Exploring self-preservation capability in toddlers during evacuation process

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Abstract

The evacuation of vulnerable people is critical and one remarkable example is young children. Whereas some experts have suggested the age young children can evacuate without having to be physically assisted, we must admit that the empirical evidence of this is limited. Here we investigated the performance of ninety-four children aged 0-3 during five evacuation trials in a day-care centre. We confirmed that self-preservation is age-dependent. However, this capability may vary due to individual/developmental differences i.e. one-third of children (1-2 years old) evacuated by their own and around one-fifth of children (2-3 years old) needed assistance. We also found no gender differences in self-preservation. Results of this study also suggest that the characteristics of the scenario (i.e. adult/child ratios and travel distances) and the decisions and actions of staff members during the pre-evacuation stage (i.e. gathering, preparing, and encouraging children) are factors affecting self-preservation. These findings challenge our current understanding of the impact of self-preservation capability on children's safety.

Keywords: Self-preservation; Very young children; Evacuation.

1 Introduction

Children are considered somewhat vulnerable given the potential for cognitive and mobility limitations that might impair their evacuation performance [1,2]. Thus, understanding when these limitations are present and how to minimize their impact is of crucial importance. Indeed, the study of children evacuation has been of interest to researchers over the last few years. This has been assessed via multiple approaches including survey research [3-5], literature review [6], controlled/laboratory experiments [7-10], observational experiments [1,11-16] and the use of modelling and simulation [17-21]. Broadly speaking, the first evidence from the literature is that children and adults differ in behaviour and movement. The second evidence is that evacuation performance of children is age-dependent i.e. primary school children are likely to move slower but to be more compliant with the personnel instructions than secondary school children [1].

In the last few years, there has been a growing interest in this subject-matter with a number of studies concentrated on pre-schoolers and/or school-age children. Therefore, an important focus is the investigation of evacuation capabilities in toddlers (< 3 years). To date, there is little agreement on the age children are capable to follow staff instructions and evacuate by their own. The NFPA 101, Life Safety Code [22] and the International Fire Code [23] use 30 months as a reference for self-preservation. Teachers in day-care centres and experts in child development suggested 30-36 months as the lower age limit [4]. They argued that at this age, most children are considered able to understand and follow simple instructions and walk on horizontal surface without physical support towards exits.

A key aspect to consider is that children grow and develop at different rates [24-26]. Prefrontal cortex which involves higher cognitive functions such as planning, and reasoning undergoes considerable maturation during early childhood and changes with age [27-30]. According to Piaget [31], as children get older, their mental representations of the world become more numerous and elaborate (e.g. self-awareness [32]). This tells children how to react to incoming stimuli or information [33]. Cultural and social contexts also contribute to differences in cognitive development of children [34, 35]. Similarly, motor development is fast, and it is influenced by both sociological factors and genetic factors in early childhood [36]. Early walking patterns of children differ [37,38] and the age to start independent walking can vary from one child to another [39] (ranged between 8.5 and 20 months) [26]. Therefore, while some very young children are capable to evacuate others may well lack the required cognitive and motor skills thus needing the intervention by staff members (e.g. carrying, handholding, continued bodily contact).

Empirical evidence of self-preservation in children is limited. One study identified the potential difficulties for pre-schoolers (3-6 years) to open doors during evacuation [40]. In another study familiarity of children with the evacuation system and procedures was found to be an important factor in the speed of evacuation [41]. The most outstanding study reported the level of assistance for children during evacuation in day-care centres [42]. Self-preservation (i.e. no physical assistance) was observed in the initial phase of the evacuation in 20.2 % and 85.9% of children 0-2 and 3-6 years old respectively. Note that children 0-2 year old were actually from 6 months to children turn 3 years. As stated by the author, future research should focus on narrow age ranges to identify "how the change develops with age". This study also suggests future research to explore the effects of adult/child ratios on total evacuation times and using simulations for this endeavour.

Although these studies provide useful information to interpret young children safety during evacuation, the following questions remain open: at what age children are capable to accept staff instructions and evacuate by their own? and what impact does this have on the evacuation process?. The present study aims to add new data and information which will help to address these questions. We analyse data from ninety-four children (0-3 years old) during five evacuation exercises conducted in a day care building between 2013 and 2018. The performance of each child by age was observed independently allowing the opportunity to draw conclusions about this subject matter to 1) increase our understanding of the vulnerable populations in question, 2) quantify the nature of this vulnerability and 3) provide means to aid model developments. Throughout this paper, the term self-preservation will refer to the capability of children to take instructions from staff and follow those instructions without having to be physically assisted for evacuation. The physical assistance is divided into two levels [42]: carried and other physical assistance which includes adult hand holding and/or bodily contact during the evaluation movement.

2 Method

Ninety-four children: 22 (0-1 years old), 41 (1-2 years old) and 31 (2-3 years old) participated in the study (male 47% female 52%). None of them had physical or cognitive impairments. The analysis involves five evacuation trials (Table 1) that were conducted in collaboration with the health and safety unit of the University of Cantabria. Participants (staff members and children) were not exposed to any extreme or unusual circumstances and sensitive information was not gathered. Parents were informed about the procedure, the data collection method and the benefits from participating and they expressed their consent. The precise conditions on each day of the trials differed. Trials 2 and 4 were conducted in the afternoon involving less participants (children and staff members) and old toddlers were absent in trial 5. Also, the number of children per adult was different across the evacuation trials (Table 2). However, on average the observed child/adult

ratios met the NFPA 101 requirements [22] and those child/adult ratios recommended by experts of different countries [5]: infants (mean ± SD = 2.5 ± 1.06); young toddlers (mean ± SD = 4.2 ± 2.51) and older toddlers (mean ± SD = 5.5 ± 3.04).

Trial	Date	Staff members	Age groups		
			Infants (<12 months)	Young toddlers (1-2 years)	Older toddlers (2-3 years)
1	04/24/2013	6	7	12	14
2	05/22/2014	3*	2	4	-
3	06/10/2015	6	7	13	15
4	05/18/2017	3	1	1	2
5	04/12/2018	4	5	11	-

* One adult was not directly involved in evacuation

Table 1. Basic information of the evacuation trials.

Trial	Child/adult ratios for age groups		
	Infants (<12 months)	Young toddlers (1-2 years)	Older toddlers (2-3 years)
1	3.5	6	7
2	2	4	-
3	3.5	6.5	7.5
4	1	1	2
5	2.5	5.5	-

Table 2. Observed child/adult ratios in the evacuation trials.

Figure 1 illustrates the geometrical details of the day care building with three classrooms (C0, C1 and C2), a dinning room and a small office. There is only one exit: a double-leaf door 1.7 m wide. The evacuation trials were carried out using the following course of action. The director of the center knew the date and the time of the trial. Staff members (all female) were aware that the evacuation trial was going to take place when they saw us locating the video-cameras. However, we ensured that staff members had understood that we wanted to know how many children could evacuate without help. The cameras were turned on, one by one and staff members were instructed to go into the classrooms with their children groups, as they usually do: infants (<12 months) in classroom C0, young toddlers (1-2 years) in classroom C1 and older toddlers (2-3 years) in classroom C2 (see Figure 2). Then, children and staff involved in routine activities in the classrooms (e.g. playing, listening to a story). After 15 min, an ignited piece of paper was used to activate a smoke detector in the technical room (Figure 1). The fire alarm sounded, and the situation was verified by the director through the fire control panel. Then, staff members started evacuation either encouraging children to evacuate or assisting/carrying them. Whereas all infants were directly carried, toddlers were given instructions to evacuate. Staff members decide to assist/carry those toddlers who did not started evacuation by their own. Children were evacuated to the outside and gathered at the previously determined assembly point. The evacuation trial terminated when all occupants left the building.

Six video-cameras were used for the data collection. Three cameras were positioned inside the classrooms (Figure 2) and other three cameras covered the lobby and the exit door (Figure 1). For each child, we determined the evacuation capability as a categorical variable: self (S) or assisted (A). Then, we split the A category into two observed techniques: carried (C) or physical assistance (PA) which includes adult handholding and/or bodily contact [42].

We also measured evacuation variables produced by each category: pre-evacuation time, travel speed and evacuation time. The video-recordings (images at 30 frames/s) were analysed frame by frame. The pre-evacuation time was defined as the frame from the alarm to each child starts evacuation movement (alone or with a staff member). To determine the travel speed, we divided the floor plan into a grid of squared cells (0.3 x 0.3 m) using CAD drawings to track individual trajectories and measure the travel distances (Figure 3), which were divided by the time taken to cover them (i.e. between frame A and frame B). The evacuation time was taken at a specific frame when the body of each child crossed the exit door from the alarm. The exact frames were noted, transcribed into a spreadsheet and transformed to seconds.

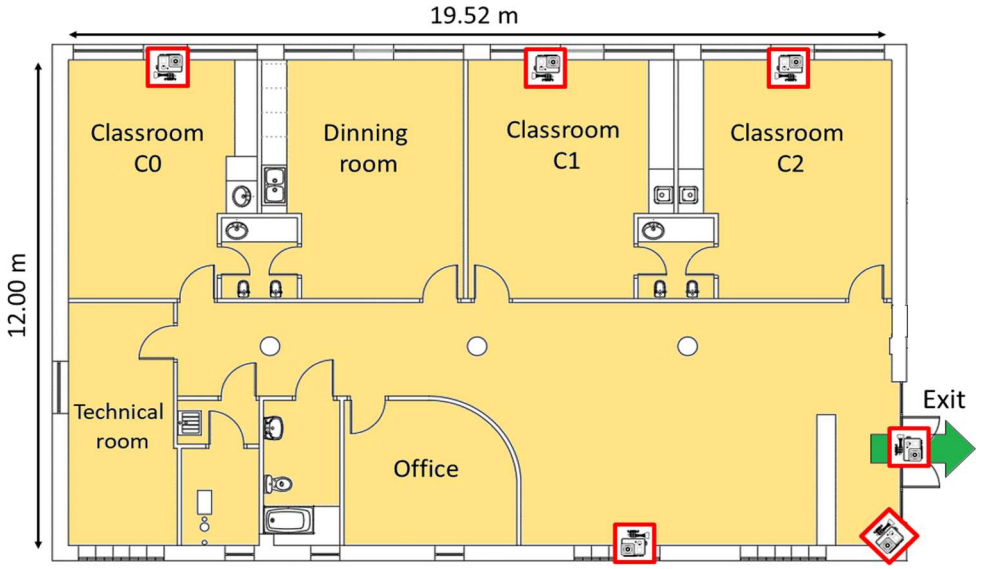


Fig. 1. Layout of the kindergarten building and video-cameras position.

Fig. 2. Children in classrooms C0, C1 and C2 before the alarm.

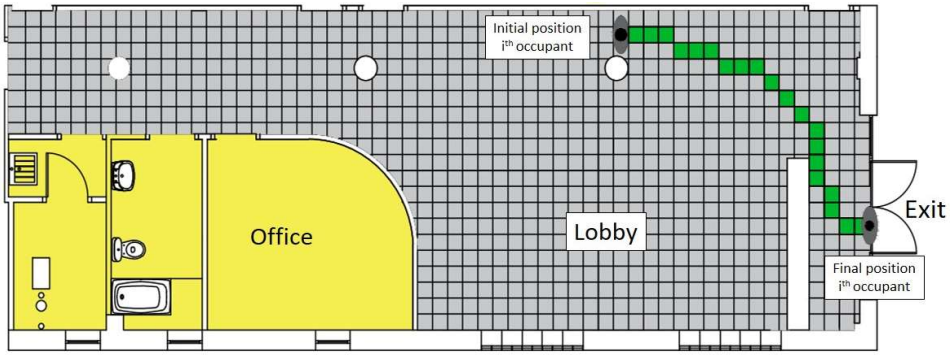


Fig. 3. Grid of squared cells used to track individual trajectories.

Categorical variables were compared using Fisher's exact test and Chi square test of independence. The assumptions underlying the analyses for continuous variables were checked. To test the data for normality we conducted D'Agostino K^2 tests for all our measured evacuation variables, from which the following p-values obtained: travel speed: S, $p = .544$, C, $p = .823$ and PA, $p = .359$; pre-evacuation time: S, $p = .430$, C, $p = .139$ and PA, $p = .056$; evacuation time: S, $p = .474$, C, $p = .121$ and PA, $p = .086$. Data samples did not differ significantly from that which normally distributed. Therefore, parametric tests were considered. Then, we conducted Levene's test for equality of variances and the requirement of homogeneity was not met in some comparisons. Consequently, Welch's *t*-test was used. We also conducted Mann-Whitney to compare small samples (<25). The correlation between child/adult ratios and evacuation parameters (pre-evacuation times and evacuation time) were investigated using Spearman's rank correlation coefficient (rho). Alpha level of 0.05 was used for all statistical tests. The datasets of this study are available from the authors upon request.

3 Results

Self-preservation. *Age.* As expected, all infants needed carrying during evacuation (Table 3). Old toddlers are more likely to self-preservation than young toddlers (77.41% vs 34.14 % respectively, $p < .001$, Fisher's exact test).

	Infants (<12 months)	Young toddlers (1-2 years)	Older toddlers (2-3 years)	N
S.- Self	0	14	24	38
A.- Assisted	22	27	7	56
C.- Carried	22	6	1	29
PA.- Physical assistance	0	21	6	27

Table 3. The observed frequency for self-preservation (S) and assisted (A) evacuation techniques: carried (C) and physical assistance (PA) across age groups and evacuation trials.

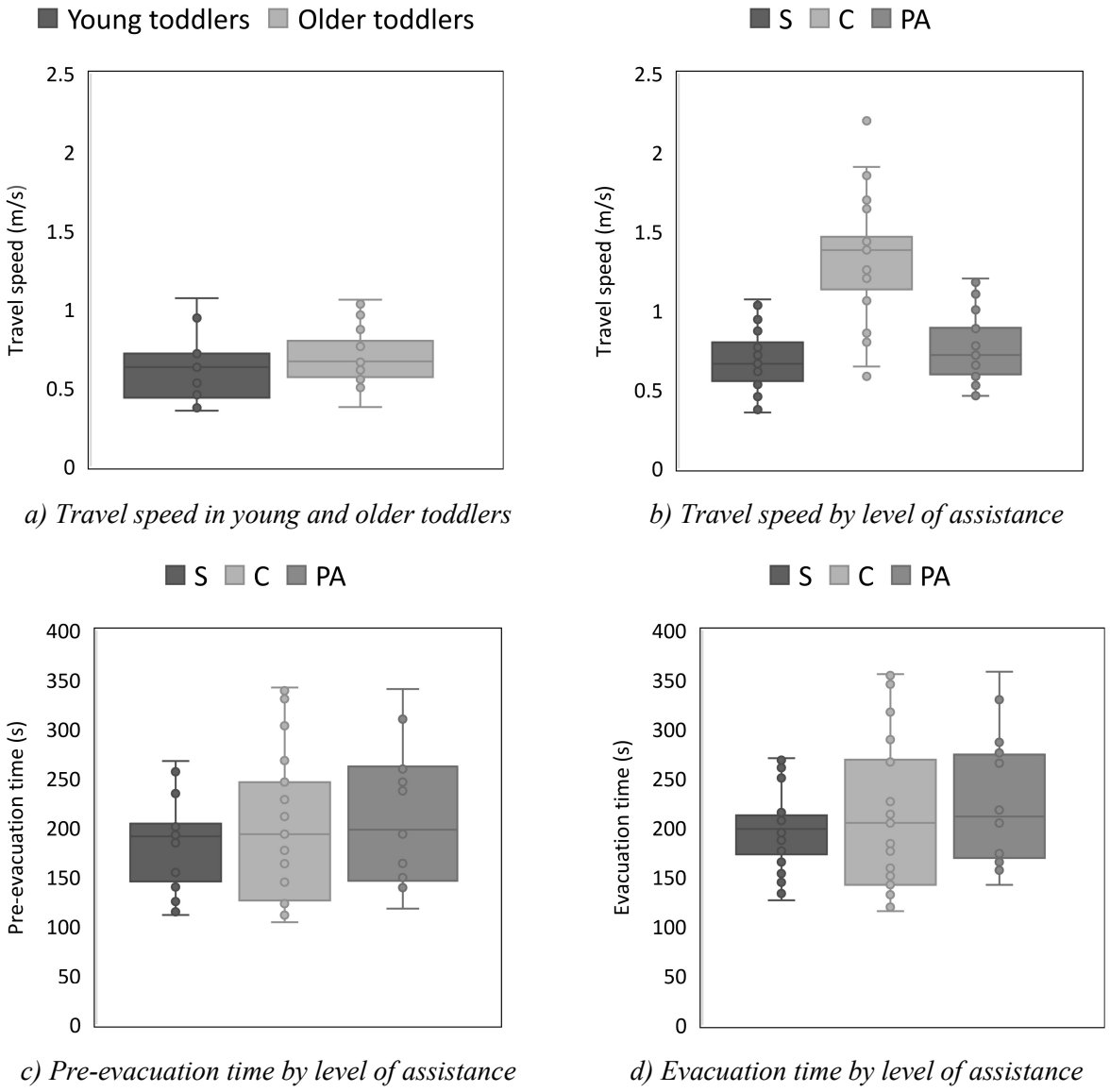
Gender. Since each child was identified by gender, we explore whether gender might be relevant to self-preservation. A chi-square test of independence shows that there is no significant association between gender and self-preservation capability in toddlers ($1, N = 71) = 0.20$, $p = .655$.

Reaction to the alarm. Among the ninety-four children, two children (a young toddler and an older toddler) were observed getting upset during trials 3 and 5 respectively. They cried because they did not want to leave, and they were carried by staff members.

Evacuation performance. *Travel speed.* Data from three children who walked erratically and six children who ran were removed. As result, travel speeds of 29 children are included in the final analysis. The median travel speeds in young toddlers and older toddlers are 0.63 m/s and 0.66 m/s respectively (Figure 3a) and the distributions in the two groups do not differ significantly (Mann-Whitney $U = 75$, $n_1 = 11$, $n_2 = 18$, $p = .289$; $d = .409$). The travel speed is on average faster in C technique (*mean* ± *SD* = 1.33 ± 0.41 m/s) than in PA technique (*mean* ± *SD* = 0.77 ± 0.23 m/s) ($t(41) = 6.176$, $p < .001$; $d = 1.696$) and S (mean ± SD = 0.67 ± 0.20 m/s) ($t(37) = 7.387$, $p < .001$; $d = 1.997$) (Figure 3b). As expected, this difference is not significant between PA technique and S ($t(49) = -1.442$, $p = .155$; $d = .395$). It should be noted that C and PA techniques involve a limited number of children assisted by each staff member. The observed frequencies of assisting evacuation across the trials are: C1 carrying one child at a time (45.16 %), C2 carrying two children at a time (12.90 %), C1 and PA1 carrying one child and holding one child's hand at the same time

(16.13 %), PA2 holding one child's hand (12.90 %), PA2 holding two children's hands at the same time (9.68 %) and PA3 holding 3 children's hands at the same time (3.23 %).

Pre-evacuation time. The comparison of the observed pre-evacuation times (Figure 3c) shows that C technique (mean ± SD = 197.90 ± 78.39 s) does not differ significantly from PA technique (mean ± SD = 208.93 ± 65.53 s) ($t(53) = -0.752$, $p = .569$; d = .152) and S (mean ± SD = 185.28 ± 42.26 s) ($t(40) = 0.784$, $p = .437$; $d = 0.200$). Similarly, the difference between PA technique and S is not significant (Welch's $t(41) = 1.647$, $p = .107$; $d = .473$). Therefore, the results when comparing different conditions (C, PA and S) do not reach statistical significance. However, pre-evacuation times produced by C and PA techniques are more dispersed than those produced by S (Figure 4a). The amount of variation systematically differs between C technique and S ($F(1,65)=15.00$, $p < .001$) and between PA technique and S ($F(1,63)=15.65$, $p < .001$).



a) Travel speed in young and older toddlers

b) Travel speed by level of assistance

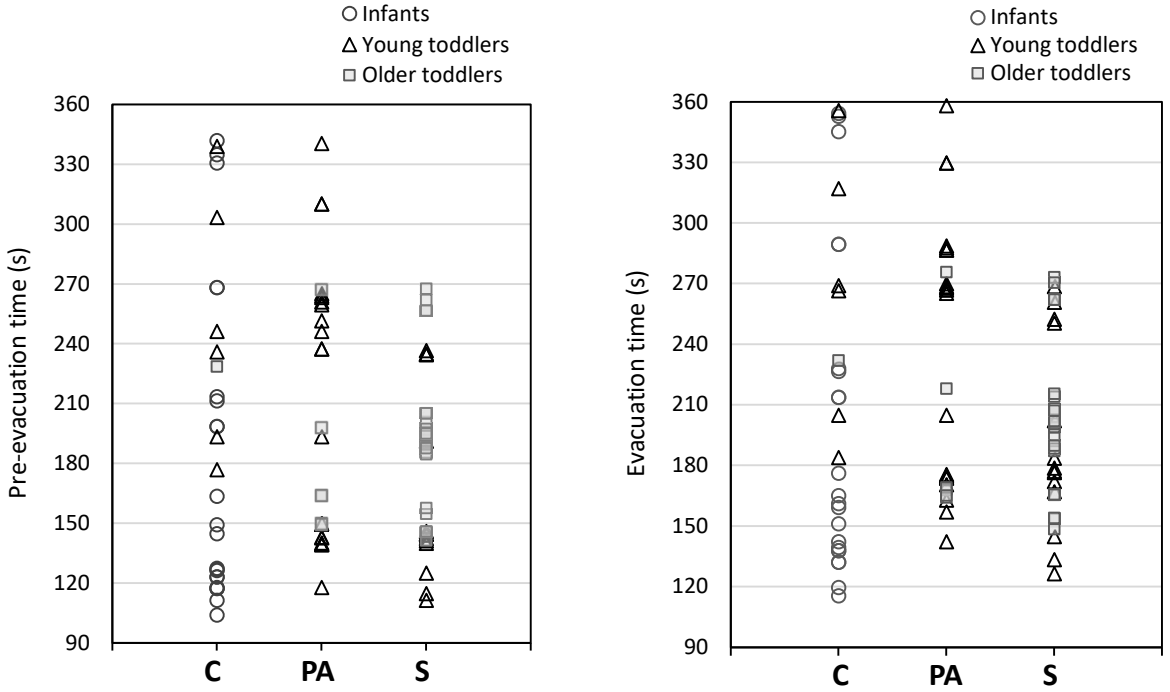
c) Pre-evacuation time by level of assistance

d) Evacuation time by level of assistance

Fig. 3. Box plots of evacuation variables. Young toddlers (1-2 years). Older toddlers (2-3 years). S= children who carried out self-preservation; C= children who were carried by staff members; PA= children who needed continuous physical support (adult handholding or continuous bodily contact).

Evacuation time. On average, individual evacuation times produced by different levels of assistance do not differ significantly (Figure 3d): C technique (mean ± SD = 214.12 ± 78.74 s) vs PA technique (mean ± SD = 225.76 ± 62.78 s) ($t(52) = -0.608$, $p = .273$; $d = .163$); C technique vs

S (mean ± SD = 199.17 ± 39.84 s) ($t(39) = 0.935$, $p = .355$; $d = .239$); PA technique vs S ($t(39) = 1.192$, $p = .063$; $d = .505$). Like pre-evacuation performance, a significant difference is found in the evacuation time variances (Figure 4b) between C technique and S ($F(1,65)=18.81$, $p < .001$) and between PA technique and S ($F(1,62)=18.05$, $p < .001$).



a) Pre-evacuation times from the alarm. *b) Evacuation times from the alarm.*

Fig. 4. Scatter plots by level of assistance. Each dot represents a child: circles are infants (<12 months); triangles are young toddlers (1-2 years) and squares are older toddlers (2-3 years). Categorical variables in x axis are C= children who were carried by staff members, PA= children who needed continuous physical support (adult handholding or bodily contact) and S= children who carried out self-preservation.

Table xx summarizes statistical results for better visualization.

Variable	**Comparison**	**Test**	**H_0*:**
Pre-evacuation time	C technique-PA technique	Welch's t-test	F
Pre-evacuation time	C technique-S	Welch's t-test	F
Pre-evacuation time	PA technique-S	Welch's t-test	F
Pre-evacuation time	C technique-PA technique	Levene's test	R
Pre-evacuation time	C technique-S	Levene's test	R
Pre-evacuation time	PA technique-S	Levene's test	R
Travel speed	C technique-PA technique	Welch's t-test	R
Travel speed	C technique-S	Welch's t-test	R
Travel speed	PA technique-S	Welch's t-test	F
Evacuation time	C technique-PA technique	Welch's t-test	F
Evacuation time	C technique-S	Welch's t-test	F
Evacuation time	PA technique-S	Welch's t-test	F
Evacuation time	C technique-PA technique	Levene's test	R
Evacuation time	C technique-S	Levene's test	R
Evacuation time	PA technique-S	Levene's test	R
* F=fail to reject (no significant difference); R= rejected (significant difference)			

Fig. XX. Summary of statistical results. S= self-preservation (no physical assistance); PA technique= physical assistance (handholding and/or bodily contact); C technique= carrying.

Child/adult ratio. We additionally explored the relationship between child/adult ratio and evacuation outcomes (pre-evacuation time and evacuation time). Correlations were assessed by Spearman's rank correlation coefficient (rho). Infants pre-evacuation times showed a moderate correlation with child/adult ratio (

As expected,

the association of child/adult ratio and evacuation time for infants was significant (r_s=0.467, p(2-tailed) =0.026) whereas the associations for young toddlers and older toddlers were not (young toddlers r_s=-0.170, p(2-tailed) =0.292; older toddlers r_s=-0.170, p(2-tailed) =0.292)

Spearman's Rho test was used to measure the strength of association between child/adult ratios and pre-evacuation and evacuation times.

4 Discussion

We investigated the evacuation of ninety-four very young children during five evacuation trials in a day-care centre. Each child was treated as providing independent data in our study. Evacuation capability and the related evacuation variables were measured and pooled for subsequent analysis. Although this study is exploratory and interpretative in nature, it provides an important opportunity to advance in our understanding of the evacuation involving very young children.

At what age children are capable to accept instructions from staff members and evacuate by their own? Our results here confirm that self-preservation is age-dependent. Older toddlers (2-3 years old) are more likely to self-preservation than young toddlers (1-2 years old). However, we emphasize that 34 % of young toddlers were observed evacuating by their own (i.e. they only received verbal instructions from the staff members), and 23 % of older toddlers needed assistance. These pieces of evidence are consistent with previous findings [42] and contrast with age limits (e.g. 30-36 months) suggested by some experts [5] also used by fire safety codes [22, 23]. The current results, therefore, put us in the position to infer that age plays a central role, but it is not the unique variable to consider. It, therefore, remains an open question for further research to investigate other factors that may also impact on toddler's capability to protect themselves from emergencies. For instance, some experts indicate that, by the age of 42 months, children can react without being upset in case of an emergency [5]. In our study, only two children (one 2-3 years old and one 1-2 years old) were upset when heard the fire alarm and consequently they had to be carried by staff members. In addition, we find no relationship between gender and self-preservation. Female and male toddlers are equally likely to evacuate by themselves. It would be interesting for future research to explore the relation between individual skills (e.g. gross/fine motor, language/understanding and learning) - as every child develops differently - and response to different stimulus (e.g. fire alarm systems, instruction from adults with whom children are not familiar) under different evacuation conditions (e.g. using unfamiliar escape routes).

What impact does self-preservation have on the evacuation process? While limited to a simple scenario (a small day-care centre), the current study can help to draw conclusions about the potential impact of self-preservation on children evacuation. Previous studies claimed differences

in travel speed between children 0-2 years old and children 3-6 years old (i.e. the average travel speed increases with age) [7, 42]. However, we find that travel speed does not differ greatly between young toddlers (1-2 years) and older toddlers (2-3 years). There can be two reasons why we may not have observed any significant difference in our measures. First, as noted in the Introduction, children grow and develop at different rates. This null finding may be due to individual variations in motor performance (e.g. walking experience) with no clear differences in groups which were artificially divided by year. Second, our measures might not be sufficient sensitive due to the short travel distances used (between 3 and 12 m). Additional work is needed to confirm these explanations and to further examine the potential effects of age intervals when sampling/analysing groups of children.

Staff members may tend to carry infants and toddlers to speed up evacuation [5]. As expected, C technique is significantly faster than S and PA ones as that speed depends on the adults who carry the children. Importantly the observed ways to assist children across the evacuation trials contrast with results from a previous survey study [5] (Figure 5). The higher percentage of C1 (carrying one child at a time) observed here may indicate that, in practice, staff members try to move as fast as possible. C1 could be also interpreted by staff members as a less risky way to carry children. Note that most children who needed carrying were infants. Another explanation would be the lack of realism perceived by staff members during the evacuation trials. Therefore, they simply dismissed carrying as many children as possible (e.g. C2) at the same time. Of course, on the basis of the data presented here, these explanations are merely speculative. However, these explanations make distinctly different questions for future research.

The current results show no significant difference between S and PA technique in pre-evacuation times. We similarly find no difference between S and C technique. The time to start evacuation was affected by decisions and actions of staff members (prepare, encourage and/or decide to assist/carry children) as well as the travel distances they had to cover when carrying children. It is argued here that the required holding time for some children who were carried (C technique) was compensated by the required time to prepare and encourage children who evacuated (S) and children who were physically assisted (PA technique). However, the dispersion of pre-evacuation times is significantly greater in C and PA techniques across the trials (see widely scattered values in Figure 4a), which is very much in line with our initial expectation. The first and the last children to start evacuation (before 120 s and after 300 s from the alarm) were either carried or physically assisted (Figure 4a). Similarly, the differences between the evacuation times produced by C and PA techniques and S are not significant. Like pre-evacuation performance, the differences are found in the variances. These results suggest, perhaps surprisingly, that, in some scenarios, 1) the presence of children incapable of self-preservation may not have a great impact on evacuation times and 2) the evacuation of children capable of self-preservation may take longer than expected. Therefore, the adult-child ratios, the travel distances, the assisting techniques and the evacuation procedures are important factors to consider. Additional work is needed to examine the potential effects of these factors on children safety. A reasonable approach to tackle this issue could be to develop and use specialized evacuation models [43].

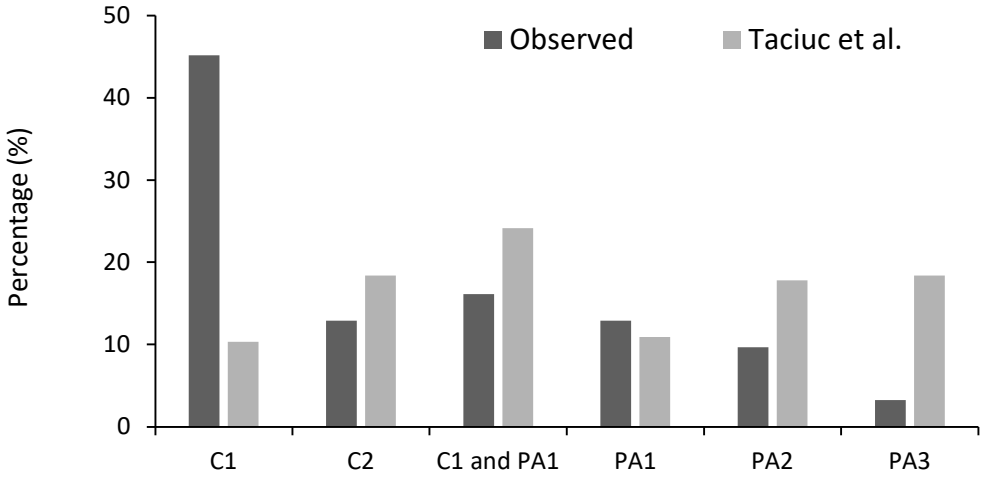


Fig. 5. Comparison of assisting evacuation ways observed across the evacuation trials and those reported by experts in a questionnaire [5]. The question was: In which of the following ways would you be able to assist in the evacuation of a facility? Categorical variables in x axis are: C1= carrying one child at a time; C2= carrying two children at a time; C1 and PA1= carrying one child and holding one child's hand at the same time; PA2.= holding two children's hands at the same time; PA3= holding 3 children's hands at the same time.

The current study has several strengths. First, it adds new insights to the limited literature on children evacuation, which predominantly has been concerned with children >3 years old. Second, the measurement methods used in this study balance observations from evacuation trials (independent measurements of individual performance) with transparency (straightforward to be accurately reproduced or replicated by interested parties). Third, rather than large age groups children were divided by year allowing a more detailed analysis of "how the change develops with age" [42]. Finally, we provide useful information for further safety assessments and evacuation modelling purposes.

The current study also has its limitations. First, the rich but largely uncontrolled setting of the study (i.e. the precise conditions on each day of the trials differed, free decisions and procedures by staff members, lack of realism) may have contributed to the absence of a detailed experimental design. Second, small sample sizes were used (22 infants, 41 young toddlers and 31 older toddlers). Further replication of this kind of observational experiments involving more participants for further meta-analysis is highly desirable. Third, results are limited to horizontal movement through a short and familiar evacuation route (daily used by children) since regulations and guidelines tend to recommend such requirements [44]. Therefore, we did not have the opportunity to measure self-preservation capabilities of children through unfamiliar evacuation routes on stairs. Fourth, the precise age of children was unknown. They were artificially divided into groups by year. For example, two children of similar age (e.g. age of 23 months and 25 months) with similar cognitive and motor skills could have been assigned to different groups.

In conclusion, using observational experiments, the current study has demonstrated evidence of self-preservation capability in very young children. Overall, our findings contrasted with current age limits (e.g. 30-36 months) and provided new insights to consider in safety design and practice. Results presented here helped us to formulate new research questions. This paper also has provided an exciting opportunity to promote the importance and study of toddlers' evacuation.

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