

# Effectiveness of Virtual Reality for Teaching Pedestrian Safety

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## ABSTRACT

Sixty percent to 70% of pedestrian injuries in children under the age of 10 years are the result of the child either improperly crossing intersections or dashing out in the street between intersections. The purpose of this injury prevention research study was to evaluate a desktop virtual reality (VR) program that was designed to educate and train children to safely cross intersections. Specifically, the objectives were to determine whether children can learn pedestrian safety skills while working in a virtual environment and whether pedestrian safety learning in VR transfers to real world behavior. Following focus groups with a number of key experts, a virtual city with eight interactive intersections was developed. Ninety-five children participated in a community trial from two schools (urban and suburban). Approximately half were assigned to a control group who received an unrelated VR program, and half received the pedestrian safety VR intervention. Children were identified by group and grade by colored tags on their backpacks, and actual street crossing behavior of all children was observed 1 week before and 1 week after the interventions. There was a significant change in performance after three trials with the VR intervention. Children learned safe street crossing within the virtual environment. Learning, identified as improved street-crossing behavior, transferred to real world behavior in the suburban school children but not in the urban school. The results are discussed in relation to possibilities for future VR interventions for injury prevention.

## INTRODUCTION

**P**EDESTRIAN INJURIES are one of the greatest risks to children in terms of morbidity and mortality, and the most common cause of serious head trauma.<sup>1</sup> The child development literature suggests that children are at particular risk because their exposure as pedestrians increases at a time when their skills and judgment levels are not sufficiently developed. Factors that may influence the occurrence of pedestrian injuries in children include level of attentiveness, traffic speed judgment, impul-

siveness, and risk-taking behavior.<sup>2,3</sup> Sixty percent to 70% of the pedestrian injuries in children under the age of 10 years are the result of the child either improperly crossing intersections, or dashing or darting out into the street between intersections.<sup>1</sup>

A systematic review of the prevention research for pedestrian injuries found that preventive measures utilized to date include educational programs, environmental modifications, vehicle modifications, daylight savings time, community campaigns, and reflective clothing.<sup>1</sup> The consensus of the educational

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program literature is that skills training is generally effective in improving child pedestrian behavior, particularly in those programs that include practical training opportunities in a realistic learning environment and use repetition to promote skill acquisition.<sup>4-6</sup> Recommendations for further research by review bodies have included observing pedestrian behavior in real world situations following interventions,<sup>1</sup> and developing a precise and easy-to-use exposure method for training.<sup>7</sup> Most street-crossing teaching takes place in the classroom, where general verbal instructions such as “be careful” and “look before crossing” are given, without an emphasis on appropriate street-crossing behavior. Therefore, traditional classroom teaching methods are largely ineffective in teaching children safe street-crossing skills that will generalize to real-world situations.<sup>8</sup>

Virtual reality (VR) technologies provide a safe, controlled environment to teach children pedestrian skills and behaviors. VR gives opportunities for consistent feedback, for practice and repetition, a motivating medium for children, and wide accessibility through Internet distribution.<sup>9</sup> Related to pedestrian safety, VR has been used to (1) teach children safer street crossing behavior;<sup>10</sup> (2) teach children with mobility impairments how to safely cross streets using a motorized wheelchair;<sup>11</sup> and (3) teach children with autism how to perform simple street-crossing-related tasks.<sup>12</sup> These studies have used traditional immersive VR, whereas we opted for the less immersive desktop VR (projected on three synchronized computer monitors) because it is less costly, more accessible, does not induce motion sickness, yet still provides a good sense of immersion in the virtual world.

## MATERIALS AND METHODS

The CrossPoints Project involved several stages including an extensive literature review, focus group consultations, software formulation and design, and, finally, testing of the software. A summary of the injury prevention literature provided a list of intersection and

site characteristics that are associated with child pedestrian injuries. This information was used as a reference point for both the development of the focus group consultation guide and as a source for triangulation of data with the focus group and content experts. Risk factors identified from the literature included human factors, physical environmental factors, street intersection characteristics, and exposure time.

These factors were then submitted to a series of experts to assist in prioritizing those that should be included in the software. The key target groups who participated in the content development of the CrossPoints software, included police, school resource officers, traffic investigators, local safety council, public health department, emergency department staff, physical therapists, occupational therapists, crossing guards, parents, and teachers. The data from these groups were transcribed verbatim and synthesized using qualitative thematic and content data analyses. The decisions from the focus groups, consumers, and software specialists were then assimilated to determine the final content of the software.

### *Software formulation and development*

Using both the literature review and focus group information, the research team mapped out a virtual city that encompassed all the factors identified as important for inclusion into the software. The virtual city consists of eight intersections, each designed to teach children about different aspects of pedestrian safety. The intersections are different in terms of type (stop sign, lights, no signage), size (one-way, two-way, four-way traffic), and distractions (e.g., noise, pedestrians, park). All intersections require that the child display four safety behaviors: (1) stop at the curb, (2) look left-right-left (L-R-L), (3) walk on the sidewalk versus the street, and (4) stay attentive while crossing the street. This script was programmed using EON Software, a three-dimensional authoring tool. The resulting program provides a realistic depiction of urban and suburban settings, developed to be displayed on either three computer monitors

situated in a semicircle or on a single monitor. A head-tracking device (designed by the Vivid Group) was utilized to determine head movements, specifically to measure whether the child looked L-R-L before crossing the street. As well, a feedback component was incorporated into the software that prompts the child to stay on the sidewalk, stop at the curb, and look L-R-L, if not done. When a child comes too close to a moving vehicle, a large warning "Danger—too close!" flashes across the screen, resulting in the child being automatically sent back to the curb to retry the crossing. This strategy proved to be effective in pilot testing without traumatizing the children. The program was pilot-tested with 20 children (12 girls and eight boys in grades 2–5) for general usability and content validity. No differences in performance were found for gender, age, or grade, and the children found the program easy to use and interesting, suggesting that the program was age appropriate.

#### *Evaluation of the software*

Using a controlled before-after design, an urban and a suburban school were recruited to participate in evaluating the software. Within each school, half of the children in grades 4–6 were randomly assigned the CrossPoints software and the other half received an alternate desktop VR program. To examine transfer of training effects, real world observations of the children crossing streets before and after the VR intervention were made.

#### *Participants*

Ninety-five children participated in the study. In the urban school, 47 children from grades 4–6 (males = 18, females = 29) participated in either the intervention group ( $n = 22$ ) or the control group ( $n = 25$ ). The majority of students in the urban school came from families who had recently immigrated to Canada, so English was not their native language. Forty-eight children from a suburban school in grades 4–6 also participated in the study (males = 26, females = 22), with 26 students in the intervention group and 22 students in the control group.

#### *Real world data collection*

Three research assistants observed children crossing intersections near their school for 1 week prior to initiating the VR intervention and the week following the intervention. Reflective tags, attached to backpacks, identified children in the study. Six different colors of tags were used to distinguish the grade of the child and whether they were in the control or intervention group. Rivara et al.<sup>13</sup> successfully used a similar protocol to examine pedestrian behavior in children. Children were observed for the following four behaviors: (1) walking on the sidewalk versus walking on the street; (2) stopping at the curb; (3) looking L-R-L before crossing; and (4) staying attentive while crossing the street. For each correct action, they were given one point.

#### *Virtual reality intervention*

The computers were set up in school libraries, and children were tested individually. Both programs took 30–45 min to complete. The computer set-up for the intervention program comprised of three 21" computer monitors placed in a semicircle in front of the child. The program was displayed across all three computers, with the two outer computers simulating peripheral vision. The control program was displayed on a single 21" monitor.

The children receiving the CrossPoints program were required to travel from their virtual home to a virtual school along a designated path that crossed eight different intersections. Each child completed the entire journey three times: (1) pretraining, (2) training, and (3) posttraining. Feedback was given to the child only during the training session, with the first and last trial serving as baseline and follow-up measures. Examples of feedback include comments to return to the path, to stop at the curb, to look L-R-L before and during crossing, and to wait for the green light. If the child comes too close to a vehicle, he or she is returned to the curb to reattempt a safe crossing. The dependent measures of the study were the same four factors assessed in the real world. For each correct behavior, the child received

one point. For the three intersections that involved street-crossing lights, the child received an additional point if he or she waited for the light to turn green. Finally, if a car hit the child, he or she automatically received a negative point for each collision, and the total number of hits was computed for each intersection.

In order to determine whether training in a virtual environment can improve children's skills and knowledge of pedestrian safety, we predicted that children participating in the VR intervention group would display significantly better postbaseline VR pedestrian safety scores than their initial baseline VR pedestrian safety scores. To examine whether pedestrian safety learned in a virtual environment transfers to real world behavior, we hypothesized that children who received CrossPoints would have significantly improved postintervention real world pedestrian safety scores compared to children who received the control program.

## RESULTS

Before the VR intervention, 284 observations of children crossing intersections near the urban school and 101 observations of children at the suburban school were recorded. Following the intervention, 220 observations at the urban school and 82 observations at the suburban school were recorded. Scores for each observation ranged from 0 to 4, based on their recorded behavior. *t*-Tests were conducted on the dependent measure (score for each correct behavior—staying on the side walk, stopping at the curb, looking L-R-L, and keeping vigilant while crossing) to determine whether the data from both schools should be combined. The preurban scores and the presuburban scores boarded on significant differences,  $t(383) = 1.87, p = 0.062$ , while the postintervention scores indicated significant differences in behavior between schools,  $t(300) = -2.49, p = 0.01$ . Thus, the data between the two schools were treated separately.

To determine if the VR training impacted on knowledge of pedestrian safety rules, the VR pre- and posttraining measures were compared. The pretraining condition consisted of the first eight intersections, and the posttrain-

ing condition consisted of the last eight intersections. During both the baseline and follow-up trials, training feedback was not provided to the child. Table 1 depicts the intervention scores (mean/SD) by trials per school.

Along with the data for the baseline and follow-up measures (trials 1 and 3) and the training session (trial 2), a gains score was computed, which consisted of trial 3 minus trial 1. Paired *t* tests for the urban school for trial 1 and trial 3 indicated significant differences in behavior across the eight intersections,  $t(21) = -6.91, p < 0.001$ . As well, significant differences were noted for the suburban school,  $t(25) = -10.15, p < 0.001$ . In both instances, the children improved their street crossing behavior on the third trial, indicating a learning effect of pedestrian safety rules. To examine whether grade or gender influenced knowledge acquisition, an analysis of variance (ANOVA) was calculated for each school (gains score  $\times$  grade  $\times$  gender). There were no significant differences at either school for this comparison.

To examine whether the VR educational component transferred to real world behavior, comparisons of the real world pre and post training scores were conducted. For the urban school, no significant differences were found using a  $2 \times 2$  ANOVA for pre  $\times$  post scores and the control vs. intervention group on the behavior measure. However, the same analyses conducted on the suburban school revealed a significant main effect for session (pre vs. post score),  $F(1,181) = 4.22, p < 0.05$ . Adjusted means score for the precondition ( $X = 1.42$ ) compared to the postcondition ( $X = 1.9$ ) indicated that children at the suburban school improved street-crossing behavior following the VR intervention. Thus, for this group, a transfer of training effect took place.

The effects of grade level and gender on behavior scores were examined individually at each school using separate ANOVAs. At the suburban school, a main effect was found for grade level,  $F(2,181) = 1.58, p < 0.001$ . Grade 5 students had the highest behavior scores ( $X = 3.4, SD = 1.0$ ) compared to grade 4 ( $X = 1.96, SD = 1.4$ ) or grade 6 ( $X = 1.0, SD = 1.2$ ). Gender did not influence behavior, and grade level was not a significant factor for the urban

TABLE 1. INTERVENTION SCORES (MEAN [SD]) BY TRIALS PER SCHOOL

<i>School</i>	<i>Trial 1</i>	<i>Trial 2</i>	<i>Trial 3</i>	<i>Gains score</i>
Urban	11.07 (5.6)	17.16 (4.9)	19.34 (4.9)	8.27 (5.6)
Suburban	12.73 (6.3)	21.18 (6.7)	24.47 (4.7)	11.74 (5.9)
Combined	11.97 (5.6)	19.34 (6.2)	22.11 (5.4)	10.15 (5.9)

school. Thus, transfer of training effects were found for the suburban school, and at that school, grade 5 students showed the greatest improvement following the VR intervention.

## DISCUSSION

We demonstrated that desktop VR is a promising tool for teaching pedestrian safety. Our results showed that, even with the brief exposure to the VR software, students learned the four major lessons (staying on the sidewalk, stopping at the curb, looking L-R-L, and remaining vigilant while crossing the road) necessary to be successful within the program. It was clear that most students who participated did not know all four of these lessons prior to exposure to the program; thus, CrossPoints provides an innovative way to introduce pedestrian safety concepts. Although the learning demonstrated within the program is important, it is possible that the participants just got better at doing what was required to be successful in CrossPoints and did not truly learn new pedestrian skills. This is why it was important to also demonstrate that learning transferred to real world behavior. Students who were walking to and from a suburban school did improve their pedestrian behaviors after the VR intervention. Unfortunately, the same transfer of learning did not occur in the urban school setting. Previous research attempting to show transfer of learning from a training situation has had varying degrees of success. For example, it has been shown that education can increase knowledge, that training in real streets has potential to change behavior, and that parental education is needed to maximize success.<sup>5,13,14</sup>

Although it is important that we found learning within the VR program and transfer of learning to the real world situation for some children, based on the lack of transfer of learn-

ing in the urban school and the variability in the grades tested in the suburban school, we would recommend that future studies include (1) more time for each student with the VR program; (2) a VR program as similar to the real situation as possible; (3) social factors such as peer pressure be built into the virtual environment; and (4) the VR intervention be introduced as part of a program of pedestrian safety that uses other tools and classroom support. This final suggestion might have particularly helped in the urban school given the number of students who were functioning in English as their second language.

Some of the questions raised by our results could be explored through a more rigorous evaluation design, larger sample sizes, and further testing to examine whether there is a dose response to program exposure. However, our findings are important as they suggest that VR programs could serve as an important adjunct to educational programs regarding pedestrian safety for children, and thereby prevent the needless and often life-threatening traumatic injuries that result when children are hit by motor vehicles.

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