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# Physical and cognitive capabilities of children during operation and evacuation of a school bus emergency roof hatch

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ABSTRACT

While many school bus routes exclusively transport kindergarten, first, and second grade (K-2) children, school bus emergency exits are designed based on the physical capabilities of an average adult male. This makes the usability of emergency exits less than optimal for K-2 children. The objective of this study was to determine if children in (K-2) are capable of opening and evacuating from a school bus roof hatch in an emergency rollover scenario. Maximum push force exertions of 91 K-2 students were measured during operation of a typical school bus emergency roof hatch (designed to meet Federal Motor Vehicle Safety Standard [FMVSS] No. 217 specifications). Ability to read and comprehend emergency-related words and roof hatch operating instructions was also evaluated for 58 students. Forty-two percent (42%) of kindergarten students were unable to exert the maximum permissible design force (89 N) necessary to operate the roof hatch. Only 20% of the participants in kindergarten were able to open the roof hatch. In a controlled environment, the majority of students (96%) were willing and able to self-extricate through the opening. However, only 33% of students had the cognitive skills necessary to understand how to open the roof hatch. Eighty-nine percent (89%) of participants who completed both the physical and cognitive aspects of the study were unable to successfully operate the school bus roof hatch.

## 1. Introduction

School buses in the United States transport approximately 26 million children daily. Despite being the safest mode of student transportation, approximately 26,000 school bus accidents occur every year (NASDPTS, 2000; McCray and Brewer, 2005). While emergency evacuation training is performed twice per year in many school districts across the country (no federal standard exists and state regulations vary), the training is typically focused on evacuating through the front and rear emergency doors of school buses when the school bus is in a standard orientation. School bus rollover accidents are often viewed as the most complex and dangerous type of accidents since occupants are unfamiliar with the rolled-over bus orientation. Roof hatches are one of the primary means of egress for rollover bus accidents (Matolcsy, 2010) with strength and stature being factors affecting both usability and egress rates (Pollard and Markos, 2009). Testing the ability of younger school bus riders to self-extricate through a roof hatch is critical for assessing the effectiveness of the current emergency evacuation system, particularly because training is not typically provided during school bus emergency evacuation training (emergency roof hatch evacuation training is rarely performed to prevent students from operating the device during normal transport). For children to operate the roof hatch, they also must be able to read and understand the instructions written on the hatch.

### 1.1. Roof hatch standards

Federal Motor Vehicle Safety Standard (FMVSS) No. 217 specifies that the maximum permissible force allowed to operate the release mechanism of a school bus roof hatch is 89 N or less. These force requirements were developed considering the physical capabilities (including stature) of an average adult male (Pollard and Markos, 2009). The primary occupants of most school buses are young children that do not have the physical capabilities and stature characteristics to meet

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these requirements. In many instances, the bus driver is the only adult on the school bus. Should the driver be incapacitated due to illness, injury, or any other reason, it may be solely up to the children to evacuate the bus until further adult assistance arrives. The difficulty in evacuating passengers from bus accidents influences post-crash injury outcomes (Peden et al., 2004). Therefore, it is important to determine if children in kindergarten through second grade (K-2) have the physical and cognitive capabilities to operate and evacuate through the roof hatch of a rolled-over school bus without adult intervention.

### 1.2. Strength capabilities of children

A Consumer and Competition Policy Directorate of the Department of Trade and Industry study measured the strength of children and adults to provide reference data for use in the design of safer products (Department of Trade and Industry, 2002). Maximum push exertions using two or more fingers of the participant's dominant hand on a (50 mm × 50 mm) plastic cube ranged from 7 N to 35 N for 2–5 year old males ($\bar{x}$ = 27 N, SD = 13), and 36 N to 125 N for 6–10 year old males ($\bar{x}$ = 66 N, SD = 24). Similarly, Peebles and Norris (2003) found that index finger push force on a 20 mm circular diameter force plate ranged from 16 N to 35 N for 2–5 year old males ($\bar{x}$ = 20 N, SD = 5) and 31 N to 62 N for 6–10 year old males ($\bar{x}$ = 52 N, SD = 13).

Based on these two studies, the average push force for young children was lower than the 89 N maximum established in FMVSS No. 217 for roof hatch operation (NHTSA, 2011). Furthermore, the push forces measured in these studies are likely to be higher than that which can be exerted on a roof hatch knob since there is less surface area on which to exert the force (16.3 $cm^2$ for the roof hatch vs. 25.8 $cm^2$ for the plastic cube). Additionally, the location of the force plate in the studies was at the participants' elbow height affording a relatively favorable posture and the potential to use body weight. The relative location of the roof hatch knob for children is much higher (above elbow height) than for adults. An average kindergarten age child would have to reach over their shoulder to push the roof hatch knob, whereas the average adult could use their body weight while pushing on the knob (see Fig. 1).

### 1.3. Cognitive abilities of children

During the early elementary years, children go through substantial cognitive development including increasing the number of items held in their mind after a delay [Gathercole, 1998], updating working memory with new information (Hongwanishkul et al., 2005), and both verbal and nonverbal tasks (Alloway et al., 2004). Reading ability, specifically, goes through rapid development during the elementary years. Children at this stage largely rely on memory of words and are still learning to decode (Ehri, 2008). At this stage, word identification accounts for over half of the variance in reading comprehension. To understand the written instructions on the roof hatch, students must be able to identify or decode each of the words on the hatch. Assuming the children can read the instructions, the next step is for them to be able to understand and follow the instructions. This requires children to "hold" the instructions in their mind as they are acting them out. Currently, there is no research on the abilities of children to read emergency-related words or to understand emergency instructions.

### 1.4. Study aims

The overarching goal of this study was to determine if children in kindergarten, first, and second grade are capable of opening and evacuating from a school bus roof hatch in an emergency rollover scenario. To address this goal, we established two primary aims. The first was to characterize the strength capabilities of children to determine whether they have the ability to operate and exit through the emergency escape roof hatch on a school bus. Specifically, we aimed to determine:

1a. The maximum push force and torque that can be exerted on a roof hatch knob by children in K-2.
1b. Whether K-2 students are able to disengage the release mechanism and open a school bus emergency escape roof hatch.
1c. Whether K-2 students have the physical capabilities to self-extricate through a roof hatch of a school bus in a rolled-over orientation.

The second aim of the study was to investigate if children can read, define, and act out the instructions written on the roof hatch by determining:

2a. If there are grade-related differences in the ability to read emergency-related words and if this differs from non-emergency related sight words.
2b. If there are grade-related differences in the ability to define emergency-related words and if this differs from non-emergency related sight words.
2c. If children can read the roof hatch instructions and follow the

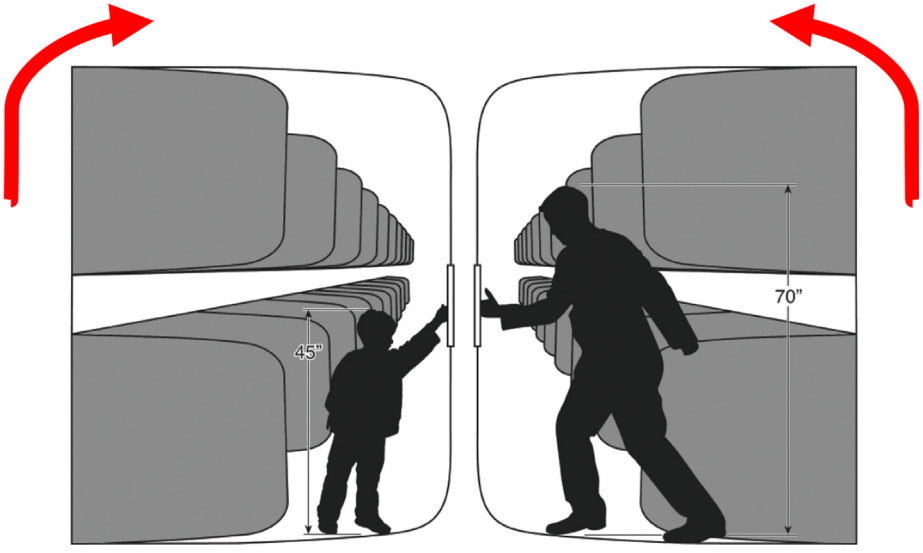


**Fig. 1.** Scaled illustration of rolled-over school bus.