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Elementary students' evacuation route choice in a classroom: A questionnaire-based method

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HIGHLIGHTS

- A questionnaire-based experiment is conducted to study children's evacuation behavior.
- Position, congestion, group behavior and backtracking behavior have significant effects on children's route choice.
- Gender and guidance have no prominent impacts on children's route choice.
- Age only affects children's backtracking behavior.

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ABSTRACT

Children evacuation is a critical but challenging issue. Unfortunately, existing researches fail to effectively describe children evacuation, which is likely due to the lack of experimental and empirical data. In this paper, a questionnaire-based experiment was conducted with children aged 8–12 years to study children route choice behavior during evacuation from in a classroom with two exits. 173 effective questionnaires were collected and the corresponding data were analyzed. From the statistical results, we obtained the following findings: (1) position, congestion, group behavior, and backtracking behavior have significant effects on children route choice during evacuation; (2) age only affects children backtracking behavior, and (3) no prominent effects based on gender and guidance were observed. The above findings may help engineers design some effective evacuation strategies for children.

1. Introduction

Recently, the pedestrian flow model has become an effective tool to explore evacuation behaviors, especially in various emergency situations [1–4]. Understanding the pedestrian behavior and corresponding complex phenomena during evacuation is critical to enhance the evacuation safety and efficiency, which are affected by pedestrian route choice behavior. To study pedestrian route choice behavior, researchers have proposed many pedestrian flow models and conducted some pedestrian flow experiments. For example, Helbing et al. [5] used a lattice gas model and conducted an experiment to study the evacuation of students from a classroom. Isobe et al. [6] used an experiment and simulation to study evacuation from a dark room. Nagatani and Nagai [7] used a biased random walk model to study pedestrian route choice during evacuation

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from a dark room with an exit. Varas et al. [8] applied route distance to design an algorithm to calculate a cell's potential based on cellular automaton and then explored pedestrian route choice behavior. Huang and Guo [9] proposed a modified floor field model to study evacuation from room with internal obstacles and multiple exits. Huang et al. [10] applied the Hughes' dynamic continuum model to explore pedestrian route choice strategy. Asano et al. [11] pointed out that pedestrian motion behaviors have anticipatory properties and proposed a model to explore route choice behavior. Guo and Huang [12] applied the logit-based choice principle to develop a route choice rule that considers route distance, exit width and the number of pedestrians who choose each exit. Chang and Yang [13] conducted a questionnaire survey and in-depth interviews with passengers involved in the flight CI-120 accident to study emergency evacuation from the cabin. Guo et al. [14] used simulation and experiments to study pedestrian route choice behavior during evacuation under good and zero visibility. Bode et al. [15] used an interactive virtual environment to simulate pedestrian exit route choice. Kinateder et al. [16] utilized experiments to study the effects of social influence on pedestrian route choice and destination choice during emergency evacuation from a tunnel. Lovreglio et al. [17] used a binary logit model to study the effects of herding behaviors on pedestrian exit choice during an emergency, and the impacts of certain environmental and social factors on the pedestrian exit choice during a local emergency [18]. Shi et al. [19] conducted some controlled laboratory experiments to explore the merging crowd behavior during evacuation.

However, most of the above models assumed that all pedestrians are homogeneous (i.e., pedestrians' movements are the same under the same conditions). In fact, pedestrians' movements may be different even under the same scenarios. To conquer this limitation, researchers proposed some pedestrian flow models with heterogeneity (e.g., age, gender, mental state, etc.). For instance, Guy et al. [20] used six variables (e.g., aggressive, shy, assertive, tense, active, impulsive) to study heterogeneous crowd behavior. Manley et al. [21] developed an agent-based pedestrian flow model with heterogeneity to explore the influences of bomb burst on evacuation in an international airport. Koo et al. [22] explored the effects of residents with disabilities on evacuation from a high-rise building. Christensen et al. [23] proposed an agent-based pedestrian flow model to explore the differences between two evacuations (i.e., heterogeneous pedestrians with disabilities and homogeneous pedestrians). Kuligowski et al. [24] studied pedestrian stair velocity in a six-story building and compared the evacuation of older adults and that of people with mobility impairments. Shen et al. [25] used an evacuation experiment to test the effects of visibility and gender on the evacuation efficiency. Tan et al. [26] investigated the impacts of different knowledge levels of buildings' internal structure on evacuation efficiency. Song et al. [27] proposed a pedestrian flow model that considered selfish and selfless behaviors to study the evacuation from a square room.

However, the above pedestrian flow models do not consider or study children evacuation. As for children, their self-control ability and decision making ability may be weaker than that of adults due to the differences in physiology, cognitive level, and social level. Hence, the above models cannot be readily used to explore children evacuation. The official data from 2014 demonstrate that children aged 0 to 14 accounted for 16.5% of the population in China [28], i.e., children have been an important component of society. Most children often conduct many transportation activities independently. For example, children aged 7 to 12 are able to engage in many transportation activities in primary school (e.g., evacuation drill), which motivates researchers to study children traffic behavior (e.g., evacuation behavior). For example, Barton et al. [29] explored the roles of gender, age and cognitive development on children route choice behavior during the evacuation process. Cuesta and Gwynne [30] collected evacuation data from the same school to statically study the evacuation of children aged 4 to 16.

In this paper, a questionnaire using a printed map is used to study the impacts of seven factors (i.e., age, gender, position, congestion, guidance, group behavior, and backtracking behavior) on the route choice behavior of children during evacuation from a classroom with two exits. This paper is organized as follows: the questionnaire and corresponding experiments are introduced in Section 2; data analysis and discussions are provided in Section 3; and conclusions are summarized in Section 4.

2. Methodology

In this section, we design a questionnaire and apply it to carry out an experiment at the primary school attached to Beihang University. Before designing the questionnaire, we give the following basic assumptions:

(1) Many factors have impacts on elementary students' route choice behavior during evacuation from a classroom, but we only consider seven factors (i.e., position, congestion, guidance, group behavior, backtracking behavior, age, and gender) in the questionnaire.

(2) The scenarios used in the questionnaire are fixed as a classroom (see Fig. 1). All desks and chairs cannot be moved during evacuation; the widths of the three aisles are equal; the gray rectangles denote chairs, the black rectangles denote the desk, and the big black rectangles denote the platform.

We conducted several random sampling pilot surveys of students in different grades to refine the questionnaire and to identify the appropriate survey group. The detailed steps are as follows:

(1) In the first pilot survey, we randomly selected five students from grade 1 to complete the questionnaire because cognitive levels of students in grade 1 are the lowest. If the majority of students cannot understand or complete the questionnaire without any assistance, we cannot choose the students in grade 1 to complete the questionnaire in our experiment. If the majority can understand and independently complete most aspects of the questionnaire, we revise the cases (that some students cannot understand) and select other five students to re-conduct the revised questionnaire. We revise the questionnaire as often as needed until the students (selected to conduct the pilot survey) can understand and independently complete the finalized questionnaire.

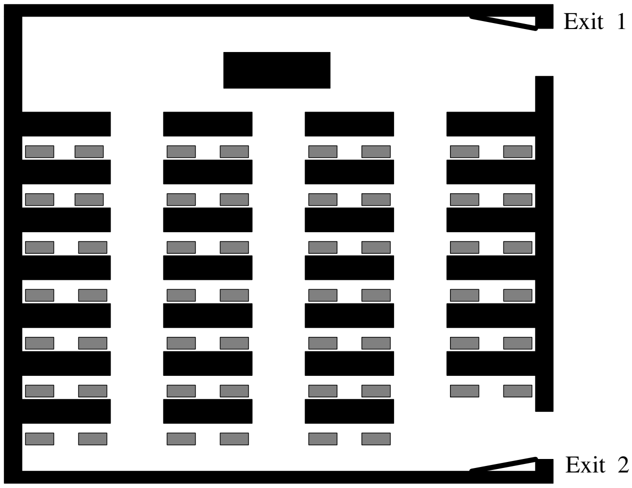

Fig. 1. The classroom layout used in the questionnaire.

Table 1
The nine cases and the corresponding factors in the questionnaire.

Group	Cases	Factors to investigate
I	(a)–(b)	Position
II	(c)–(d)	Congestion
III	(e)–(f)	Guidance
IV	(g)–(h)	Group behavior
V	(i)	Backtracking behavior

(2) The first pilot survey results showed that not all students in grade 1 can understand or complete the above questionnaire, so we selected the students in grade 2 to conduct the second pilot survey. Like the first pilot survey, we randomly selected five students in grade 2 to conduct the same questionnaire.

(3) The second pilot survey results demonstrated that not all students can understand and complete the above questionnaire, so we selected the students in grade 3 to conduct the third pilot survey. Like the second pilot survey, we randomly chose five students in grade 3 to conduct the above questionnaire.

(4) The third pilot survey results illustrated that 3 students in grade 3 can understand and complete the above questionnaire and that 2 students cannot understand or complete the questionnaire. Hence, we only revised the cases that can neither be understood nor independently completed and selected other students in grade 3 to re-conduct the revised questionnaire. Like the third pilot survey, we randomly chose five additional students in grade 3 and re-conducted the revised questionnaire.

The fourth pilot survey results indicated that the 5 students in grade 3 can understand and complete the revised questionnaire. As a result, we carried out one full-scale survey of students in grade 3 to 6 at the primary school attached to Beihang University by use of the revised questionnaire from the fourth pilot survey. The finalized questionnaire is as follows:

(1) The questionnaire includes nine cases, i.e., (a)–(i). The nine cases can be sorted into five groups (see Fig. 2 and Table 1). As for each case, the context and instructions provided to the students are shown in Table 2; each participant's gender and age were collected in the questionnaire's preface (see Table 2).

(2) Since each case is a static scenario, each child only cares his/her current situation and does not to care his/her future situation after he/she completes each case scenario of the questionnaire.

(3) When each child conducts each case in the questionnaire, he/she only cares the factors (that are reflected in his/her current case) and does not consider other factors.

Finally, we used the designed questionnaire to conduct the experiment. Here, we chose 4 classes from grades 3 to 6 (i.e., one class for each grade) to conduct the experiment on March 17, 2016. The requirements of the experiment are as follows:

(1) Students in the experiment do not include those chosen in the previous four random sampling pilot surveys to ensure that each student chosen completes the questionnaire for the first time.

(2) The experiments should instantaneously be conducted in the four classes to ensure that each student chosen does not hear any information from other students related to the questionnaire.

(3) All students should independently complete the questionnaire (see Fig. 3) to ensure that each student chosen is not influenced by others during the process of completing the questionnaire.

(4) Each child should choose his expected route in case (a) to case (h) and provide the corresponding reasons.

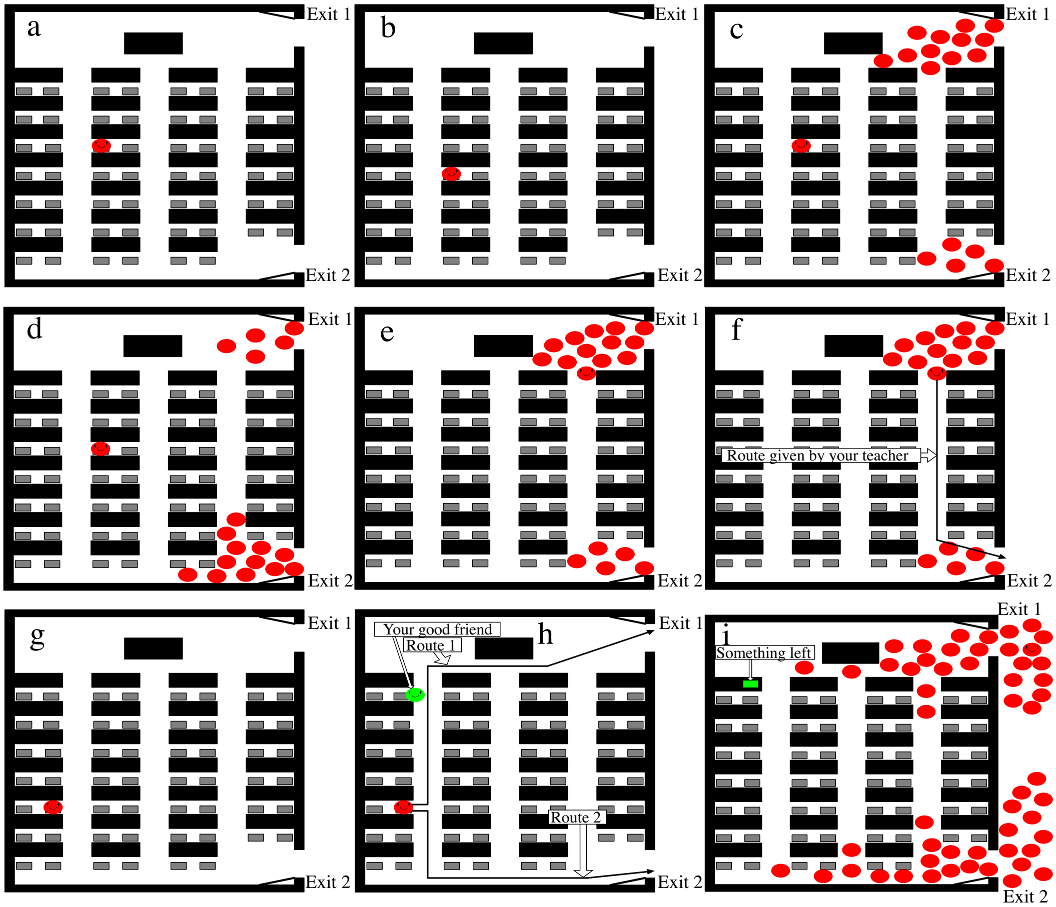

Fig. 2. The scenario of nine cases used in the questionnaire. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2
The contents of the questionnaire.

Age: ____ years old; Gender:____; Grade:____.	
In Fig. 2, the red circle with a smiley face denotes a participant who is to draw one route (to exit 1 or 2) in the blank area based on the information provided in the map, and the position of the red circle is the participant's current position; the green circle with a smiley face denotes a friend of the participant, and the position of the green circle is the participant's friend's current position; other red circles denote other classmates, and the position of other red circles denote other classmates' current position.	
(a)–(e), (g)	The participant should quickly evacuate from the classroom and only draw one route (to exit 1 or 2) that he/she most desires.
(f)	The participant's teacher provides a guidance route to him/her. Will he/she follow the guidance? He/she should only give an answer, i.e., (Yes/No).
(h)	The participant should choose a route from Route 1 or Route 2, which were provided in the map.
(i)	When the participant leaves the classroom, he/she suddenly finds that something is left on his/her seat. At this time, he/she has the following three choices: (A) immediately return, (B) return after all classmates have left the classroom, or (C) return after the activity is over. The participant should only choose one answer from the three options.

Fig. 3. A photo taken during the experiment.

Table 3
Basic information regarding children completing the experiment.

Age	Number of children (%)	Male	Female
8	26 (15.0)	13	13
9	37 (21.4)	20	17
10	37 (21.4)	30	17
11	52 (30.1)	26	26
12	21 (12.1)	12	9
Total	173 (100)	91 (52.6)	82 (47.4)

The experiment processes in each chosen class are as follows: first, a student helper from our research group distributed the questionnaire; second, the student helper introduced the questionnaire's requirements, monitored the students as they completed the questionnaire, and gathered the questionnaire after each student finished it. All of the questionnaires were completed in half an hour.

In the experiment, we collected 173 effective questionnaires. The mean age of the children is 10.03 years, and the standard deviation is 1.269. Additional other basic information is shown in Table 3.

3. Data analysis and discussions

The objective of this study is to investigate the impacts of position, congestion, guidance, group behavior, backtracking behavior, age, and gender on children's route choice behavior during evacuation from a classroom with two exits (see Fig. 1). This can be investigated through hypothesis testing. The null hypothesis can be expressed as follows: position, congestion, guidance, group behavior, backtracking behavior, age and gender have no significant effects on children's route choice behavior during evacuation from a classroom with two exits.

To analyze the data, we have provided the following notes:

(1) For cases (a)–(h): 1 denotes the choice of exit 1 and 2 denotes the choice of exit 2.

(2) For case (i): 1 denotes option A, 2 denotes the option B, and 3 denotes option C.

First, we explore the effects of position, congestion, guidance, group behavior and backtracking behavior on children's route choice behavior during evacuation from a classroom with two exits. For the factors of position, congestion, guidance and group behavior, the data are studied using the paired-samples t-test. For the factor of backtracking behavior, the data are studied using the one-simple t-test and the hypothesized value for the population mean from the null hypothesis of 3. The data and the statistical results are shown in Table 4.

Position

If a child's position is obviously close to a certain exit, he/she will easily choose this exit. Hence, we do not explore the situation in which the position is obviously close to a certain exit. Therefore, we can use case (a) and case (b) to study the impacts of position on children's route choice behavior during evacuation from the scenario shown in Fig. 1, where the positions in case (a) and case (b) are in the third row and the fourth row, respectively.

In case (a), 153 children chose exit 1. In this scenario, 143 children considered that the distance was shorter, and 10 children thought that fewer desks/chairs were in the route. Also in case (a), 20 children chose exit 2, with 6 children believing that the distance was shorter, 8 children finding no obstacle in the route, 3 children believing more children would choose

Table 4
Data regarding position, congestion, guidance, group behavior and backtracking behavior in the questionnaire.

Factor	Case	Exit 1	Exit 2	M	SD	*P*-value	*Hn*
Position	(a)	153	20	1.12	0.32	<0.001	Reject
	(b)	4	169	1.98	0.15		
Congestion	(c)	16	157	1.91	0.29	<0.001	Reject
	(d)	173	0	1	0		
Guidance	(e)	29	144	1.83	0.38	0.493	No reject
	(f)	26	147	1.85	0.36		
Group behavior	(g)	0	173	2	0	<0.001	Reject
	(h)	75	98	1.57	0.50		
Backtracking behavior	(i)	–	–	2.55	0.58	<0.001	Reject

Note: Exit 1: the number of children choosing exit 1; Exit 2: the number of children choosing exit 2; M: mean; SD: standard deviation.

exit 1, and 3 children choosing exit 2 for other reasons. In case (b), 4 children chose exit 1, with 2 children believing that the distance was shorter and 2 children indicating that fewer desks/chairs were in the route; Also in case (b), 169 children chose exit 2, with 10 children believing there were fewer desks/chairs in the route, 151 children indicating that the distance was shorter, and 8 children believing that the route had no obstacles. The above data indicate that most children chose the exit that is closest to their current position. A detailed analysis of the reasons given by participants indicates that each child makes his/her exit choice primarily based on the distance and the number of obstacles. By calculating the P-value, we find that it is less than 0.001, which demonstrates that position has a significant impact on children's route choice behavior. Therefore, the null hypothesis is not supported because the results in case (a) are significantly different from the results in case (b). The above findings imply that most children can accurately judge the distance between their current position and an exit and make their decisions based on distance.

Congestion

To study the effects of congestion on children's route choice behavior, we fix other factors and use cases (c) and (d) to study the effects. The initial positions of the participants in cases (c) and (d) are both in the third row, the density near exit 1 is much higher than the density near exit 2 in case (c), and the density near exit 2 is much higher than the density near exit 1 in case (d).

In case (c), 157 children chose exit 2, with 153 children indicating that the pedestrian level near exit 2 was not crowded, 2 children believing that the distance is shorter, and 2 children choosing exit 2 for other reasons; Also in case (c), 16 children chose exit 1 with 1 child indicating that the children at exit 2 had left the classroom when he/she reached the exit, 13 children believing that the distance was shorter, and 2 children choosing exit 2 for other reasons. On the other hand, in case (d), all children chose exit 1, with 117 children believing that the pedestrian level near next 1 was not crowded, 7 children indicating that the distance as shorter, and 49 children choosing exit 1 for both of these reasons. The above data demonstrate that most children chose the exit where the density was obviously low. By calculating the P-value, we find that it is less than 0.001, which indicates that congestion has a significant effect on children's route choice behavior. Therefore, the null hypothesis is not supported since the results in case (c) are significantly different than those in case (d). The findings reveal that most children can accurately judge congestion level and make decisions based on congestion level.

Guidance

Like congestion, we fix other factors and utilize case (e) and case (f) to explore the influences of guidance on children's route choice behavior. In case (e) and case (f), the child's position is close to exit 1, but the density near exit 1 is prominently higher than the density near exit 2 and there is a guided route only in case (f).

In case (e), 29 children chose exit 1 because they believed that the distance was shorter; and 144 children chose exit 2 because they considered that the pedestrian level near exit 2 was not crowded. In case (f), 26 children chose exit 1, with 2 children indicating that all children would choose exit 2, 1 child failing to follow the guidance, and 23 children believing that the distance was shorter. Also in case (f), 147 children chose exit 2, with 132 children believing that the pedestrian level near exit 2 was not crowded and 15 children following guidance. A detailed analysis of the reasons given by participants indicates that most children did not mention the guidance given by the teacher. In calculating the P-value, we find that it is 0.493, which demonstrates that guidance has no prominent effect on children's route choice behavior during evacuation from the classroom, as shown in Fig. 1. Hence, the null hypothesis cannot be rejected. In reality, most children are more likely to follow their teachers' instructions. However, the statistical results in case (e) and case (f) have no prominent differences, although there is a guidance route in case (f). We should be cautious in generalizing the results in case (f). The reason this phenomenon occurs may be due to the fact that guidance on the map is more like a sign in case (f) instead of direct guidance from a teacher in the real world. The above results demonstrate show that some children may ignore signs in their surroundings. However, if the surrounding becomes more complex, the above phenomenon may be more prominent.

Group behavior

We fix other factors and use case (g) and case (h) to study the effects of group behavior on children's route choice behavior. In both two cases, there are two routes. A child in the fifth row has a good friend in the first row in case (h).

In case (g), 173 children chose exit 2, with 165 children indicating that the distance was shorter, and 8 children believing that fewer desks/chairs were in the route. In case (h), 75 children chose exit 1, with 13 children indicating that walking

Table 5
Data related to gender in the nine cases.

	(a)		(b)		(c)		(d)		(e)	
	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value
Male Female	1.12 (0.33) 1.11 (0.32)	0.821	2 (0) 1.95 (0.22)	0.045	1.92 (0.27) 1.89 (0.32)	0.460	1 (0) 1 (0)	–	1.85 (0.36) 1.82 (0.39)	0.612
	(f)		(g)		(h)		(i)			
	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value		
Male Female	1.86 (0.35) 1.84 (0.37)	0.775	2 (0) 2 (0)	–	1.59 (0.49) 1.54 (0.50)	0.454	2.63 (0.55) 2.48 (0.61)	0.090		

Note: M: mean; SD: standard deviation.

Table 6
Data related to the children's age in the nine cases.

	(a)		(b)		(c)		(d)		(e)	
	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value
Group 1 Group 2	1.13 (0.34) 1.11 (0.31)	0.725	1.95 (0.22) 1.99 (0.10)	0.181	1.83 (0.38) 1.95 (0.21)	0.015	1 (0) 1 (0)	–	1.73 (0.45) 1.89 (0.31)	0.013
	(f)		(g)		(h)		(i)			
	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value	M (SD)	*P*-value		
Group 1 Group 2	1.79 (0.41) 1.88 (0.32)	0.145	2 (0) 2 (0)	–	1.54 (0.50) 1.58 (0.50)	0.593	2.33 (0.57) 2.68 (0.56)	<0.001		

Note: M: mean; SD: standard deviation.

together with friends would be helpful to them and their friends, and 62 children indicating that they were willing to walk together with their friends. Also in case (h), 98 children chose exit 2, with 85 children believing that the distance was shorter, 9 children believing that their lives were more important than those of their friends, and 4 children choosing exit 2 for other reasons. The above data indicate that more than 40% of children's route choice behavior was influenced by a good friend. In other words, the children exhibited group behavior. By calculating the P-value, we find that it is less than 0.001, which reveals that group behavior has a significant effect on children's route choice behavior. Therefore, the null hypothesis is not supported.

Backtracking behavior

We use case (i) to study the effects of backtracking behavior on children's route choice behavior. In case (i), 8 children chose option A, 61 children chose option B, and 104 children chose option C. This indicates that 8 children immediately returned to the classroom, 61 children returned after all students leave the classroom, and 104 children returned after the activity was completely over (i.e., 104 children did not exhibit backtracking behavior). The above data indicate that some children exhibit backtracking behavior, which generates multi-directional movement that is an important factor in many crowd accidents. By calculating the P-value, we find that it is less than 0.001, which demonstrates that backtracking behavior has a significant impact on children's route choice behavior. Hence, the null hypothesis is not supported.

Next, we explore the influences of gender and age on children's route choice behavior during evacuation from the scenario shown in Fig. 1. For the two factors, the independent-samples t-tests are used to assess the significance level, with the related data displayed in Tables 5–7.

Gender

For gender, we use the collected data to calculate the P-values in cases (a)–(i) and find that they are greater than 0.01, which indicates that there is no significant difference between males and females in cases (a)–(i).

Age

As for the age factor, we divide the collected data into two groups, where the children's age in group 1 is 8–9 years and the age in group 2 is 10–12 years. By calculating the P-value in each case, we find that only the P-value in case (i) is less than 0.001, which demonstrates that there are significant differences between the two groups of children only in case (i) and that age has a significant influence only on the children's backtracking behavior. Thus, we further study the data in Table 6, with more detailed data shown in Table 7. From Table 7, we can conclude the following findings:

(1) As for the option A, there are no prominent differences between the two groups of data, which demonstrates that age has no prominent effects on option A.

(2) As for options B and C, prominent differences exist between the two groups of data, which demonstrates that age has a significant impact only on options B and C. In other words, more children in group 1 chose option B because they cared more about their forgotten things, while more children in group 2 chose option C because they did not care as much about items left behind. The findings imply that younger children are more likely to return to the classroom.

Table 7
Detailed data regarding the children's age in case (i)

	(i)		
	A (%)	B (%)	C (%)
Group 1	3 (4.8)	36 (57.1)	24 (38.1)
Group 2	5 (4.6)	25 (22.7)	80 (72.7)

4. Conclusions

Many models and methods have been proposed to study pedestrian flow, but little effort has been made to study children's route choice behavior since it is difficult to obtain experimental and empirical data. In this paper, we used a questionnaire-based experiment to explore the effects of position, congestion, guidance, group behavior, backtracking behavior, age, and gender on children's route choice behavior during evacuation from one classroom with two exits. The experimental results indicate that position, congestion, group behavior, and backtracking behavior have significant effects on children's route choice behavior during evacuation from one classroom with two exits, while guidance has no prominent impact. In addition, the statistical data reveal that there are no prominent differences between male and female behavior in cases (a)–(i) and that age has a significant impact only on children's backtracking behavior. The results may have important values on the safety management of elementary students, preventing unpredictable catastrophes, the design of building structure as well as formulating emergency preplans.

However, it should be noted that we only consider seven factors, and each factor is considered independently in the designed questionnaire. And the reasons provided by children may be incomprehensive since they are written in simple words by children. Therefore, more factors (e.g., cognitive level, etc.) [31–33] and more traffic characteristics [34–43] should in the future be considered in the questionnaire and some experiments should be conducted to verify the questionnaire results.

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