by a mere 0.4 meters. The school layout and place of eleven CCTV cameras are schematically shown in Figure 1 (see Figures 2–6).

2.2 Experiment setups and procedure

To investigate the influence of evacuation graphical signs on children's evacuation behavior, the study organized the evacuation drills into two sets, as presented in Table 1. The first six



Source(s): Authors' own work

Figure 1. School's layout, camera setting, and evacuation signs

Source(s): Authors' own work

Figure 2. Left) Normal evacuation in exp 1–2, Right) Students in exp 1–3 moving toward the blocked path to pass through there

experiments were conducted without graphical signs, while during the next set, the research team prepared the evacuation graphical signs [3] during the break time between the two sets; therefore, the children were not aware of the signage placement before the drills, which did not interfere the consistency of the experiments. In both sets, the research team closely examined

Source(s): Authors' own work

Figure 3. Line formation in exp 1–1, Middle) Congestion in exp 1–1, Right) Students blocked the way of the crowd in exp 1–6

Source(s): Authors' own work

Figure 4. Left) Confusion in wayfinding in exp 2–2, Right) Evacuation sign guided the student to find the evacuation route exp 2–2

Source(s): Authors' own work

Figure 5. A sudden change of evacuation route influenced by herding behavior exp 2–1

the evacuation features and behavior of the pupils while varying factors, such as the placement of guidance and visibility conditions. The children were instructed to wear colorful hats during the experiment to ensure accurate data extraction. Those seated in the learning space with

Source(s): Authors' own work

Figure 6. Students decided to change the exit route due to the high density at the arrival moment in exp 2–4

Table 1. Experiments' setup and information

	Experiment	Adult guidance in the corridor and position?	Smoke?	Graphical sings?	Duration	Participants
Set 1	*1–1*	No	No	No	74	77
	1–2	Two, sub-area 1 and 2	No	No	46	66
	1–3	One, sub-area 2	No	No	104	62
	1–4	No	Yes	No	82	84
	1–5	Two, sub-area 1 and 2	Yes	No	37	80
	1–6	One, sub-area 2	Yes	No	150	86
Set 2	*2–1*	No	No	Yes	52	84
	2–2	One, sub-area 2	No	Yes	55	79
	2–3	No	Yes	Yes	42	86
	2–4	One, sub-area 2	Yes	Yes	40	79

Note(s): That when no teacher is in a sub-area, they are inside the classroom, and vice versa, except for experiments 1–1 and 1–3, which had no adult guidance. In experiments 1–2 and 1–4, teachers were present in both classrooms and sub-areas
Source(s): Authors' own work

access to one gate (classroom 1) wore red hats, while students seated in the front and back sides of the classroom with two entrances (classroom 2) were given blue and yellow hats, respectively.

All ten evacuation drills were executed within a single day, commencing with experiment 1–1 at 8:30 a.m. and concluding with experiment 2–4 at noon. This sequential arrangement ensured that students could not exchange information regarding the drills. Except for two grade 1 classes (1–2 and 1–3) that partook in only one drill, the remaining nine classes engaged in two distinct experiments. Consequently, the students' encounter with the final experiment differed from the preceding one. This methodology was employed to prevent cross-influence of experiences and maintain the integrity of the research outcomes. Both classrooms were simultaneously evacuated, ensuring synchronicity in the experiment. Once all students reached the designated playground area, the experiment concluded; the students returned to their classrooms on the second floor to prevent interrupting the experiments, the research team prepared for the subsequent drills, and the next group of students came to the designed classrooms.

Based on the National Standard of the People's Republic of China, four different types of evacuation signs with a size of 36*13.5 cm and colored green and white have been chosen (Figure 1) (National Standard of the People's Republic of China, 2015). Since smoke particles may obstruct higher-level surfaces, floor-level guidance could ensure that the evacuation instructions remain visible, contributing to a clearer path identification for children; thus, evacuation signs were placed every nine meters on the floor (National Fire Protection Association, 2018). During the evacuation drills incorporating smoke machines, four smoke machines with power ratings of 1,500 and 3,000 Watts were utilized to alter the environment's visibility. Observers systematically assessed the clarity of visibility by visually inspecting the corridor from eye level to ceiling height. The same type and quantity of smoke machines were used, and evacuation scenarios were designed to be comparable. However, recognizing that visibility is a dynamic and subjective phenomenon, observers and participants were attuned to changes in visibility as the evacuation scenario progressed. It is important to note that the smoke used in the study was not harmful to humans.

2.3 Data extraction and analysis

In emergencies, evacuation speed and population density are crucial factors influencing safety. Faster speed minimizes exposure to risks, while managing density prevents congestion, ensuring a smooth flow to safety in a primary school setting. Density, d_s^i, is the number of students per unit area, and in this study, it was calculated at each second using Eqn (1) and (2):

$$d_s^i = \frac{N_s^i}{\Delta A} \tag{1}$$

Where ΔA is the covering area of each sub-area, N_s^i is the number of students within the sub-area at each second. To count the number of children passing through the passage (N_s^i), the videos were initially transformed into individual frames using Corel Visio Studio, maintaining the original frame rate of 30 frames per second. Subsequently, the authors manually tallied the number of children passing through the sub-areas in each frame to extract the students' speed in each sub-area.

Individuals' speed (V_S) is calculated by using the following equation.

$$V_S = \frac{\Delta I}{\Delta T} \tag{2}$$

Using the entire area of the sub-area (ΔI) takes a conservative approach by assuming that students could occupy any part of the designated space during evacuation. This accounts for the possibility of students moving to different locations based on factors such as panic, confusion, or obstacles. ΔT is the time the students spend in the area. However, as some students did not simply pass the passage to exit and showed back-and-forth movement, the distance cannot be accurately calculated. Therefore, Kinovea [4] software was used to measure the individuals' speed in sub-areas 2 and 3.

Afterward, the cleaned data were analyzed to answer the following null hypotheses:

(1) The classroom gates' distance inside the sub-areas, visibility situation, availability of adult guidance, and evacuation signs affect evacuation speed.

(2) There is no significant difference in evacuation speed between the evacuation drills guided by the different guidance systems.

(3) There is no significant difference in evacuation speed of the drills guided by adults and evacuation signs in normal and affected visibility conditions.

(4) There is no significant difference in the density of the sub-areas among the different evacuation drills.

(5) Affected visibility caused higher evacuation density.

(6) The evacuation density follows a specific pattern over time.

Using a Generalized Linear Model (GLM), the relationship between the classroom gates' distance, visibility situation, availability of adult guidance, evacuation signs, and evacuation speed could be modeled. This method is commonly used in evacuation planning research and effectively identifies factors influencing evacuation behavior (Tzeng *et al.*, 2016; Sadri *et al.*, 2017). Additionally, by using statistical tests such as the Kruskal-Wallis and Mann-Whitney *U* tests, the study was able to determine if any significant differences exist in evacuation speed between the different guidance systems or between the drills guided by adults and evacuation signs in normal and affected visibility conditions. The Krushkal-Wallis test determines whether there is a difference in the distribution of dependent variables with more than two groups, while the Mann-Whitney test compares the dependent variables' distribution with two groups (Myles and Wolfe, 1973). ANOVA, previously applied in evacuation studies (Li *et al.*, 2020; Koshiba and Nakayama, 2021), was used to compare the evacuation densities between different scenarios of evacuation drills. In addition, curve fitting analysis was applied to predict the density in each evacuation drill, which was previously applied to determine the behavior difference between emergency and non-emergency evacuation (Gu *et al.*, 2016). Overall, the methods used in this study were well-suited to address the research hypotheses and can provide valuable insights for improving emergency evacuation plans and procedures in similar settings.

3. Results

3.1 General observations

The evacuation behaviors of students within the corridors exhibit both commonalities and distinctions across different experiments. In Experiment 1–2, the evacuation proceeded smoothly as students adhered to the instructions provided by the guides, contributing to a favorable flow rate and overall efficiency. In contrast, during Experiment 1–3, a notable variation occurred as some students deviated from the prescribed route, attempting to navigate a deliberately obstructed pathway that extended the evacuation duration.

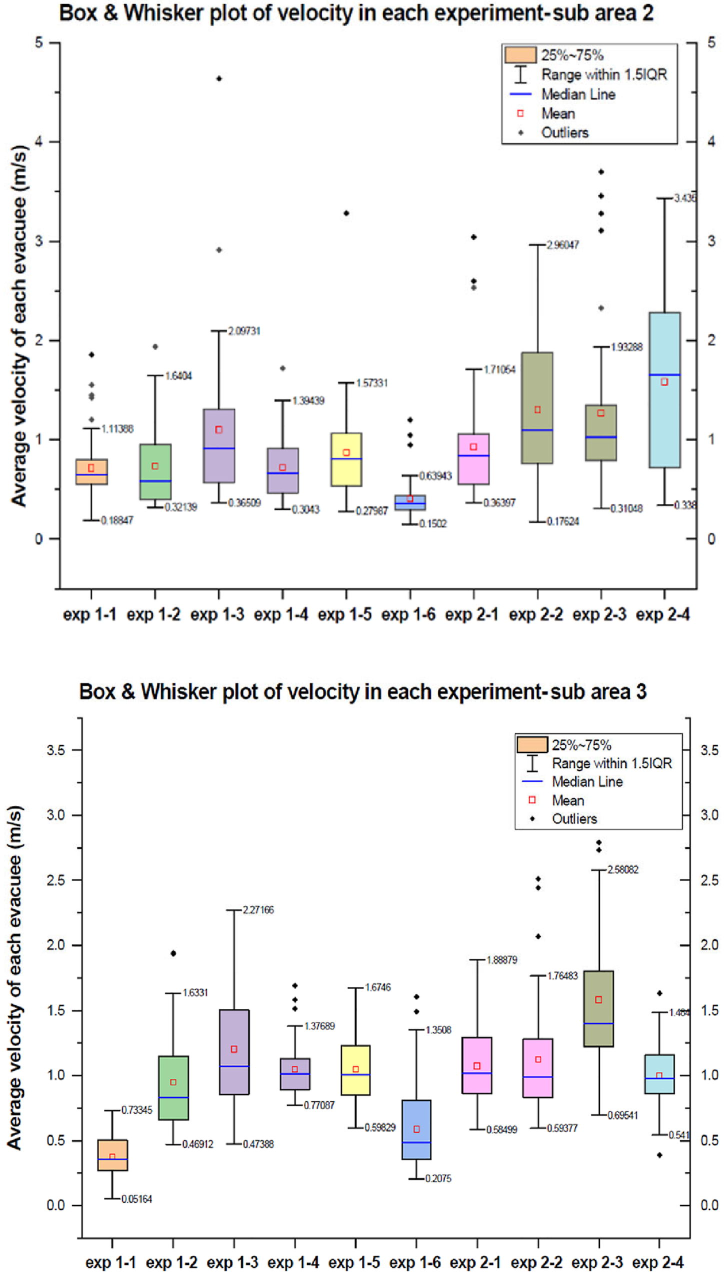
The guidance provided by the teachers exerted a discernible influence on the evacuation conduct of the students. In Experiment 1–5, a teacher departed from the classroom ahead of all the students, contrary to the prescribed training protocol. Experiment 1-, resulted in confusion and congestion among the evacuees. In Experiment 1–1, the initial student to exit the classroom assumed a leadership role, significantly impacting the collective movement of the group. Furthermore, as the students from the second classroom reached sub-area 2 before those from the first classroom had completed their evacuation in Experiment 1–1, the population density within sub-area 2 continuously escalated, further influencing the movement patterns of the students.

Experiment 1–4 revealed that the evacuation decisions and speed of the children within sub-area 2 might be adversely affected by the poor visibility. Notably, the initial two students exiting the classroom with two gates experienced a brief period of uncertainty, spending several seconds wandering in sub-area 2 before committing to their escape at the 51st second. In Experiment 2–2, students in classroom 1 predominantly opted for the closer corridor gate, Gate B. However, some encountered difficulties navigating the route, as evidenced by video footage from sub-area 2, which showed students exhibiting confusion in wayfinding until the 12th second. Experiment 2–2 demonstrated the beneficial role of graphical signs in aiding students in wayfinding and reducing confusion.

In Experiment 2–1, the students followed each other's route choices, resulting in all of them evacuating through gate A. In contrast, Experiment 2–4 witnessed the influence of higher population density, prompting certain students to alter their evacuation routes and opt for Gate A due to the congestion they encountered.

3.2 Evacuation speed

3.2.1 Individuals' speeds: box plot analysis and group comparisons. Considering that every experiment has a positive or negative impact on the students' speed, the main descriptive statistics of the ten evacuation drills are given in Figure 7 as box plots visualizing each drill's speed distribution, mean, and median. The whisker extended to the minimum and maximum values within 1.5 times the interquartile range (IQR) of the first and third quartiles,



Source(s): Authors' own work

Figure 7. Comparison of evacuation drills' speed

respectively. Any values that fall outside this range are shown as outliers. As the study delves into the analysis of entrance design's influence on the evacuation process, the data presented and scrutinized in the subsequent sections encompasses sub-areas 2 and 3, situated close to the classrooms' entrances.

The study found that the lowest mean and the smallest speed range in sub-area 2 belongs to Experiment 1–6, conducted under affected visibility when one adult-guided the students. Experiment 1–1, the baseline experiment, on the other hand, showed the lowest mean and speed range in sub-area 3. In those experiments, the speed range was tightly clustered around the median. On the other hand, the highest mean value has been recorded in Experiments 2–4 and 2–3 for sub-areas 2 and 3, respectively. Both evacuation drills were conducted using evacuation graphical signs and under low visibility situations; however, in Experiment 2–3, no adult-guided the children, contrary to Experiment 2–4. In sub-area two, Experiments 1–3 and 2–3, the study also identified outliers that might happen because the children who participated in those experiments did not take the drills seriously.

To maintain the integrity and reliability of the analysis, Experiments 1–3 [one guide in the sub-area 2, unaffected visibility, no signs] and 1–6 [one guide in the sub-area 2, affected visibility, no signs] were excluded from the study due to an identified gap between the evacuation time of the classrooms that could potentially adversely influence the final results. To provide more details on the individuals' evacuation speed and compare the speed of the first five, middle, and last students who entered the sub-areas 2 and 3, According to Figure 8, children during the baseline Experiment (exp 1–1) conducted without any guidance or signage in the normal visibility situation, the first five students who entered the sub-area 3 had longer evacuation time (to leave the sub-area 3) than the first five arrivals in guided experiments in both good and poor visibility. In that drill, the first student was sitting in the classroom with one gate blocking the other students' way, and others followed him and queued. Moreover, in sub-area 3, except for the first five arrivals, the speeds of other groups show an increasing slope. The children's speed increased under adult guidance in both visibility conditions, and they left the sub-area 3 in a timely manner. The highest evacuation speed in sub-area 3 was recorded in Experiment 2–4. Contrary to sub-area 3, in sub-area 2, no obvious increasing or decreasing pattern in evacuation speed has been detected.

3.2.2 Uncovering factors influencing evacuation speed. After examining the arrival speeds of different groups, the authors proceeded with the next step in the analysis, which involved predicting the evacuation speed. To conduct multi-linear regression assumptions, the assumptions were first checked. The scatter plot of predicted values and residual values showed a linear relationship. All Variance Inflation Factor (VIF) values of the variables used in this study were less than two, and the tolerance value is higher than 0.1, indicating no multicollinearity problem exists between all explanatory variables (Huang *et al.*, 2015). In some cases, the normality assumption in evacuation speeds was violated per the Shapiro–Wilk test. Similarly, skewness and kurtosis exceeded their 1.96 standard errors, indicating that the data is not normally distributed. Therefore, a Generalized Linear Model (GLM) analysis was conducted to examine the relationship between adults' guidance, the classroom entrances' distance in each sub-area, the presence of smoke, and evacuation signs on the individuals' average speed in the corridors. The tests' statistical significance level (alpha) was 0.05, indicating a 95% confidence level. The omnibus test for the GLM model examined the overall significance of the model. The test stated significant results, $\chi^2(4) = 146.825$, P-vale = 0.000. The model accounted for 13.2% of the variance in speed. However, a high Deviance statistic (Deviance = 278.669, df = 1,001) was observed, suggesting that the model may not fit the data. The test results are presented in Table 2.

The authors additionally monitored the correctness of the model by running assumption checks in Figure 9. The histogram of standardized residuals follows a symmetrical bell-shaped distribution, signifying that the normality assumption is reasonably met. The scatter plot of standardized residuals versus predicted values suggests that the assumption of linearity is reasonable. Additionally, the spread of the standardized residuals appears relatively constant

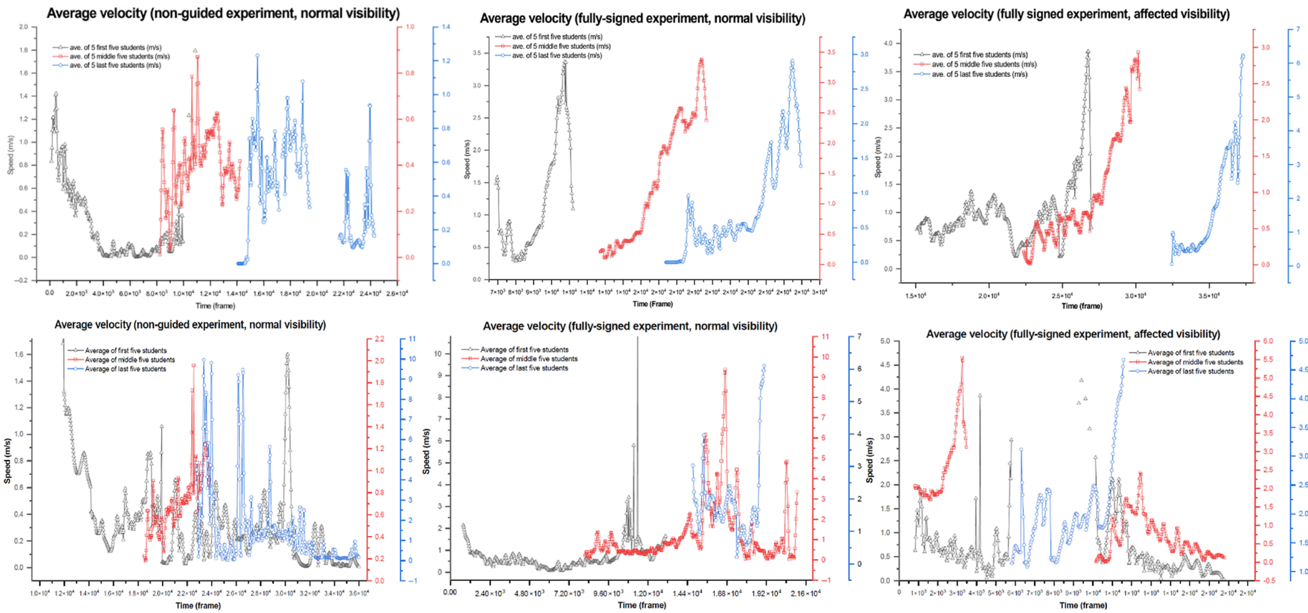


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Figure 8. Up) Comparison of average evacuees' speed in sub-area 3, Down) Comparison of average evacuees' speed in sub-area 2
*** Fully-signed experiment referred to the drills used simultaneous graphical evacuation signs and adults' guidance.

Table 2. Generalized linear model results

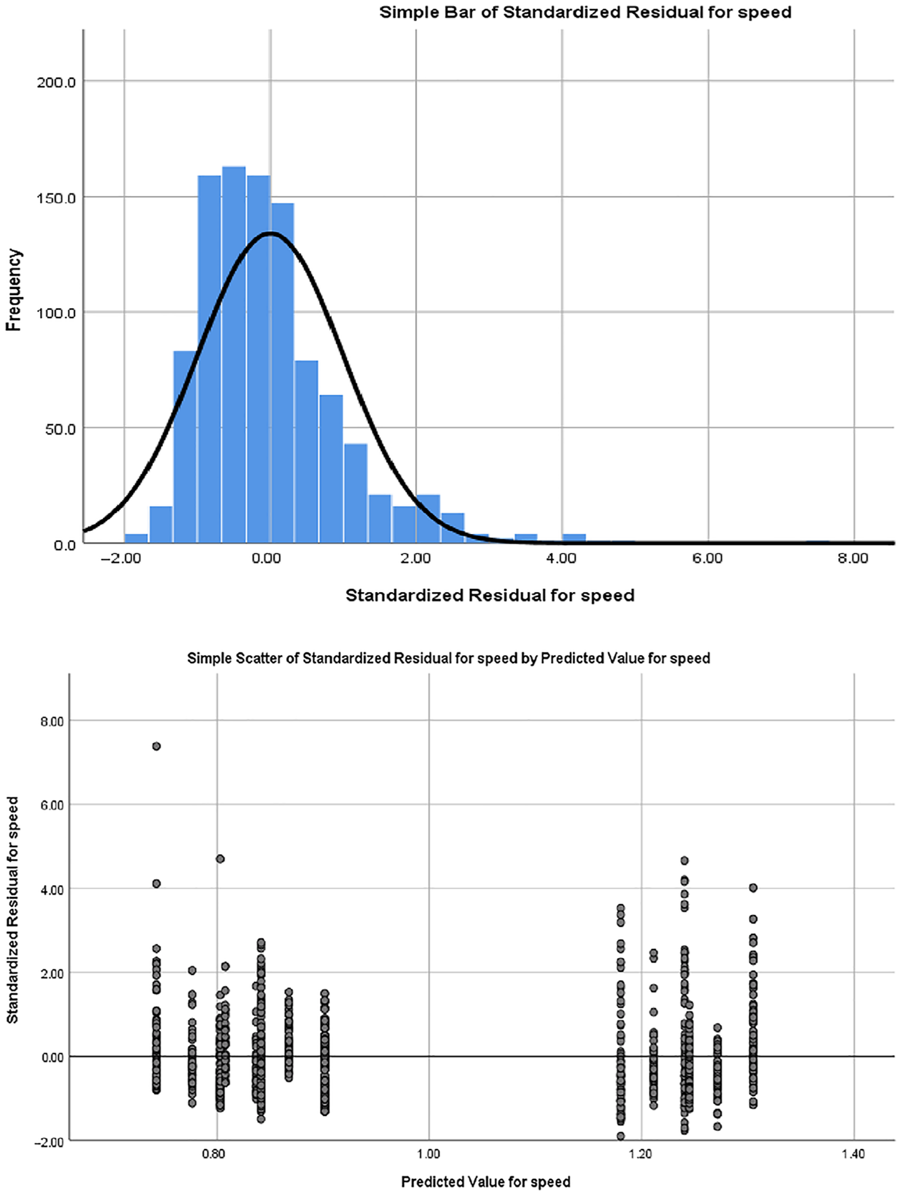
Source	Type III sum of squares	df	*F*	Sig.	Beta	95% Wald confidence interval Lower	Upper
Corrected Model	43.789	4	39.324	0.000	–	–	–
Intercept	869.848	1	3124.563	0.000	0.435	1.186	1.357
Classrooms' gates distance (ref. = far away distance)	1.022	1	3.672	0.056	−0.65	−0.131	0.001
Visibility (ref. = normal)	0.903	1	3.244	0.072	−0.60	−0.125	0.005
Teacher (ref. = absent)	0.242	1	0.870	0.351	0.034	−0.037	0.104
Evacuation signs (ref. = absent)	37.654	1	135.255	0.000	−0.404	−0.471	−0.336
Error	278.669	1,001					
Total	1325.15	1,006					
Corrected Total	322.458	1,005					

Note(s): Coding explanation: classrooms' gates distance (far away distance = 1, close distance = 2), visibility (normal = 1, affected = 0), teacher (present = 1, absent = 0), evacuation signs (Present = 1, absent = 0)
Source(s): Authors' own work

across the range of predicted values, which indicates that the assumption of homoscedasticity is met.

The model demonstrated a significant effect of signs on individuals' average speed, F (4, 1,006) = 39.324, P-value = 0.000, $\beta = -0.435$, demonstrating that the absence of evacuation signs negatively influences students' speed. However, three other independent variables did not significantly impact the average evacuees' speed in the corridors. These results suggest that advertising plays a crucial role in driving sales performance. As the results of GLM indicate, only one factor, evacuation signs, emerged as statistically significant, signifying that it has a notable impact on the overall speed at which individuals evacuate the area. This finding highlights the importance of this specific factor in influencing evacuation dynamics. Moreover, the high deviance, which could be due to the complexity of evacuation speed, should be considered when interpreting the significance of individual predictor variables. While some variables showed statistical significance, caution should be exercised when attributing causality, as the model's fit to the data was not ideal.

Mann-Whitney and Kruskal-Wallis tests were chosen due to the non-normal distribution of data to examine children's speed in corridors under different scenarios. The study hypothesized that the presence of evacuation signs, whether graphical or guided by adults, positively influences children's average speed, considering both low and good visibility conditions. Table 3 presents the Krushkal Wallis test results. In the evacuation drills with normal visibility, there is a significant difference among the groups, $\chi^2(2) = 114.045$, p-value = 0.000. Pairwise comparisons indicated that using any evacuation guidance system could increase the children's evacuation speed, among which two adults performed best in evacuation drills. In addition, the speed difference in drills with one and two adult guidance is significant at the p-value <0.05 level, indicating that multiple adult guidance at two sub-areas has resulted in a higher speed than the drill guided by a single instructor. In the case of low visibility conditions, the average speed of children led by different types of evacuation signs is significantly different ($\chi^2(2) = 194.589$, p-value = 0.000). The post hoc test reveals that evacuation speed differed significantly between the drills without guide/signs and those guided by one adult and used evacuation signs, and the evacuees in non-guided/signed drills have shown the lowest speed. Moreover, evidence suggests that the evacuation speed in the drill guided by two adults was higher than that guided by one adult. However, graphical signs significantly increased the evacuation speed compared to the drills guided by two adults.



Source(s): Authors’ own work

Figure 9. Left) standardized residuals’ frequency, Right) standardized residuals vs predicted values of speed

The study assumes that using graphical evacuation signs and adults’ guidance simultaneously results in higher average individual speed in various visibility conditions than drills without signs. The Mann-Whitney test evaluated significant differences in evacuation speed for these scenarios (see Table 4). In both good and low visibility situations, the simultaneous use of graphical signage and two adults could significantly improve the individuals’ average speed compared to the experiments in which no adult and graphical signage were used (z_{good}

Table 3. *U* test results, guidance impact on speed

Index	Group	*N*	Mean rank	Test statistic	*p*-value	Pairwise- test	Test statistic	Adj. *p*-value
Guidance and signage (good visibility)	non-guided/ signed	108	110.28	114.04	0.000	non-guided/ signed vs two guides	−90.85	0.000
	one guide	122	269.60			non-guided/ signed vs evacuation signs	−8.66	0.000
	two guides	67	201.13			non-guided/ signed vs one guide	−9.86	0.000
	only evacuation signs	126	249.20			two guides vs one guide	3.68	0.001
Guidance and signage (low visibility)	non-guided/ signed	84	204.19	194.58	0.000	one guide vs non-guided/ signed	110.23	0.000
	one guide	115	93.96			one guide vs two guides	−128.38	0.000
						one guide vs evacuation signs	−218.64	0.000
	two guides	98	222.34			non-guided/ signed vs evacuation signs	−108.41	0.000
	only evacuation signs	121	312.60			two guides vs evacuation signs	−90.26	0.000

Source(s): Authors' own work

Table 4. *U* test results, full signed drills, and visibility impact on speed

Index	Group	*N*	Mean rank	U	Z	*p*-value
Zero signage vs full- signage (good visibility)	No guide/signs	108	63.94	1,020	−8.87	0.000
	Full-signed evacuation	79	135.09			
Zero signage vs full signage (low visibility)	No guide/signs	84	72.20	2,495	−3.38	0.001
	Full-signed evacuation	85	97.65			
Full signage in good visibility vs low visibility	Good visibility	79	81.73	3,297	−0.19	0.842
	Low visibility	85	83.21			

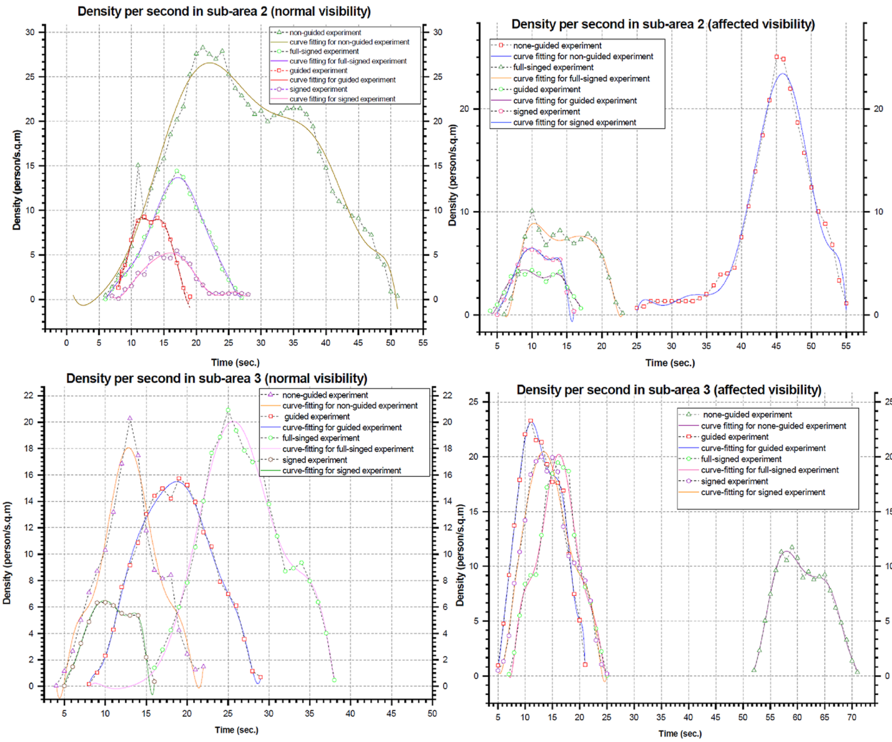
Source(s): Authors' own work

$_{\text{visibility}} = -8.878$, p-value $_{\text{good visibility}} = 0.000$, z $_{\text{low visibility}} = -3.380$, p-value $_{\text{low visibility}} = 0.001$). Mann-Whitney test was also conducted to see the difference between the full-signed evacuation experiments (the drills used simultaneous graphical evacuation signs and adults' guidance) usage in good and low visibility; however, the test could not prove the significant difference between those groups (z $= -0.199$, p-value $= 0.842$).

3.3 Density per area

3.3.1 Evacuation drills' density trends over time. Predicting density per second can provide valuable information on evacuees' entrance and exit rates. The study utilized curve fitting to develop a mathematical model predicting evacuation density changes over time. A polynomial function with high accuracy (adjusted R-squared values ranging from 0.893 to 0.993) emerged as the best fit for describing evacuation trends in different scenarios. In all eight evacuation drills (exp 1–1, 1–2, 1–4, 1–6, 2.1,2–2, 2.3, and 2–4), as depicted in Figure 10, the density exhibited a common pattern of initial increase and subsequent decrease, indicating stable movement in most cases. This trend was more pronounced in low-visibility scenarios. In sub-area 2, non-guided evacuations showed the highest maximum density, while full-signed drills had the lowest visibility in both normal and poor conditions. In sub-area 3, full-signed drills experienced the highest congestion in good and affected visibility. Comparing affected and normal visibility, regardless of signs or guidance, the highest density in normal visibility exceeded that in affected visibility in both sub-areas.

3.3.2 Evacuation drills' density comparison. The study conducted a Mann-Whitney test to analyze the impact of visibility and distance between classroom gates on evacuation density. Hypotheses were formulated assuming similar density distributions between drills with low and non-affected visibility and between drills with different gate distances. Results in Table 5 did not show significant impacts of smoke or gate distance on evacuation density (p-values >0.05). However, the gate distance p-value, close to the chosen significance level, suggests



Source(s): Authors' own work

Figure 10. Density scatter plots comparing guidance and visibility situations in sub-areas

Table 5. Average density in each experiment in sub-areas

Index	Group	N	Mean rank	U	Z	p-value
Density in sub 2 vs sub 3	Sub 2	418	421.32	88,539	−1.902	0.057
	Sub 3	456	452.34			
Density in good visibility vs low visibility	smoke	541	429.97	68,005	−1.177	0.239
	No smoke	333	449.73			

Source(s): Authors' own work

tentative evidence for potential differences in density between scenarios with varying gate distances. Further analysis was conducted by separately considering the two sub-areas.

To provide strong evidence of some of the statements above, the study conducted a one-way ANOVA test for each sub-area to compare the density per second in different evacuation drills and determine if the differences are statistically significant. The tests' statistical significance level (alpha) was 0.05. As the homogeneity of the variances has been violated based on Leven's test, Welch's ANOVA and Games Howell multiple comparison methods were chosen to determine the significant difference between the evacuation drills where differences existed. Table 6 illustrates the group comparison resulted from the Games Howell test. Welch's ANOVA indicated a significant difference in density per second in sub-area 2 based on evacuation signage availability ($F = 11.81$, p-value $= 0.000$, df $= 3$). The Games Howell test revealed significant differences between non-guided and guided evacuation drills in both sub-areas. Notably, the mean differences were substantial: non-guided vs guided (6.45), non-guided vs signed evacuation drill (5.86), and non-guided vs full-signed experiment (5.71). Positive mean differences suggest that the presence of adult guidance, evacuation signage, or their combination may lead to lower density in sub-area 2. Sub-area 3 shows that density per second is significantly associated with the evacuation signage system ($F = 6.083$, p-value $= 0.001$, df $= 3$). However, in sub-area 3, the mean difference of the influence of evacuation graphical signs and none-guided experiments on the evacuation density proved that graphical signs are less efficient than no guidance strategies in reducing the population density, which is contrary to its positive impact on the density in sub-area 2. Similarly, the Games Howell test identified that experiments assisted by graphical signs experienced higher density per second than those guided by adults (mean difference $= -4.32$) and full-guided drills (mean difference $= -3.84$).

4. Discussion

Evacuation speed and density are critical factors in ensuring the safety of students during emergencies in schools. In this study, the researchers conducted ten dissimilar evacuation drills

Table 6. Games Howell test results

	Group comparison	Mean difference	p-value	95% CI Lower bound	Upper bound
Sub-area 2	No signed vs guided	6.45	0.000	3.0611	9.8458
	No signed vs graphical signs	5.86	0.001	2.0510	9.6656
	No signed vs full-signed	5.71	0.000	2.2969	9.1158
Sub-area 3	No signed vs graphical signs	−4.56	0.004	−7.9951	−1.1280
	Guided vs graphical signs	−4.32	0.009	−7.8211	−0.8251
	Full-signed vs graphical signs	−3.84	0.040	−7.5628	−0.1173

Source(s): Authors' own work

and video-recorded them in a primary school to evaluate how evacuation guidance, built environment, evacuation signs, and visibility may affect the evacuation speed and density in the corridors. The analysis of the speed of the first five, middle, and last students who entered the sub-areas showed that the last group had smoother evacuation with less time spent there, which contradicts the observations by (Hamilton *et al.*, 2020). However, the difference between evacuees' speed and evacuation time is less substantial in the evacuation drills guided by adults. This finding is supported by previous studies showing that adult guidance can positively affect evacuation performance (Najmanová and Ronchi, 2017; Xiao *et al.*, 2017) by helping maintain a steady flow of evacuees and minimizing delays and congestion.

The study found that providing two simultaneous adult guidance in the corridors in good visibility conditions affected the students' evacuation speed; however, evacuation graphical signs in the affected visibility drills have proven to increase evacuation speed substantially, which aligns with the previous findings (Delcea *et al.*, 2020). Evacuees rely on visual cues to navigate through the corridors, and properly designed signage can help reduce confusion, leading to faster evacuation times. This finding is consistent with previous research that has demonstrated the effectiveness of evacuation signage in promoting faster and safer evacuation (Fujii *et al.*, 2021). The simultaneous use of adult guides and evacuation signs has increased the evacuees' speed in both visibility situations. The results also proved that visibility did not significantly alter the pupils' evacuation speed, which contradicts the previous findings (Xie *et al.*, 2020). One possible explanation for this contradiction would be using dissimilar evacuation strategies in this study. This finding indicates the effectiveness of combining multiple evacuation strategies in promoting efficient and safe evacuation.

In terms of density, in most experiments, the average density in the area with two gates closely located to each other is higher than in the area where the distance between the classrooms' entrances is farther. When gates are closer to each other, evacuees may face congestion and higher density, leading to slower evacuation times. This finding is consistent with previous research showing the impact of a short distance between two exits and an imbalance in crowd density (Shi *et al.*, 2022a, b). Next, the evacuation density of each drill has been successfully modeled using curve-fitting models. Thirdly, the study proved that the presence of smoke did not significantly impact the population density in the corridors. Lastly, as the study found a very close p-value regarding the impact of corridor design and the distance between the classroom gates opened in the passages, the authors focused on the effectiveness of different guidance strategies on density in two distinct sub-areas. In sub-area 2, which has a single classroom gate and a large distance from the other gate, the results revealed that the presence of guidance or evacuation signage significantly reduced population density during evacuation. Specifically, scenarios with adult guidance, graphical signs, or both showed a lower population density compared to non-guided evacuations. However, the impact of evacuation signage was different in sub-area 3, where two classroom gates with a short distance were open. Here, the study showed that graphical signs alone were less efficient in reducing population density than non-guided strategies. In fact, guided evacuations, whether with adult assistance or full-signed evacuation, resulted in lower population density, leading to higher evacuation efficiency. This finding highlights the importance of carefully considering both environmental factors and human guidance strategies when designing evacuation plans.

5. Concluding remarks, limitations and future works

As this study is pioneering in conducting real experiments in primary schools under affected visibility conditions, the findings offer firsthand insights into the evacuation safety of children of this age group that can impact evacuation performance in primary schools and can inform the development of effective evacuation plans and strategies. First, careful consideration should be given to the layout of the school when designing evacuation guidelines. This study's observations suggest that the presence of adult guidance in areas where two exits/entrances are closely located may lead to increased congestion, while signs could be more effective in these scenarios. The effectiveness of the evacuation strategies should vary based on the area's layout, emphasizing the importance of tailored evacuation plans that consider environmental factors and human guidance for enhancing school safety during emergencies. Second, both evacuation signs and adult guidance were found to effectively reduce evacuation speed in both low and good visibility conditions. Therefore, it is imperative to assign trained staff for evacuation procedures and educate children about the guidelines and meanings of graphical signs. This knowledge will be particularly useful in situations where smoke density obstructs their view, rendering adult guidance less effective.

While the findings of this study hold promise for enhancing evacuation protocols and educational facility design to ensure student safety during emergencies, it is crucial to acknowledge the research's limitations. The study was conducted in a controlled environment, and caution should be exercised when extrapolating the findings to other contexts, considering the specific conditions and factors at play. Additionally, the study focused on two classrooms in one school to conduct evacuation drills, prioritizing student safety and examining various factors. However, further research is warranted to explore the effectiveness of different evacuation strategies in diverse settings and under varying conditions. Future studies could also assess the impact of training on teachers' guiding capabilities through follow-up drills, which were not feasible in this study due to certain limitations. Addressing these limitations and conducting additional research will contribute to a more comprehensive understanding of effective evacuation strategies and further enhance emergency preparedness in educational settings.

Notes

1. Chengdu City's emergency plans prioritize rescue and emergency efforts, but lack specific guidelines for evaluating evacuation plans and training effectiveness. The Seismological Bureau collaborates with drill organizers, but implementation leadership rests with individual executive bodies. Post-drill, evacuation plans are refined by respective organizers.
2. The paper focuses exclusively on analyzing evacuation characteristics within sub-areas of the corridors, without presenting results of students' evacuation in classrooms.
3. Durable plastic graphic signs with pre-printed designs were employed, featuring adhesive backing for easy on-site application. These signs proved resilient to wear and tear caused by pedestrian traffic.
4. A video analysis software used for sports and motion analysis and previously used to detect vehicle speed (Paolino and Zampa, 2023).

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