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Human behaviour during evacuation of primary schools: Investigations on pre-evacuation times, movement on stairways and movement on the horizontal plane

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ABSTRACT

Children are a vulnerable group in society and less is known about their characteristics during evacuation than that of adults. This may lead to fire safety design of child centric buildings that fail to account for or acknowledge accurately the characteristics of children. Previous studies have indicated a distinction between adults and children in response to fire cues, however, the existing child specific literature lacks the depth required to provide certainty in design assumptions. This paper focuses on the human behaviour of children during evacuation. The key aim is to contribute to the limited existing data on the pedestrian dynamics and behavioural actions of children during an evacuation. Data from twelve full scale evacuations of four primary schools (educating children aged 4–12) is analysed. As might be expected, longer pre-evacuation times were obtained for classes accommodating younger children. A reduction in pre- evacuation times was observed through repetition of evacuation drills. The movement characteristics of children on the horizontal plane and on stairways were found to be influenced by age, and variances in travel speeds within each class group were observed. On stairways children in the lower classes moved slower and were more cautious than older children. Interestingly, it was more common for groups to be led by a pupil, resulting in faster movement speeds than those led by an adult. Observations and analysis are further discussed along with directions for further research.

1. Introduction

Children are considered a vulnerable group in society with respect to fire safety and comprise of 21% and 25% of the population in the UK and Ireland respectively [4]. In Ireland 12.5% of the population are within the age range for primary school education [4]. Hence, the primary school setting provides an obvious concentration of children in the younger age ranges leading to the proposition: Are primary schools fire safe? A question requiring more investigation and empirical data to draw conclusions.

Significant research has been undertaken over the past 30 years in the area of human behaviour in fire, to garner a greater understanding of the human involvement and interaction with the fire. However, research conducted in the area of the evacuation of children is limited and research that has been undertaken [2,5–18] has suggested that age is factor and variable in the movement parameters of children. In addition, the cognitive ability of children, especially in the lower age ranges, does not equate to the cognitive functioning of an adult, leading to the possibility of unpredictable decision making.

This paper endeavors to broaden the existing data on the human behaviour of children in fire, making comparisons to existing relevant studies, in the hope that greater knowledge shall draw attention to this vulnerable group and the salient need for acknowledgement of the characteristics of children in the design of buildings.

2. Justification

The advent of performance fire codes and application of fire safety engineering to achieve fire safe designs has driven the need for research in physical and behavioural human factors that are prevalent during a building evacuation. This is critical in vulnerable populations and research by Boyce et al. [19–22] in the area of persons with impairments was notable for this sub-group of society. Children are deemed vulnerable due to reduced cognitive and physical capabilities when compared to an adult.

In comparison to adults, the pre-frontal cortex is the part of the brain engaged for coordinated response and is not fully developed in a child's brain to allow decisions based on a behavioural process of perception, cognition and action [23]. The amygdala region of the brain which perceives emotions and controls aggression is more active in the

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decision making of children and adolescences, leading to more erratic decisions and a greater chance of nonadaptive behaviour.

Jones and Randall [24] indicated that 40% of a control group of children aged between 7 and 15 displayed emotion-focused coping in response to a simulated fire emergency scenario, suggesting that these children interpreted the scenario as one from which they could not escape. Ono and Tatebe [25] surveyed students in Brazil aged between 11 and 14. Of those surveyed, 71% declared that they would be capable of effecting escape without assistance. However, when asked to plot their escape route on a plan only a third of the same group indicated the correct route.

Whilst lessons have been learned and misconceptions of human behaviour in fire established from real fire situations [26,27], research with respect to children from behavioural and physical science perspectives has been focused on review of evacuations drills [1,10,12–14,17,18,28], questionnaires [25] and comparisons to microscopic models [2,11,15,16,29–31]. This work must be continued to ensure the characteristics of children are a factor of the design of any building, especially in the case of children centric buildings, such as schools.

2.1. Background research

Seminal literature in the field of pedestrian dynamics and human behaviour in fire by Fruin [32], Predtechenskii and Milinskii [33], Nelson and Mowrer [34], and Proulx [3], have provided guidance for designers for incorporating human factors into fire engineering solutions and are used within this paper in comparison to data obtained for children.

The pre-evacuation phase of the evacuation timeline [35] is an important consideration in any performance based solution and has been shown in studies to be the most significant portion of the evacuation [36,37]. Evacuation drills can provide important data on pre-evacuation times [3], however, drills must be unannounced to provide a realistic scenario, where upon receipt of fire cues, occupants or the responsible person make decisions based on a behavioural process [23]. Factors such as the presence of a fire warning system [6,13] and the actions of the teachers [2] have been indicated as factors of the pre-evacuation time.

A study by Kholshchevnikov [5] provided data for travel speed on the horizontal plane, of children in the age range of 3–7 and indicated a sequential increase in travel speed correlating with an increase in age. This is consistent with Lárusdóttir [10] who presented similar increases in the age ranges 0–2 and 3–6. A study by Ono [1] on the walking speed of children in elementary schools provided data for children across the age range 6–14. The speeds were determined by monitoring the first and last pupil of each class when passing points along the evacuation route. A general trend of an increase in speed with age was presented and these results shall be used for comparisons in this paper.

Kholshchevnikov [5] also presented data for travel speeds on stairways and indicated an increase in speed with age between two age groups: 4–5 and 5–7 year olds. This is consistent with Capote [2], who provided comparisons between children in pre-school, primary and secondary school education. With the greatest variance noted between pre-school and primary school children, this suggests that children in the lower age ranges are slower and as a result may be more vulnerable in an evacuation. Lárusdóttir presented data on vertical movement in elementary schools in the age range of 6–15 [14]. She indicated that children in the lower age ranges, up to the age of 12, move slower than adults and that the younger children in elementary schools have travel parameters more in common with pre-school children than other school children.

In calculating the specific flow of adults through an exit component, the inclusion of a boundary layer was discussed by Fruin [32] and Predtechenskii and Milinskii [33] to allow for lateral sway and this is represented in Nelson and Mowrer's flow curve [34], which indicates a maximum specific flow at a density of 1.9 persons/m^2 and a cessation of flow at a density of 3.77 persons/m^2. Depending on age, children occupy less than half of the floor space required by an adult [33], hence the flow rates of children vary significantly from adult data. This was indicated by Kholshchevnikov [5], who obtained a maximum flow rate of 3.8 persons/m/second at a density of 10–11 persons/m^2. Additionally, Lárusdóttir [13] obtained a maximum flow rate above 3 persons/m/second at a density of 5 persons/m^2 and observed that children were capable of escaping two a breast even in single doorways of 700 mm clear width, contrary to the theory of the boundary layer.

3. Experimental method

This paper is part of a wider study on fire safety and evacuation of primary schools being undertaken by the authors pursuant to an M.Sc. Degree, and focuses on pre-evacuation times and both horizontal and vertical movement of children during evacuations of primary schools. In Ireland, primary school children are in the age range 4–12, comprising of 8 no. class groups with a maximum teacher to pupil ratio guideline of 1:27, although individual classroom ratios may be higher. In accordance with ethical approval conditions, the specific ages of each pupil was not recorded, however, the average age of each class was considered and is indicated in Table 1 below.

3.1. The setting

Four schools located in Co Donegal, Ireland were chosen and permission to conduct the research was obtained from the school gatekeepers. Ethical approval was obtained from Institutes research ethics committee. Ethical safeguards and procedures must be an early consideration for any researcher conducting research involving children. Parental consent was obtained for each child using the passive approval method, where informed consent letters were sent to each parent affording the opportunity to withdraw their child from the study.

The size, age and design of the building were a consideration when selecting subject schools. School A, B and C, as shown in Fig. 1(a) and (b), were constructed between 2007 and 2008 and are of generic repeat design with near identical layout, although mirrored in one case. School D, as shown in Fig. 2(a) and (b), was constructed in 1982 and was not subject to compliance with building regulations, which were first introduced in Ireland in 1991.

3.2. Data collection and analysis

A survey of each building was undertaken in advance of the first drill to determine the location of cameras and necessary setup equipment. A total of 10 no. digital video cameras, with wide angled lenses where necessary, were used to record the evacuations. Cameras were mounted using varied equipment to ensure that the fabric of the building was not damaged. Suction cups, pipe clamps, pressure bars, command strips, tripods and bespoke stands were used to hold cameras in place. The camera locations were selected to provide a broad spectrum of the data required. Each final exit door and each classroom door were seen as a priority to obtain overall evacuation times and pre-evacuation times. Upon completion of each drill, the data from each camera was downloaded onto an encrypted storage device. The videos were analysed using PowerDirector 14 at a

Table 1
Average age of each class group.

Class	J. Infants	S. Infants	1st	2nd	3rd	4th	5th	6th
Age	5	6	7	8	9	10	11	12