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Using Virtual Reality to Train Children Safe Street-Crossing Skills

David C. Schwebel and **Leslie A. McClure**
University of Alabama at Birmingham

Abstract

Background—Pedestrian injuries are among the leading causes of morbidity and mortality in middle childhood. One limitation to existing pedestrian safety interventions is that they do not provide children with repeated practice needed to develop the complex perceptual and cognitive skills required for safe street-crossing. Virtual reality (VR) offers training through repeated unsupervised practice without risk; automated feedback on success of crossings; adjustment of traffic to match children's skill; and a fun, appealing environment for training.

Objective—Test efficacy of VR to train child pedestrians in safe street-crossing.

Setting—Birmingham, Alabama, USA.

Methods—A randomized controlled trial is underway with an expected sample of four groups of 60 children ages 7-8 (total $N = 240$). One group receives training in an interactive, immersive virtual pedestrian environment. A second receives pedestrian safety training via widely-used video and computer strategies. The third group receives what is judged to be the most efficacious treatment currently available, individualized behavioral training at streetside locations. The fourth group serves as a no-contact control group. All participants are exposed to a range of field- and laboratory-based measures of pedestrian skill during baseline and post-intervention visits, as well as during a six-month follow-up assessment.

Outcome Measures—Primary analyses will be conducted through linear mixed models testing change over time in the four intervention groups. Three pedestrian safety measures will serve as primary outcomes: temporal gap before initiating crossing, temporal gap remaining after crossing, and attention to traffic while waiting to cross.

Clinical Trial Registration—This study is registered at the US government website, www.clinicaltrials.gov, under the title, "Using Virtual Reality to Train Children in Pedestrian Safety", registration number NCT00850759.

Keywords

pedestrian; safety; injury; children; virtual reality; street-crossing

"Using Virtual Reality to Train Children Safe Street-Crossing Skills" is a United States government-funded randomized controlled trial comparing strategies to train 7- and 8-year-old children safe street-crossing skills. We are particularly enthused about one arm of the study, where children are being trained within an interactive and immersive virtual street environment. Below, we outline the rationale for the research, and then present the research hypotheses and methods.

Corresponding Author: David C. Schwebel, Department of Psychology, University of Alabama at Birmingham, 1300 University Blvd, CH 415, Birmingham AL 35294 USA, Phone: (205) 934-8745, Fax: (205) 975-6110, schwebel@uab.edu.

Competing Interest Declaration
The authors have no competing interests to declare.

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Study Rationale

Epidemiology of Children's Pedestrian Injuries

Pedestrian injury is among the leading causes of pediatric unintentional injury in the United States.[1 2] In a single year, 5,300 American pedestrians are killed by motor vehicles and 85,000 others are injured; over one-third of injured pedestrians are children.[2 3] In middle childhood (ages 5-9), about 60% of pedestrian injuries and mortalities occur when the child is crossing a road at or between intersections,[3-6] typically within a half-mile of the child's home[6] and when the child is headed toward a specific destination such as school.[4]

Several studies suggest young children regularly negotiate dangerous street environments alone when going to and from school.[7-9] As reviewed by Rivara and colleagues in 1989,[9] between 40% and 70% of five- to six-year-olds regularly walk to school and play near streets unsupervised. More recent data suggest 48% of 9- to 15-year-old American children who live within a mile of their school currently use "active travel" (including walking, bicycling, or other non-mechanized methods) to get to school at least once per week.[8] Although older children reported slightly higher rates of active travel than younger ones in that study, 43% of 9-year-olds and 45% of 10-year-olds used active travel to get to school. Similarly, a 1998 study in Canada found that 23% of fourth-graders walked alone to school; an additional 34% walked with other pre-teen children.[7] In that same sample, children ages 8-9 crossed a mean of 4.8 streets (SD = 5.3) to walk from home to school.[7]

In summary, young children are frequently injured when crossing streets unsupervised, these injuries occur most often when children are going to or from school, and young children frequently engage in pedestrian environments alone and with same-age peers.

Current Strategies to Train Children in Safe Pedestrian Behavior

In 2002, Duperrex and colleagues conducted a systematic Cochrane Review of randomized controlled trials designed to teach pedestrian safety, and discovered 13 publications targeting child pedestrian safety.[10] Of the 13 publications, only three used broad measures of pedestrian behavior as an outcome measure; the others relied on knowledge assessment, table-top model simulations, or inquiries concerning safe route selection. Most studies had small sample sizes and other limitations. Duperrex and colleagues[10] stated rather bluntly, "the methodological quality of the included trials was generally poor" (p. 1131), and concluded there was only limited evidence that existing behavioral interventions for reducing pediatric pedestrian injury were effective. Little has changed in the interim years, although a few promising interventions have emerged.[11]

Despite the limitations of past research, existing work does offer some indication of how effective various strategies for pediatric pedestrian training could be. Four major training strategies have been attempted: group education, individualized streetside behavioral training, computer-based training, and non-immersive virtual reality training. We review each below.

Group education—Group education is the most cost-efficient option to train children in pedestrian safety. In most studies, groups of children are exposed to a series of classroom lectures[12-14] or streetside lessons on how to cross streets.[15] These strategies, attempted with children at a range of ages (5-12), have proven effective in increasing children's knowledge about pedestrian safety; that is, children are more knowledgeable about safe behavior post-intervention than they were prior to the training. However, available research testing behavioral outcomes of group education strategies (e.g., by observing children crossing actual streets) indicates group education is *not* a successful intervention strategy, especially when behavior is monitored more than a week or two beyond the intervention period.[15] Thus, while group education apparently increases knowledge, that knowledge does not necessarily translate into improved behavior.

Individualized behavior training—One natural extension of group education is to engage in individualized education. This strategy is highly time- and labor-intensive, but shows promise as an effective training strategy.[11 16-19] Two studies used brief streetside training sessions (i.e., 10-15 minutes).[16 17] In both, the children (ages 5-8 in Barton et al.[16] and age 5 in Demetre et al.[17]) demonstrated modest improvement in most measures of pedestrian safety behavior immediately following training. However, Demetre et al. included a long-term follow-up and discovered poor retention of safety practice in the sample of 5-year-olds.[17]

Two other studies used between 4 and 12 training sessions for children as young as age.[18 19] In both reports, training sessions were conducted streetside using actual traffic. Children were taught by semi-professional adults in most cases, and by parents in one arm of Rothengatter's[18] study. Rothengatter's sample[18] was also exposed to a 20-minute audio-visual presentation on pedestrian safety; Young and Lee's[19] included training in one-way traffic for part of the sample, before training in two-way traffic. In all cases and conditions, children showed broad improvement in pedestrian safety in the short term. Available long-term data indicates retention of learning 4 months later.[18]

Together, published data on individualized behavioral training of children in streetside locations is promising. Children as young as 5 years old have demonstrated significant improvement in pedestrian safety through such training programs, and that learning has been retained for 4 months in one sample.[18]

Computer- and television-based strategies—The major drawback to individual-level training is that it is highly time- and labor-intensive, and therefore unrealistic for broad implementation in many school or community center settings. For this reason, researchers have searched for other strategies to teach children pedestrian safety, and especially for training strategies that will not require intense adult supervision of children in dangerous settings but will still give children the requisite practice and repetition at learning the complex cognitive and perceptual task of safe street-crossing.[20-23]

One appealing option is to train children via television programs or computer software. Initial work in this domain relied on videotapes, and found that fourth- through sixth-graders who were exposed to a pedestrian safety film had increased knowledge of pedestrian safety and modestly improved behavior in observed street-crossing near their schools.[21] More recently, research has focused on the efficacy of computer-based training programs. Tolmie and colleagues, for example, used a set of computer-based games, in conjunction with adult- or peer-discussion, to teach 5- through 8-year-old children how to identify safe gaps in traffic.[22] Children who were exposed to the game along with adult discussion demonstrated the most learning; any exposure to the game was superior to control children who did not play the game. There were no tests of translation to real-world environments.

Virtual reality strategies—Virtual reality represents the newest approach to pedestrian safety training. Virtual reality offers several advantages. Its virtual nature allows children to engage in potentially risky situations without exposure to real risk. Virtual environments can be programmed for systematic and predictable delivery of stimuli that is customized to an individual's skill level and learning strategy. Further, VR is highly engaging. Children generally enjoy learning in virtual worlds.

We are aware of two published reports using VR to train children in pedestrian safety.[24 25] In the McComas et al. study, 95 children in grades 4-6 were unobtrusively observed crossing the street to school and then randomly assigned to an experimental (VR training) or control (no training) condition.[24] The VR training group received three trials of crossing 8 intersections in a virtual environment shown on a non-immersive 3-monitor desktop display. The first trial was a pre-training assessment and the third a post-training assessment. The second trial was the critical one: during it, children received verbal feedback from an experimenter on the success of their crossing and the dangerous behaviors (e.g., failing to look left-right-left, failing to stay on the sidewalk) they committed. After the VR training, children were again observed while crossing a street in front of the school. The study was conducted in two schools, one urban and the other suburban. At both schools, children performed significantly better in the post-training virtual environment assessment than they did in pre-training. At the suburban school, children who received the training showed a significant increase in safety while crossing the actual street in front of their school compared to children who did not receive the training; a similar pattern was not observed at the urban school.

In the Thomson et al. study, 94 children ages 7, 9, and 11, were trained during four small-group sessions of 30-40 minutes, scheduled a week apart from each other.[25] Training consisted of work in a non-immersive virtual environment shown on a single computer screen. Children selected traffic gaps for a computerized character to cross within and were given feedback on the safety of crossings. A subset of the children's mothers served as trainers by monitoring children's progress in the computerized environment and offering feedback and lessons that corresponded to situations children encountered in the virtual world. Results suggest the children exposed to the training were safer pedestrians, both immediately post-training and at an 8-month follow-up assessment. The present study extends these early VR studies.

Hypotheses

The overarching aim of the current project is to test the efficacy of virtual reality as a tool to train children, ages 7-8, in safe street-crossing behavior. This aim is being accomplished via a randomized controlled trial with four equal-sized groups of child pedestrians (total $N = 240$). One group receives six 30-minute sessions of interactive training in an existing immersive virtual pedestrian environment. The second group receives six 30-minute sessions of pedestrian safety education via popular computer- and video-based training tools such as the Otto the Auto videotapes and the Walk Smart interactive computer software program. These programs represent the most frequently-used pedestrian safety training strategies in American schools today. The third group receives six 30-minute sessions of individualized behavioral training at streetside locations. Recent literature reviews suggest this type of training may be the most efficacious behavior-based training currently available.[10] The fourth group serves as a no-contact control group.

All four groups are exposed to a range of field- and laboratory-based measures of street-crossing and pedestrian skills during baseline and post-intervention visits, as well as during a six-month follow-up assessment. The project's three specific hypotheses include:

1. Test whether training in a virtual environment improves children's street-crossing skills. We expect the children in the VR training group will show improvement in their street-crossing skills, as measured via three benchmark variables in both field- and lab-based assessments: initiating crossing soon after a safe gap occurs; identifying safe traffic gaps within which to cross; and attending consistently to traffic from both directions. We expect this result to emerge both in repeated-measures comparison of behavior within the group trained in the virtual environment, as well as in comparison to the no-contact control group.
2. Test whether VR techniques are more efficacious in training children in street crossing skills than existing commonly-used television- and computer-based pedestrian

education tools. We expect children in the VR training group will show greater improvement on all three benchmark street-crossing variables than those children in the video/computer training group.

3. Test whether VR techniques are more efficacious in training children in street crossing skills than the most efficacious education strategy identified to date, individualized behavioral training in streetside environments. We expect children in the VR training group will show modestly greater improvement on all three benchmark street-crossing variables than those children trained by an adult in a streetside location.

Methods

Overview

We are conducting a randomized, controlled trial (RCT), with the primary goal of testing the efficacy of virtual reality as a mechanism to train children in safe street-crossing behaviors. Participants are randomly assigned to one of four groups, and then followed through four stages of research: (a) pre-intervention baseline data collection, (b) intervention, (c) post-intervention data collection, and (d) follow-up data collection 6 months post-intervention. The study has been approved by the Institutional Review Board at the University of Alabama at Birmingham.

Participants

Two hundred and forty 7- and 8-year-old children are being recruited from four Alabama communities, selected to represent the racial and socioeconomic diversity in the local area: Fairfield, Midfield, Mountain Brook, and Tarrant. The sample size was selected to detect an effect size of $f = 0.30$ between any two groups for the primary analysis, assuming an overall error rate of 0.05, and power of 95%. In addition, we inflated the sample size to account for an attrition rate of 10%. All parents of participants provide written informed consent, and children provide informed assent, as developmentally appropriate.

General Protocol

Children and their families randomly assigned to an active intervention group participate in 12 sessions: a pre-intervention laboratory session, a pre-intervention field session, 6 training sessions, a post-test laboratory session, a post-test field session, a 6-month follow-up laboratory session, and a 6-month follow-up field session. Children and their families randomly assigned to the no contact control group participate in the pre-test assessments, the post-training safety sessions, and the 6-month follow-up sessions, but do not have the 6 training sessions. Details of all session protocols appear below.

Briefly, during the pre-test sessions, baseline measures of pedestrian safety are collected in both virtual and real (field) environments. Following pre-test assessment, children are randomly assigned to one of four groups: the virtual reality intervention group, the video/computer training group, the streetside behavioral training group, or the no-contact control group. Training in all three active intervention groups is comprised of six sessions, scheduled bi-weekly over 3 weeks. Soon after intervention sessions are complete, post-training pedestrian safety measures are collected during two visits, one in the laboratory and the other in the field. Finally, two 6-month follow-up sessions assess retention of lessons learned.

Protocol: Pre-Training Assessment

Two sessions, one laboratory-based and the other field-based, assess pre-training baseline measures of children's pedestrian abilities. The longer pre-training assessment is held in the UAB Youth Safety Lab. During that visit, children complete 30 crossings within the virtual reality environment, 10 at each of three "difficulty" levels: 25 MPH traffic and light volume

(8 vehicles/minute); 30 MPH traffic and moderate volume (12 vehicles/minute); 35 MPH traffic and heavy volume (16 vehicles/minute), in a randomized order. These trials include practice trials prior to data collection and standardized instructions for children to cross when they perceive the street environment to be safe.

The second pre-training session occurs in the field. Children complete 8 crossings using the “shout” technique,[26] whereby they stand immediately adjacent to the road and shout “now” when they deem it safe to cross. Children also complete 8 crossings using the “two-step” technique,[26] whereby they stand two steps off the curb, and take two steps toward the road to indicate when they deem it safe to cross. Measures of pedestrian behavior derived from the streetside and virtual road simulations are detailed below under the header, “Pedestrian Measures”.

Basic demographic and individual difference characteristics are also collected during pre-training assessments.

Protocol: Virtual Reality Training Group

Children in the virtual reality training group receive street-crossing training in a validated, interactive, immersive virtual street environment.[27] If training is effective in this environment, we plan to conduct further research investigating strategies to disseminate virtual pedestrian safety training into school settings.

Each training session for the virtual reality intervention group is comprised of three segments of 15 virtual crossings each. Children receive computer-generated feedback concerning safety immediately following every crossing. Difficulty of crossing (i.e., density and speed of traffic) are tailored to children’s abilities, with the goal that they succeed on about 85% of trials and that traffic becomes increasingly difficult as success rates improve.

Protocol: Video/Computer Training Group

Children in the video/computer training group are exposed to some of the most popular and widely-used pedestrian training tools in the United States. These tools are commonly implemented in classroom settings, and are recommended and used by several state transportation and education agencies. Such interventions have proven moderately successful in training safe pedestrian skills among small samples of 7- and 8-year-old children in pre-post research designs.[20-22] Example programs include the WalkSafe computer software program (Oregon Center for Applied Research), *Otto the Auto on Pedestrian Safety* (AAA Auto Club), and *Step to Safety with Asimo* (National Safety Council/Honda Motor Company).

Protocol: Streetside Behavioral Training Group

Children in the streetside behavioral training group are exposed to a training program grounded in behavioral theory (e.g., modeling, reinforcing, chaining) and developed from strategies used by Rothengatter,[18] Young and Lee,[19] and Barton and colleagues.[16] Individualized streetside training has proven successful in previous trials with children as young as age 5,[18,19] including in one study that assessed retention four months post-intervention.[18] This control group represents the most efficacious treatment identified to date.

The training foci for children in this group are twofold: (a) attending to traffic in both directions, and (b) selecting safe traffic gaps. During all sessions, the child and adult stand adjacent to each other and to the street. The street is cordoned from the child with yellow “caution” tape to discourage the child from entering traffic. Researchers use a semi-structured and flexible approach to educate children based on each child’s strengths, limitations, and abilities. Specific patterns of verbal interchange replicate those used previously.[16 18] Intervention integrity is monitored.[28]

Protocol: Post-Training Assessment

The post-training assessment parallels the pre-training assessment. Two sessions are conducted, the first in the laboratory (30 crossings in the virtual environment, 10 each at different difficulty levels) and the second in the field (16 crossings, 8 each using the shout and two-step techniques).

Protocol: 6-Month Follow-Up Assessments

The follow-up assessment occurs 6 months following completion of the intervention. The protocol matches the pre- and post-training assessments.

Pedestrian Measures

In all pedestrian simulations (both virtual and streetside), three measures will be used as the primary outcome variables: gap before initiating crossing, gap size available, and attention to traffic.

The temporal gap before initiation of crossing has emerged in the literature as an indicator of cognitive complexity[29 30] and one of the best measures of children's safe pedestrian behavior. Adult cognition while crossing streets is highly honed, and many adults actually anticipate a safe crossing by entering the near lane of traffic before a vehicle passes the far lane. Young children rarely do this. Instead, children apparently do not begin to process the safety of a traffic gap until that gap appears. This causes a significant (e.g., 500-1000 milliseconds) temporal delay before children enter a safe gap. That delay increases injury risk.

Gap size available reflects the size of the gap remaining after children reach the far curb of the street. At one extreme are unsafe gaps – those in which the child is or would have been hit by an oncoming vehicle while crossing. At the other extreme are unambiguously safe gaps – those that are at least equal to twice the temporal gap required to traverse the street.

The third primary measure of pedestrian skill is attention to traffic, as measured by looks to the left and to the right while waiting to cross the street. Head-tracking equipment monitors children's visual attention to traffic from the left and right in the virtual world; it is coded on videotape from field trials.

In addition to the three primary measures, several secondary measures of pedestrian safety are available. These include missed opportunities (instances when a rejected gap is equal to or greater than 1.5 times the participant's crossing time), average wait time (average time waiting to cross the street, divided by number of cars that pass during that waiting), and gap size chosen (gap in time within which the child chooses to cross). In virtual crossings, we also assess "close calls", or instances when the child is nearly hit by a passing vehicle, and actual "hits", or collisions between the avatar and a vehicle.

Statistical Analyses

Primary data analyses will address the study's three specific aims. Specific Aim 1 is to test whether training in a virtual environment improves children's street-crossing skills. Three dependent variables will be used in the primary analysis: gap before initiating crossing, gap size available, and attention to traffic. These variables will be computed by averaging across all trials in the each of the three field tests: pre-intervention, post-intervention, and 6-month follow-up. The three dependent variables will be independently placed into a linear mixed model, in order to assess the relation between the intervention and the changes between each of the time points. We will fit the following model:

$$Y_{ij}=\beta_0+\beta_1 X_{\text{intervention}}+\beta_2 X_{\text{trial}}+\beta_3 X_{\text{intervention}} * X_{\text{trial}}+\varepsilon_{ij}$$

where trial will be entered into the model as a categorical variable utilizing effect cell coding, so that we can determine whether changes in the outcomes between different trials differ by intervention group. Of greatest interest will be β_3, as this parameter will tell us whether or not the effect of the intervention differs between trials. If we find that β_3 is significant, we will perform contrasts to determine which specific trials differ.

Specific Aim 2 is to test whether VR techniques are more efficacious in training children in street crossing skills than existing video- and computer-based pedestrian education tools. Specific Aim 3 is to test whether VR techniques are more efficacious in training children in street crossing skills than streetside behavioral training. These two specific aims will be tested utilizing contrasts in the above model.

We predict the VR will prove superior to the no-contract and video/computer control groups. VR offers the advantages of repeated practice in the cognitive and perceptual skills to be learned; opportunity to view crossings and then receive feedback on safety of crossings; and tailoring of difficulty level to the child’s skill. We predict the VR will prove moderately superior to the individualized streetside training. Individualized training at the streetside is highly time- and labor-intensive for an adult, but offers many of the advantages of VR. This may be why it is the most efficacious training strategy identified to date. It does not, however, offer the advantages of the opportunity to view success (or failure) of crossings, or the ability to tailor traffic to the child’s ability in a highly controlled manner.

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