Using virtual reality to train children in safe street-crossing skills

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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 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 To test the efficacy of virtual reality to train child pedestrians in safe street crossing.
Setting Birmingham, Alabama, USA.
Methods A randomised controlled trial is underway with an expected sample of four groups of 60 children aged 7–8 years (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, individualised behavioural 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 6-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.

Using virtual reality to train children safe street-crossing skills is a US government-funded randomised controlled trial comparing strategies to train 7- and 8-year-old children in safe street-crossing skills. We are particularly enthused about one arm of the study, in which 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.

STUDY RATIONALE

Epidemiology of children's pedestrian injuries

Pedestrian injury is among the leading causes of paediatric unintentional injury in the USA.[1 2] In a single year, 5300 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 (5–9 years), approximately 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 towards 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 *et al* in 1989,[9] between 40% and 70% of 5–6-year-olds regularly walk to school and play near streets unsupervised. More recent data suggest 48% of 9–15-year-old American children who live within a mile of their school use 'active travel' (including walking, bicycling, or other non-mechanised methods) to get to school at least once per week.[8] Although older children reported slightly higher rates of active travel than younger children 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 aged 8–9 years 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 behaviour

In 2002, Duperrex *et al*[10] conducted a systematic Cochrane review of randomised controlled trials designed to teach pedestrian safety, and discovered 13 publications targeting child pedestrian safety. Of the 13 publications, only three used broad measures of pedestrian behaviour 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 *et al*[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 behavioural interventions for reducing paediatric 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 paediatric pedestrian training could be. Four major training strategies have been attempted: group education; individualised streetside behavioural 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 years), have proved effective in increasing children's knowledge about pedestrian safety; that is, children are more knowledgeable about safe behaviour post-intervention than they were before the training. However, available research testing behavioural outcomes of group education strategies (eg, by observing children crossing actual streets) indicates group education is not a successful intervention strategy, especially when behaviour is monitored more than a week or two beyond the intervention period.[15] Therefore, whereas group education apparently increases knowledge, that knowledge does not necessarily translate into improved behaviour.

Individualised behaviour training

One natural extension of group education is to engage in individualised education. This strategy is highly time and labour intensive, but shows promise as an effective training strategy.[11 16–19] Two studies used brief streetside training sessions (ie, 10–15 minutes).[16 17] In both, the children (aged 5–8 years in Barton *et al*[16] and 5 years in Demetre *et al*[17]) demonstrated modest improvements in most measures of pedestrian safety behaviour immediately following training. However, Demetre *et al*[17] included a long-term follow-up and discovered poor retention of safety practice in the sample of 5-year-olds.

Two other studies used between four and 12 training sessions for children as young as 5 years.[18 19] In both reports, training sessions were conducted streetside using actual traffic. Children were taught by semiprofessional adults in most cases and by parents in one arm of the study by Rothengatter.[18] Rothengatter's sample[18] was also exposed to a 20-minute audio-visual presentation on pedestrian safety; the study by Young and Lee[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 indicate the retention of learning 4 months later.[18]

Together, published data on individualised behavioural training of children in streetside locations is promising. Children as young as 5 years of age have demonstrated a significant improvement in pedestrian safety through such training programmes 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 labour intensive, and therefore unrealistic for broad implementation in many school or community centre 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 by television programmes or computer software. Initial work in this domain relied on videotapes, and found that fourth to sixth graders who were exposed to a pedestrian safety film had increased knowledge of pedestrian safety and modestly improved behaviour in observed street crossing near their schools.[21] More recently, research has focused on the efficacy of computer-based training programmes. Tolmie *et al*,[22] for example, used a set of computer-based games, in conjunction with adult or peer discussion, to teach 5–8-year-old children how to identify safe gaps in traffic. 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 customised to an individual's skill level and learning strategy. Furthermore, virtual reality is highly engaging. Children generally enjoy learning in virtual worlds.

We are aware of two published reports using virtual reality to train children in pedestrian safety.[24 25] In the study by McComas *et al*,[24] 95 children in grades 4–6 were unobtrusively observed crossing the street to school and then randomly assigned to an experimental (virtual reality training) or control (no training) condition. The virtual reality training group received three trials of crossing eight intersections in a virtual environment shown on a non-immersive three-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 behaviours (eg, failing to look left–right–left, failing to stay on the sidewalk) they committed. After the virtual reality 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 with children who did not receive the training; a similar pattern was not observed at the urban school.

In the study by Thomson *et al*,[25] 94 children aged 7, 9 and 11 years, were trained during four small group sessions of 30–40 minutes, scheduled a week apart from each other. Training consisted of work in a non-immersive virtual environment shown on a single computer screen. Children selected traffic gaps for a computerised 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 computerised 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 virtual reality studies.

HYPOTHESES

The overarching aim of the current project is to test the efficacy of virtual reality as a tool to train children, aged 7–8 years, in safe street-crossing behaviour. This aim is being accomplished by a randomised 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 at present. The third group receives six 30-minute sessions of individualised behavioural training at streetside locations. Recent literature reviews suggest this type of training may be the most efficacious behaviour-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 6-month follow-up assessment. The project's three specific hypotheses include:

1. **To test whether training in a virtual environment improves children's street-crossing skills**. We expect the children in the virtual reality training group will show improvement in their street-crossing skills, as measured by three benchmark variables in both field and laboratory-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 a repeated-measures comparison of behaviour within the group trained in the virtual environment, as well as in comparison with the no-contact control group.
2. **To test whether virtual reality 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 virtual reality training group will show greater improvement on all three benchmark street-crossing variables than those children in the video/computer training group.
3. **To test whether virtual reality techniques are more efficacious in training children in street-crossing skills than the most efficacious education strategy identified to date, individualised behavioural training in streetside environments**. We expect children in the virtual reality training group will show modestly greater improvements on all three benchmark street-crossing variables than those children trained by an adult in a streetside location.

METHODS

Overview

We are conducting a randomised controlled trial, with the primary goal of testing the efficacy of virtual reality as a mechanism to train children in safe street-crossing behaviours. 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; six 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 six 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 behavioural training group; or the no-contact control group. Training in all three active intervention groups is composed 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 the 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 (eight vehicles/minute); 30 mph traffic and moderate volume (12 vehicles/minute); 35 mph traffic and heavy volume (16 vehicles/minute) in a randomised order. These trials include practice trials before data collection and standardised 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 eight 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 eight 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 behaviour derived from the streetside and virtual road simulations are detailed below in '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 composed of three segments of 15 virtual crossings each. Children receive computer-generated feedback concerning safety immediately after every crossing. The difficulty of crossing (ie, density and speed of traffic) is tailored to children's abilities, with the goal that they succeed on approximately 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 USA. These tools are commonly implemented in classroom settings, and are recommended and used by several state transportation and education agencies. Such interventions have proved 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 behavioural training group

Children in the streetside behavioural training group are exposed to a training programme grounded in behavioural theory (eg, modelling, reinforcing, chaining) and developed from strategies used by Rothengatter,[18] Young and Lee[19] and Barton *et al*.[16] Individualised streetside training has proved successful in previous trials with children as young as 5 years,[18 19] including in one study that assessed retention 4 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 semistructured 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, eight each using the shout and two-step techniques).

Protocol: 6-month follow-up assessments

The follow-up assessment occurs 6 months after 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 the 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 behaviour. 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 (eg, 500–1000 ms) 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 the 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 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 relationship between the intervention and the changes between each of the time points. We will fit the following model:

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

where trial will be entered into the model as a categorical variable utilising 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 virtual reality 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 virtual reality techniques are more efficacious in training children in street-crossing skills than streetside behavioural training. These two specific aims will be tested utilising contrasts in the above model.

We predict that virtual reality will prove superior to the no-contact and video/computer control groups. Virtual reality 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 virtual reality will prove moderately superior to the individualised streetside training. Individualised training at the streetside is highly time and labour intensive for an adult, but offers many of the advantages of virtual reality. 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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Competing interests None.

Ethics approval This study was conducted with the approval of the Institutional Review Board at the University of Alabama at Birmingham.

Patient consent Obtained.

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