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# Assessing self-preservation capabilities in toddlers during evacuations

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ABSTRACT

The evacuation of vulnerable people is critical and also comprises the evacuation of young children. Although some experts have suggested the age that young children can evacuate themselves without having to be physically assisted, we must acknowledge the fact that the empirical evidence supporting this assertion is limited. In this study, we investigated the performance of 94 children aged 0–3 during five evacuation trials conducted in a day-care centre and confirmed that self-preservation is age-dependent. However, this capability may vary due to individual and developmental differences, for example, one-third of children, aged 1–2 years, evacuated on their own, while approximately one-fifth of children, aged 2–3 years, required assistance. Furthermore, we found no gender differences in relation to self-preservation. The results of this study also suggest that the characteristics of the scenario, namely, adult to child ratios and travel distances, and the decisions and actions of staff members during the pre-evacuation stage, which involved gathering, preparing, and encouraging children, served as factors that affect self-preservation. These findings challenge our current understanding of the impact of self-preservation capability on children's safety.

## 1. Introduction

Children are considered somewhat vulnerable, given the potential limitations associated with their cognitive ability and mobility that can impair their evacuation performance (Cuesta and Gwynne, 2016; Nilsson and Fahy, 2016). Thus, understanding the presence of these limitations and the minimisation of their impact is of crucial importance. Indeed, studies concerning the evacuation of children have been of interest to researchers over the past few years. These studies have been assessed via multiple approaches including survey research (Ozkaya, 2001; Ono and Tatebe, 2004; Taciuc and Dederichs, 2013), literature reviews (Mytton et al., 2017), controlled laboratory experiments (Larusdottir and Dederichs, 2012; Abulhassan et al., 2016, 2018; Li et al., 2020; Bruck, 1999), observational experiments (Cuesta and Gwynne, 2016; Ono, 2012; Kholshevnikov et al., 2012; Hamilton et al., 2017, 2019; Najmanová and Ronchi, 2017; Fang et al., 2019) and the use of modelling and simulation (Klüpfel et al., 2003; Capote et al., 2012; Cuesta et al., 2013, 2017; Liang et al., 2019). On further study, the first evidence gathered from the existing literature is that concerning the different behaviours and movements of children and adults. The second evidence relates to the evacuation performance of children and it is found to be age-dependent; for example, primary school children are likely to move slower but are more compliant with the instructions provided by personnel compared with secondary school children (Cuesta and Gwynne, 2016).

In the last few years, this topic has received considerable research attention, with several studies being concentrated on preschoolers and school-age children. Therefore, the evacuation capability of toddlers, i.e., children aged less than 3 years, has not been an important focus area. To date, there is little agreement on the age at which children are capable of following staff instructions and evacuating on their own. The NFPA 101, Life Safety Code (NFPA 101, Life Safety Code, 2018), and the International Fire Code (International Fire Code, 2018) use 30 months as the reference age for self-preservation. Additionally, teachers in day-care centres and experts in child development suggest 30–36 months as the lower age limit (Taciuc and Dederichs, 2013). They argue that, at this age, most children are considered able to understand and follow simple instructions and walk on a horizontal surface, without physical support, towards exits.

A key aspect to consider is that children grow and develop at different rates (Ficher, 1985; Bartsch and Estes, 1996; Jenni et al., 2013). The prefrontal cortex, which regulates higher cognitive functions such as planning and reasoning, undergoes considerable maturation during early childhood and changes with age (Tsujimoto, 2008; Hodel, 2018; O'Muircheartaigh, 2014; Tierney and Nelson, 2009). According to Piaget and Cook (1952), as children get older, their mental representations of the world become more numerous and elaborate, in other words, children develop self-awareness (Brownell et al., 2007).

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This dictates how children to react to incoming stimuli or information (Rosser et al., 1984). Cultural and social contexts also contribute to differences in the cognitive development of children (Perret-Clermont, 1980; Walker, 2007). Similarly, motor development is fast and is influenced by both sociological factors and genetic factors during early childhood (Piek et al., 2002). Moreover, early walking patterns in children differ (Bertsch, 2004; Hallemans, 2006), and the age at which they begin to walk independently, can vary from one child to another (Ivanenko et al., 2007), especially for children in the age group of 8.5–20 months (Jenni et al., 2013). Therefore, while some very young children are capable of evacuating, others may lack the required cognitive and motor skills, thus needing the intervention of staff members who may need to carry, handhold, or provide continued bodily support.

As previously noted, empirical evidence concerning self-preservation in children is limited. One study identified the potential difficulties faced by preschoolers, aged 3–6 years, in opening doors during an evacuation (Campanella et al., 2011). In another study, the familiarity of children with the evacuation system and procedures was found to be an essential factor in the speed of the evacuation (Murozaki and Ohnishi, 1985). The most outstanding study reported the level of assistance required by children during an evacuation in day-care centres (Larusdottir, 2014). Self-preservation, i.e. no physical assistance (PA), was observed in the initial phase of the evacuation in 20.2% and 85.9% of children aged 0–2 and 3–6 years old, respectively. Note that children aged 0–2 years included children aged 6 months and those about to turn 3 years old. 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 to child ratios on the total evacuation times and by employing simulations for this endeavour.

Although these studies provide useful information to interpret the safety of young children during evacuations, the following questions remain open, namely, at what age are children capable of following staff instructions and evacuating on their own? Furthermore, what impact does this have on the evacuation process? The present study aims to add new data and information, which will help address these questions. We analyse data from 94 children, aged 0–3 years, during five evacuation exercises conducted in a day-care centre between 2013 and 2018. The performance of each child, by age, was observed independently, allowing the opportunity to deduce subject matter to (1) increase our understanding of the vulnerable populations in question, (2) quantify the nature of the vulnerability and (3) provide means to aid model development. 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 during the evacuation. In cases where PA was provided, the cases were divided into two categories (Larusdottir, 2014), namely, being carried and other PA which included adult handholding and bodily contact during the evacuation.

## 2. Method

Ninety-four children participated in the study and comprised 47% male and 52% female subjects. Additionally, none of the children had physical or cognitive impairments. The analysis involved five evacuation trials, as shown in Table 1, and was conducted in collaboration with the health and safety unit of the University of Cantabria. Participants, including staff members and children, were not exposed to any extreme or unusual circumstances, and sensitive information was not gathered during the study. Furthermore, parents were informed about the procedure, the data collection methodology, and the benefits of participating in the study, for which they expressed their consent. The precise conditions on each day of the trials differed. Trials 2 and 4 were conducted in the afternoon and involved fewer participants, which included children and staff members, while old toddlers were absent in trial 5. In addition, the number of children and adults differed across the evacuation trials, as seen in Table 2. However, on average the observed child to adult ratios met the NFPA 101 requirements (NFPA 101, Life Safety Code, 2018) and child to adult ratios recommended by experts in different countries (Taciuc and Dederichs, 2013): infants (mean ± SD = 2.5 ± 1.06); young toddlers (mean ± SD = 4.6 ± 2.21) and older toddlers (mean ± SD = 5.5 ± 3.04).

Fig. 1 illustrates the layout of the day-care building comprising three classrooms, namely C0, C1 and C2, a dining room and a small office. Additionally, only one exit, a double-leaf door 1.7 m wide, was present, as shown in the figure. The evacuation trials were carried out using the following course of action. The director of the centre was made aware of the date and the time of the trial. Next, staff members, all of whom were female, were made aware of the evacuation trial and video cameras were installed on the premises. However, we ensured that staff members had understood that a portion of the study related to how many children could evacuate without help. The cameras were turned on one by one, and staff members were instructed to enter classrooms with their groups of children, as they usually do. Infants, aged less than 12 months, were located in classroom C0, young toddlers, aged 1–2 years, in classroom C1 and older toddlers, aged 2–3 years, were located in classroom C2, as shown in Fig. 2. Next, children and staff engaged in routine activities in the classrooms, like playing and listening to a story. After 15 min, an ignited piece of paper was used to activate a smoke detector in the technical room, as shown in Fig. 1.

Consequently, the fire alarm was activated, and the situation was verified by the director through the fire control panel. Staff members then began the evacuation either by encouraging children to evacuate or by assisting or carrying them. Although all infants were carried by the teachers, the toddlers were given instructions to evacuate, and staff members decided to assist or carry toddlers who did not evacuate on their own. Children were evacuated to the area outside and gathered at a previously determined assembly point. The evacuation trial terminated when all occupants left the building.

Six video cameras were used for data collection. Furthermore, three cameras were positioned inside the classrooms, as seen in Fig. 2, and the other three cameras covered the lobby and exit door, as shown in Fig. 1. Each child’s evacuation capability was determined as a categorical variable, namely, self (S) or assisted (A). We then split the category ‘A’ into two observed techniques, namely, carried (C) or PA, which included adult handholding and bodily contact (Larusdottir, 2014).

We also measured the evacuation variables produced by each category, namely, the pre-evacuation time, travel speed, and evacuation time. The video-recordings, collected at 30 frames/s, were analysed frame by frame. The pre-evacuation time was defined as the frame in which the alarm was activated to when each child began the evacuation, whether alone or with a staff member. To determine the travel speed, we divided the floor plan into a grid of squared cells ($0.3 \times 0.3$ m) using CAD drawings to track individual trajectories and measure the travel distances, as shown in Fig. 3, which were divided by the time taken to cover the distance, i.e. between frame A and frame B. The evacuation time was referenced using a specific frame when the body of each child crossed the exit door and began when the alarm was activated. The exact frames were noted, transcribed into a spreadsheet and converted to seconds.

The categorical variables were compared using Fisher’s exact test and the 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 measured evacuation variables, from which the following $p$-values were obtained. For travel speed: S, $p = .544$, C, $p = .823$, and PA, $p = .359$. For pre-evacuation time: S, $p = .430$, C, $p = .139$, and PA, $p = .056$. For evacuation time: S, $p = .474$, C, $p = .121$, and PA, $p = .086$. Data samples did not differ significantly from that of a normally distributed sample. Therefore, parametric tests were considered. We then conducted Levene’s test for equality of variances, and the requirement of

**Table 1**
Basic information concerning evacuation trials.

| 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 2**
Observed child to adult ratios in the evacuation trials.

| Trial | Child to 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 | – |

homogeneity was not met in some comparisons. Consequently, Welch's *t*-test was used. We also conducted the Mann-Whitney test to compare small samples containing less than 25 data points. The correlation between child to adult ratios and the evacuation process was analysed using Spearman's rank correlation coefficient, rho. An alpha level of 0.05 was used for all statistical tests. The datasets in this study are available from the authors upon request.

## 3. Results

### 3.1. Self-preservation

#### 3.1.1. Age

As expected, all infants were carried during the evacuation, as seen in Table 3. Older toddlers were more likely to exhibit self-preservation than young toddlers (77.41% vs 34.14% respectively, $p < .001$, Fisher's exact test).

#### 3.1.2. Gender

Since each child was identified by gender, we further explored whether gender might be relevant for self-preservation. A chi-square test of independence showed no significant association between gender and self-preservation capability in toddlers (1, $N = 71$) = 0.20, $p = .655$.

#### 3.1.3. Reaction to the alarm

Among the 94 children, two children, namely 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 were carried by staff members.

### 3.2. Evacuation performance

#### 3.2.1. Travel speed

Data from three children who walked erratically, and six children who ran, were removed. As a result, the travel speeds of 29 children were included in the final analysis. The median travel speeds of young toddlers and older toddlers were 0.63 m/s and 0.66 m/s, respectively, as seen in Fig. 4a. Moreover, the distributions of the two groups did not differ significantly (Mann-Whitney $U = 75$, $n_1 = 11$, $n_2 = 18$, $p = .289$; $d = 0.409$). The travel speed is, on average, faster for technique C (*mean* ± *SD* = 1.33 ± 0.41 m/s) than PA (*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) ($t(37) = 7.387$, $p < .001$; $d = 1.997$), as shown in Fig. 4b. As expected, this difference is not significant between techniques PA and S ($t(49) = -1.442, p = .155$; $d = 0.395$). It should be noted that techniques C and PA involve a limited number of children, assisted by a staff member. The observed

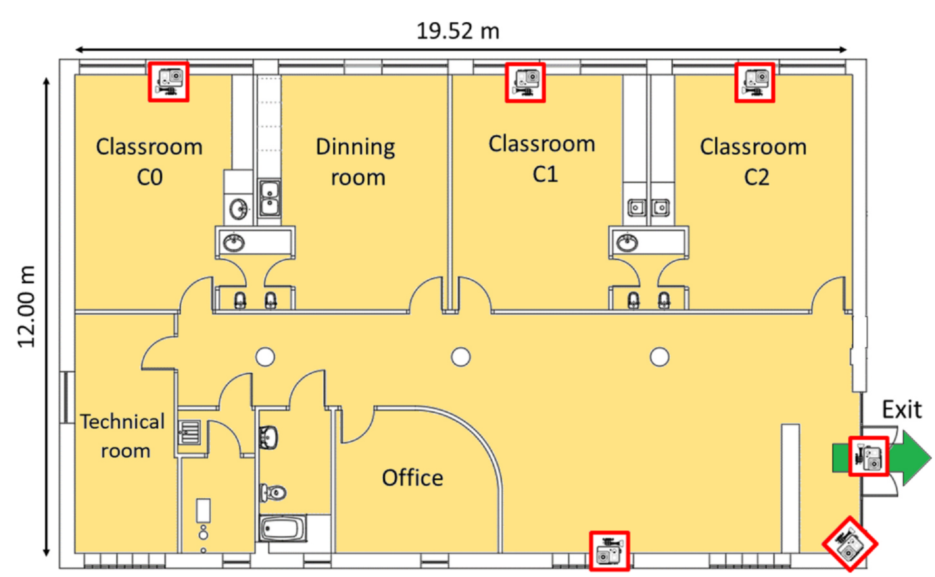



**Fig. 1.** Layout of the kindergarten building and video-camera positions.

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

frequencies of evacuation assistance across the trials are C1, which represents carrying one child at a time (45.16%), C2, which represents carrying two children at a time (12.90%), C1 and PA1 represent carrying one child and holding one child's hand at the same time (16.13%), PA2 represents holding one child's hand (12.90%), PA2 represents holding two children's hands at the same time (9.68%), and PA3 represents holding 3 children's hands at the same time (3.23%).

### 3.2.2. Pre-evacuation time

The comparison of the observed pre-evacuation times, as seen in Fig. 4c, shows that technique C (*mean* ± *SD* = 197.90 ± 78.39 s) does not differ significantly from PA (*mean* ± *SD* = 208.93 ± 65.53 s) ($t(53) = -0.752$, $p = .569$; d = 0.152) and S (*mean* ± *SD* = 185.28 ± 42.26 s) ($t(40) = 0.784$, $p = .437$; $d = 0.200$). Similarly, the difference between techniques PA and S is not significant (Welch's $t(41) = 1.647$, $p = .107$; $d = 0.473$). Therefore, the results when comparing different conditions, namely C, PA and S, do not meet the conditions for statistical significance. However, pre-evacuation times produced by the techniques C and PA are more dispersed than those produced by S (Figs. 4c and 5a). The amount of variation systematically differs between techniques C and S ($F(1, 65) = 15.00$, $p < .001$) and between techniques PA and S ($F(1, 63) = 15.65$, $p < .001$).

### 3.2.3. Evacuation time

On average, individual evacuation times produced by different levels of assistance did not differ significantly, as seen in Fig. 4d. This was observed in comparisons of techniques C (mean ± SD = 214.12 ± 78.74 s) vs PA (mean ± SD = 225.76 ± 62.78 s) ($t(52) = -0.608$, $p = .273$; $d = 0.163$), techniques C vs S (mean ± SD = 199.17 ± 39.84 s) ($t(39) = 0.935$, $p = .355$; $d = 0.239$), and techniques PA vs S ($t(39) = 1.192$, $p = .063$; $d = 0.505$). Likewise, for pre-evacuation performance, a significant difference was found in the evacuation time variances, as seen in Figs. 4d and 5b, between techniques C and S ($F(1, 65) = 18.81$, $p < .001$) and between techniques PA and S ($F(1, 62) = 18.05$, $p < .001$).

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

| | 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 4 summarises statistical results to provide an overall view for readers.

### 3.2.4. Child to adult ratio

We also analysed the relationship between child to adult ratios and the resulting evacuation parameters, namely, pre-evacuation time and evacuation time. The correlations were assessed by employing Spearman's rank correlation coefficient, rho. The child to adult ratio was found to be positively correlated with the pre-evacuation time ($rho = 0.483$, $p = .026$) and evacuation time ($rho = 0.466$, $p = .032$) for infants. The other correlations analysed for toddlers did not show statistical significance (pre-evacuation time $rho = -0.202$, $p = .091$; evacuation time $rho = -0.12$, $p = .317$).

## 4. Discussion

We investigated the evacuation of 94 very young children during five evacuation trials in a day-care centre. Each child was treated as an independent data source in our study. The evacuation capability and related evacuation variables were measured and pooled for subsequent analysis. Although this study is exploratory and interpretative, it provides a valuable opportunity to advance our understanding of evacuations involving young children.

*At what age are children capable of accepting and following instructions*

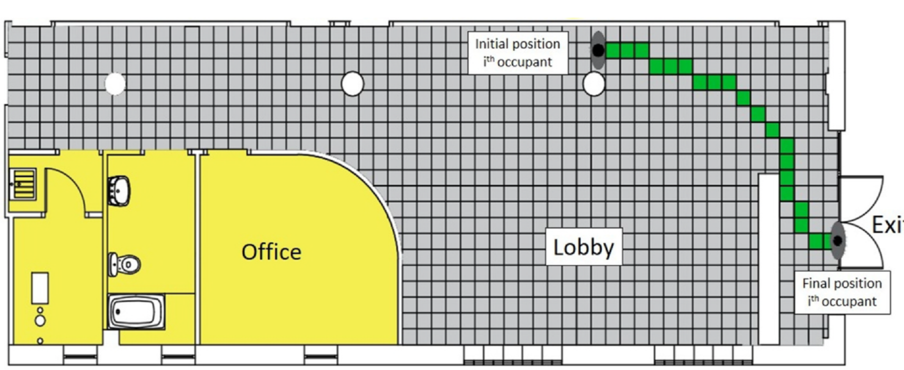



**Fig. 3.** Grid of squared cells used to track individual trajectories.

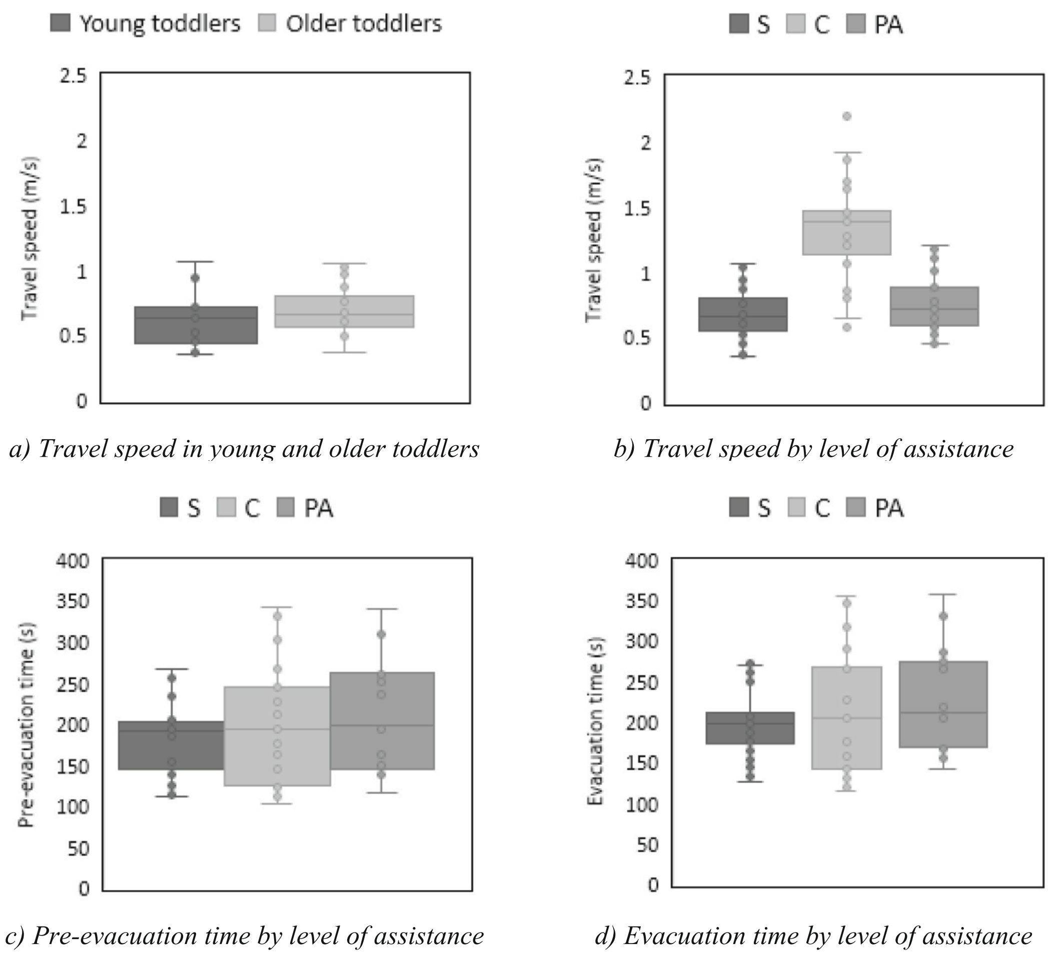


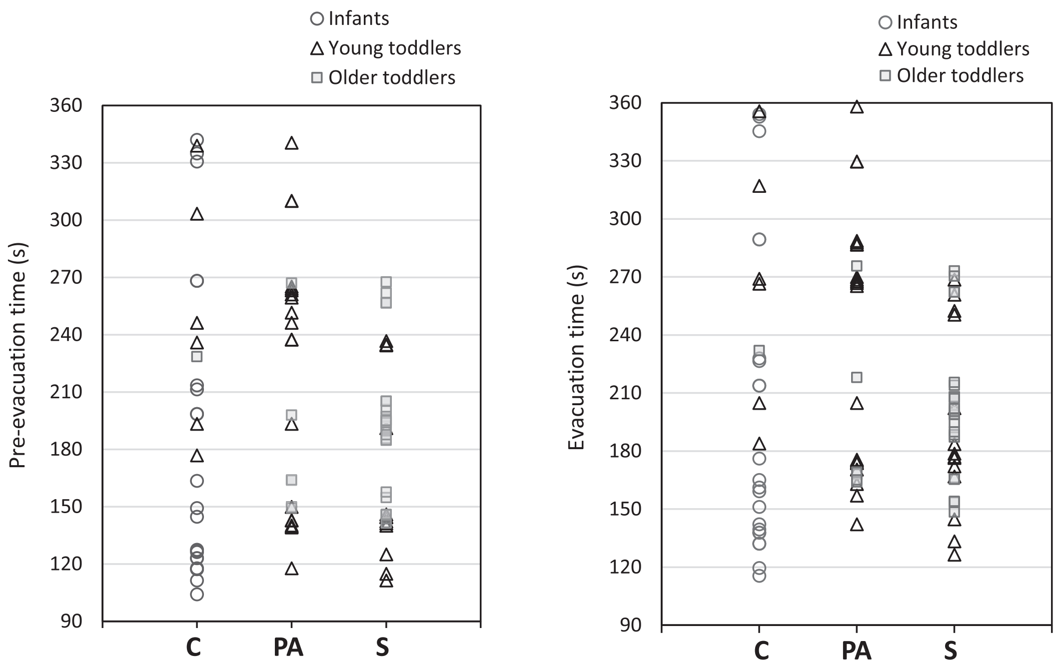

**Fig. 4.** Box plots of evacuation variables. Young toddlers (1–2 years old). Older toddlers (2–3 years old). S = children who demonstrated self-preservation; C = children who were carried by staff members; PA = children who needed continuous physical support, either adult handholding or continuous bodily contact.

*from staff members and evacuating on their own?* Our results confirm that self-preservation is age-dependent. Older toddlers, aged 2–3 years, are more likely to exhibit self-preservation than young toddlers, aged 1–2 years. However, we emphasise that 34% of young toddlers were observed evacuating on their own, i.e. they only received verbal instructions from staff members, and 23% of older toddlers needed assistance. These pieces of evidence are consistent with previous findings (Larusdottir, 2014) and contrast age limits, for example, 30–36 months, suggested by some experts (Taciuc and Dederichs, 2013) and used by fire safety codes (NFPA 101, Life Safety Code, 2018; International Fire Code, 2018). The current results, therefore, enable us 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 a toddler's ability to protect themselves during emergencies. For instance, some experts indicate that, by the age of 42 months, children can react without being upset in the case of an emergency (Taciuc and Dederichs, 2013). In our study, only two children, one aged 2–3 years and the other aged 1–2 years old, were upset when exposed to the fire alarm and consequently, had to be carried by staff members.

Additionally, we found no relationship between gender and self-preservation; in other words, female and male toddlers are equally likely to evacuate by themselves. It would be interesting for future research to explore the relationship between individual skills and responds to different stimuli under different evacuation conditions.

*What impact does self-preservation have on the evacuation process?* While limited to a simple scenario, such as a small day-care centre, the current study can help conclude the potential impact of self-preservation on children's evacuation. Previous studies claimed differences in travel speed between children aged 0–2 years and children aged 3–6 years old, i.e. the average travel speed increases with age (Larusdottir and Dederichs, 2012; Larusdottir, 2014). However, we found that travel speed does not differ significantly between young toddlers, aged 1–2 years and older toddlers, aged 2–3 years old. 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, such as walking experience, with no apparent differences in groups which were artificially divided by year. Second, our measures might not be sufficiently sensitive owing to the short travel distances used, which ranged between 3 and 12 m. Additional work is needed to confirm these explanations and examine the potential effects of age intervals when sampling and analysing groups of children.

Child to adult ratios has been reported to be associated with the evacuation process of infants. However, correlations for toddlers were not significant. These results suggest that the number of staff members is relevant when children are incapable of exhibiting self-preservation. Staff members may tend to carry young children to speed up the evacuation process (Taciuc and Dederichs, 2013). As expected, technique C is significantly faster than S and PA as speed depends on the adults who carry the children. Notably, the observed methods of assisting children across evacuation trials contrast with the results from a previous survey study (Taciuc and Dederichs, 2013), as seen in Fig. 6.




*a) Pre-evacuation times, since alarm activation*  *b) Evacuation times, since alarm activation*

**Fig. 5.** Scatter plots by level of assistance. Each dot represents a child, where circles represent infants less than 12 months old, triangles represent young toddlers aged 1–2 years, and squares represent older toddlers aged 2–3 years. Categorical variables on the x-axis are C which represents children who were carried by staff members, PA which represents children who needed continuous physical support, namely, adult handholding or bodily contact and S which represents children who exhibited self-preservation.

**Table 4**
Summary of statistical results. S represents children that exhibited self-preservation, i.e., required no PA; PA represents children that required physical support, either via handholding or bodily contact; and C represents children that were carried.

| Variable | Comparison | Test | $H_0$* |
|---|---|---|---|
| *Pre-evacuation time* | C – PA | Welch's *t*-test | F |
| *Pre-evacuation time* | C – S | Welch's *t*-test | F |
| *Pre-evacuation time* | PA – S | Welch's *t*-test | F |
| *Pre-evacuation time* | C – PA | Levene's test | R |
| *Pre-evacuation time* | C – S | Levene's test | R |
| *Pre-evacuation time* | PA – S | Levene's test | R |
| *Travel speed* | C – PA | Welch's *t*-test | R |
| *Travel speed* | C -S | Welch's *t*-test | R |
| *Travel speed* | PA – S | Welch's *t*-test | F |
| *Evacuation time* | C -PA | Welch's *t*-test | F |
| *Evacuation time* | C – S | Welch's *t*-test | F |
| *Evacuation time* | PA – S | Welch's *t*-test | F |
| *Evacuation time* | C – PA | Levene's test | R |
| *Evacuation time* | C – S | Levene's test | R |
| *Evacuation time* | PA – S | Levene's test | R |

* F = fail to reject (no significant difference); R = rejected (significant difference).

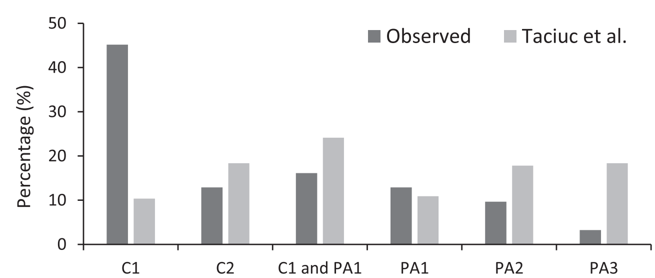



**Fig. 6.** Comparison of assisted evacuation observed across evacuation trials and those reported by experts in a questionnaire (Taciuc and Dederichs, 2013). The question posed was: In which of the following ways would you be able to assist in the evacuation of a facility? Categorical variables along the 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), and PA3 (holding 3 children's hands at the same time).

The higher percentage of C1, which refers to carrying one child at a time, observed here may indicate that, in practice, staff members try to move as fast as possible. Technique C1 could also be 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, in the case of C2, at the same time. Of course, based on the data presented here, these explanations are merely speculative. However, these explanations pose distinctly different questions for future research.

The current results show no significant difference between techniques S and PA concerning pre-evacuation times. We similarly find no difference between techniques S and C. The time at which the evacuation was started was affected by decisions and actions of staff members, namely gathering, preparing, encouraging and deciding to assist or carry children, as well as the travel distances they had to cover while carrying children. It is argued here that the required holding time for some children who were carried, namely technique C, was compensated by the required time to prepare and encourage children who evacuated, namely technique-S, and children who were physically assisted, namely technique PA. However, the dispersion of pre-evacuation times is significantly higher in techniques C and PA across the trials, as seen in Fig. 5a, which is very much in line with our initial expectation. The first and last children to being evacuating, either before 120 s and after 300 s from the time the alarm was activated, were either carried or physically assisted, as seen in Fig. 5b. Similarly, the differences between the evacuation times produced by techniques C and PA and S are not significant. Likewise, for the 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 exhibiting self-preservation may not have a significant impact on evacuation times and (2) the evacuation of children capable of self-preservation may take longer than expected. Therefore, the adult to child ratios, travel distances, assisting techniques and evacuation procedures are important factors to consider. Additional work is needed to examine the potential effects of these factors on child safety. A reasonable approach to tackle this issue could be to develop and use specialised evacuation models (Cuesta et al., 2016).

The current study has several strengths. First, it adds new insights to the limited literature on child evacuation, which predominantly has been concerned with children aged more than 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" (Larusdottir, 2014). Finally, we provide useful information for further safety assessments and evacuation modelling purposes.

The current study also has its limitations. First, the rich but mostly uncontrolled setting of the study, i.e. the precise conditions on each day of the trials differed, free decisions and procedures conducted by staff members, and lack of realism, may have contributed to the absence of a detailed experimental design. Second, small sample sizes were used, which comprised 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, which is used daily by the children, since regulations and guidelines tend to recommend such requirements (Guide to Human Behavior in Fire, 2017). Therefore, we did not have the opportunity to measure the self-preservation capabilities of children through unfamiliar evacuation routes, for example, using the stairs. Fourth, the precise age of children was unknown. They were artificially divided into groups by year. For example, two children of similar age, namely 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, namely 30–36 months, and provided new insights to be considered in safety design and practice. The results presented here helped formulate new research questions. This paper also provided an exciting opportunity to promote the importance and study of toddlers' evacuation.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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