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Training Children in Pedestrian Safety: Distinguishing Gains in Knowledge from Gains in Safe Behavior

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Abstract

Pedestrian injuries contribute greatly to child morbidity and mortality. Recent evidence suggests that training within virtual pedestrian environments may improve children's street crossing skills, but may not convey knowledge about safety in street environments. We hypothesized that (a) children will gain pedestrian safety knowledge via videos/software/internet websites, but not when trained by virtual pedestrian environment or other strategies; (b) pedestrian safety knowledge will be associated with safe pedestrian behavior both before and after training; and (c) increases in knowledge will be associated with increases in safe behavior among children trained individually at streetside locations, but not those trained by means of other strategies. We analyzed data from a randomized controlled trial evaluating pedestrian safety training. We randomly assigned 240 children ages 7–8 to one of four training conditions: videos/software/internet, virtual reality (VR), individualized streetside instruction, or a no-contact control. Both virtual and field simulations of street crossing at 2-lane bi-directional mid-block locations assessed pedestrian behavior at baseline, post-training, and 6-month follow-up. Pedestrian knowledge was assessed orally on all three occasions. Children trained by videos/software/internet, and those trained individually, showed increased knowledge following training relative to children in the other groups (ps < 0.01). Correlations between pedestrian safety knowledge and pedestrian behavior were mostly non-significant. Correlations between change in knowledge and change in behavior from pre- to post-intervention also were non-significant, both for the full sample and within conditions. Children trained using videos/software/internet gained knowledge but did not change their behavior. Children trained individually gained in both knowledge and safer behavior. Children trained virtually gained in safer behavior but not knowledge. If VR is used for training, tools like videos/internet might effectively supplement training. We discovered few associations between knowledge and behavior, and none between changes in knowledge and behavior. Pedestrian safety knowledge and safe pedestrian behavior may be orthogonal constructs that should be considered independently for research and training purposes.

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Keywords

Injury; Walking; Children; Virtual reality

Introduction

In the United States, 459 children died from pedestrian injuries in 2010 and another 215,188 were treated in emergency departments following pedestrian injuries (National Center for Injury Prevention and Control (NCIPC), 2013). Among children ages 7 and 8, the target age group for the present research, there were 37 pedestrian injury deaths in the US and 3,792 pedestrian injuries treated in emergency departments in 2010 (NCIPC, 2013). Global data are less precise, but estimates exceed 30,000 child pedestrians killed annually worldwide (Toroyan & Peden, 2007). Strategies to reduce child pedestrian injuries and deaths are urgently needed.

Until recently, empirical research suggested that the most consistently effective strategy to teach children to cross streets safely was individualized streetside training (see Duperrex, Bunn, & Roberts, 2002; Schwebel, Davis, & O'Neal, 2012 for reviews). Guided by semi-structured protocols but permitting some tailoring to children's skills and needs, individualized streetside training has been demonstrated as an effective strategy to improve children's street crossing knowledge and ability in multiple studies (Barton, Schwebel, & Morrongiello, 2007; Demetre et al., 1993; Rothengatter, 1984; van Schagen, 1988).

A significant limitation to individualized training in pedestrian safety is the extent of adult labor required to train children. Few community agencies or schools have sufficient resources to provide individualized pedestrian safety training to children. A recently promoted alternative to this approach constitutes training children within virtual pedestrian environments (Schwebel & McClure, 2010; Schwebel et al., 2012). Like individualized training at streetside locations, training in a virtual environment permits repeated practice of the cognitive and perceptual task of crossing a street that may improve perception of moving traffic and decision-making about traffic gaps in which it is safe to cross. Such training also can provide reinforcing verbal feedback to children concerning the safety of their crossings, thus offering a behavioral reward system for progress and success that is similar to that of individualized training. Early work in non-immersive virtual pedestrian environments (Bart, Katz, Weiss, & Josman, 2008; McComas, MacKay, & Pivik, 2002; Thomson et al., 2005), combined with recent work in a semi-immersive and interactive virtual environment (Schwebel, McClure, & Severson, 2014), suggest that 7- and 8-year-old children learn street-crossing behavior and skills following training in a virtual environment.

Training in virtual reality (VR) may fall short, however, in teaching children relevant knowledge about aspects of pedestrian safety beyond safe gap selection. Knowing how to cross a street safely is only valuable if one knows where to cross a street (e.g., to cross at crosswalks rather than diagonally across an intersection) and how to negotiate obstacles to safe pedestrian behavior (e.g., handling parked cars, shrubbery, or other visual obstacles). Individualized streetside training with an adult in pedestrian safety is fluid, allowing instructors to include lessons on topics such as where and how to cross streets (e.g., route selection), where and how to look for potential hazards, and how to handle unexpected situations such as parked cars, hills, curves, and approaching emergency vehicles. Training in VR, at least in its current form, is more rote: children develop cognitive, perceptual, and motoric skills via repeated practice crossing a virtual street but do not gain broader lessons of knowledge about how to engage safely in street environments. If VR pedestrian safety training does not provide children with basic knowledge skills, intervention programs that use VR to train children in pedestrian safety might also include strategies such as videos or internet programs that can convey relevant knowledge with minimal adult labor burden. Previous research evaluating pedestrian safety videos and internet programs suggest they result in increased knowledge about pedestrian safety but may not improve actual behavior in street environments (Glang, Noell, Ary, & Schwarz, 2005; Preusser & Lund, 1988; Tolmie et al., 2005; Zeedyk and Wallace, 2003).

Our study was designed to test three hypotheses: (a) children can gain relevant pedestrian safety knowledge via videos, software and internet websites and from individualized streetside training; they gain less knowledge from training in a virtual environment and none if randomly assigned to a no-contact control group; (b) pedestrian safety behavior will be associated with broad knowledge of pedestrian safety both prior to any training and after training; and (c) increases in pedestrian safety knowledge as a result of training will be associated with increases in pedestrian safety behavior among children trained via individualized streetside training, but not among children trained in pedestrian safety via alternative strategies such as videos/software/internet or VR. The hypotheses were tested using existing data from a randomized controlled trial designed to evaluate three strategies to train 7- and 8-year-old children in pedestrian safety (Schwebel & McClure, 2010; Schwebel et al., in press).

Methods

Participants

Two-hundred-and-forty 7- and 8-year-old children were recruited from community sources in the Birmingham, Alabama area, of whom 231 were randomly assigned to condition (see Fig. 1 for CONSORT flowchart of participation). Nine children were dropped during baseline visits, prior to randomization, for one of three reasons: they were either discovered to be ineligible based on their age after consenting and enrollment ($n = 3$), they were unable to understand and follow the study protocol ($n = 3$), or they failed to complete the baseline assessment ($n = 3$).

Demographic information was reported by parents. The randomized sample of 231 children was 43 % male and an average age of 8.0 years old ($SD = 0.7$). The sample was racially diverse, with 52 % of parents identifying their children as White, 42 % as African American, and 7 % either as other races/ethnicities or as bi- or multi-racial. All parents provided written informed consent, and children provided informed assent. The study was approved by the Institutional Review Board of the University of Alabama at Birmingham.

The Virtual Reality Pedestrian Environment

The VR pedestrian environment used in this study, including hardware and software specifications, is detailed elsewhere (Schwebel, Gaines, & Severson, 2008). Briefly, the simulated environment replicates an actual crosswalk near a local school. The crosswalk is located mid-block and crosses a two-lane bi-directional road. Children stand atop a wooden curb with three monitors in front of them, semi-immersed so that they feel they are inside the virtual world but have some external stimuli (e.g., black curtains) to reduce risk of motion sickness. They view traffic moving bi-directionally and are instructed to step down when they deem it safe to cross. Upon stepping, children trigger the system to initiate a race- and gender-matched avatar to cross the simulated street. At that moment, the environment switches from the first to third person to allow children to learn whether or not their crossing was safe. The avatar walks at each child's typical walking speed, assessed previously in a different room across multiple trials.

The virtual environment includes ambient and traffic noise and was validated in a trial demonstrating that behavior in the virtual world matched that of the actual street environment, both among children and adults (Schwebel et al., 2008).

General Protocol

Following consent processes, children completed 12 (if randomly assigned to an intervention group) or six (if randomly assigned to the control group) sessions: a pre-intervention laboratory session, a pre-intervention field session, 6 training sessions (omitted for control group), 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. During the pre-test sessions, baseline measures of pedestrian safety were collected in both virtual and real (i.e., field) environments. Baseline assessment of pedestrian safety knowledge was collected in the laboratory.

Following pre-test assessment, children were randomly assigned to one of four groups: VR training, video/computer training, streetside training, or no-contact control. Training in all three intervention groups comprised six 30-min sessions, scheduled bi-weekly over 3 weeks. Soon after intervention sessions were completed, post-training pedestrian safety and knowledge measures were collected. Finally, two follow-up sessions assessed pedestrian behavior and knowledge 6 months after completion of the intervention. Protocols for each session appear below.

Pre-Training Assessment

Two sessions, one laboratory-based and the other field-based, assessed pre-training baseline measures of each child's pedestrian abilities. The laboratory visit comprised 30 crossings within the VR environment, ten at each of three "difficulty" levels: 25 MPH traffic and light volume (8 vehicles/min); 30 MPH traffic and moderate volume (12 vehicles/min); and 35 MPH traffic and heavy volume (16 vehicles/min), in a randomized order. Traffic appeared using random generation patterns so the same traffic pattern never appeared across trials or visits. Prior to the VR assessment trials, children completed 8 practice trials and received standardized instructions to cross when they perceived the street environment to be safe.

The second pre-training session occurred in the field in front of a crosswalk on a two-lane bi-directional road, but not the same location as that in the VR simulation. Children completed eight crossings using the “shout” technique, in which they stood immediately adjacent to the road and shouted “now” when they considered it safe to cross (Demetre et al., 1992). Children also completed 8 crossings using the “two-step” technique, in which they stood two steps off the curb, and then took two steps toward the road to indicate when they deemed it safe to cross (Demetre et al., 1992).

Children’s knowledge of pedestrian safety was assessed through a 10-item oral instrument evaluating children’s general knowledge about pedestrian safety. Examples of topics addressed included route selection, proper looking before and while crossing, and how to walk safely on streets without sidewalks. We scored items as either correct or incorrect and summed the number of correct answers (range = 0–10) for analysis purposes. Correct answers were not provided to children.

Virtual Reality Training

Children in the VR training group received six training sessions in the VR environment, each comprising three segments of 15 virtual crossings (45 total crossings per session) and lasting about 30 min. Crossings were accompanied by computer-generated feedback concerning safety or risk delivered by a child-friendly cartoon character. The level of crossing difficulty was tailored to children’s abilities, with the goal that children succeed on about 85 % of trials.

Video/Internet Training

Children in the video/computer training group were exposed to six sessions with some of the most widely-used pedestrian training tools in the United States. Each session lasted about 30 min. The tools were chosen based on their broad use (e.g., recommended by state departments of transportation), accessibility to a broad population, and relevance to child pedestrian safety. Each training session provided general pedestrian safety lessons rather than focusing on particular aspects of pedestrian safety. Materials presented, by trial, were:

- Training Trial 1: WalkSmart computer software (Oregon Center for Applied Research; ORCAS, 2014)
- Training Trial 2: I’m no Fool video (Walt Disney Pictures, 1956) and Willie the Whistle video (NHTSA; National Safety Council/National Highway Traffic Safety Association, US Department of Transportation, 2014)
- Training Trial 3: Safer Journey website (FHWA; Federal Highway Association, US Department of Transportation, 2014)
- Training Trial 4: Step to Safety with Asimo video (National Safety Council/Honda Motor Company; Honda Motor Company, 2005) and Otto the Auto on School Bus Safety video (AAA Foundation for Traffic Safety, 1994)
- Training Trial 5: Otto the Auto computer software (California State Automobile Association, American Automobile Association; California State Automobile Association, 2014)

- Training Trial 6: Otto the Auto videos on Pedestrian Safety and Being Seen in Traffic (AAA Foundation for Traffic Safety, 2006)

Streetside Training

Children in the streetside behavioral training group were exposed to six 30-min sessions of individualized streetside training from research assistants. During all sessions, the child and adult stood adjacent to each other and to the street. The training program was grounded in behavioral theory (e.g., modeling, reinforcing) and developed from strategies used by Rothengatter (1984), Young and Lee (1987), and Barton et al. (2007). A semi-structured and flexible approach was based on each child's strengths, limitations, and abilities (as judged by the trainer), with two primary foci: attending to traffic in both directions and selecting safe traffic gaps. Secondary topics such as route selection, looking behavior, and coping with obstacles were also addressed. Streetside locations were selected at marked crosswalks that became increasingly challenging (heavier traffic) across the sessions; all were two-lane bi-directional roads with mid-block unsignaled crosswalks.

Post-Training and Follow-Up Assessments

The post-training and follow-up assessments paralleled the pre-training assessment. Pedestrian safety knowledge was assessed and two sessions were conducted to evaluate safe pedestrian behavior, the first in the laboratory and the second in the field. Post-training assessments began approximately a week after the last training session for children in intervention groups ($M = 6.8$ days, $SD = 6.2$), and approximately 5 weeks after the pre-intervention assessment ended for children in the control group ($M = 36.2$ days, $SD = 12.4$). The follow-up assessment occurred approximately 6 months following completion of the post-intervention assessment ($M = 182.5$ days, $SD = 11.9$).

Pedestrian Measures

Pedestrian safety outcomes were collected in two locations, the VR and the field. The VR offered a controlled traffic scenario where speed and traffic volume were standardized across participants and where potential bias from weather, time of day, and other environmental characteristics were controlled. The field assessment offered a more realistic and ecologically valid measure of behavior with real-world traffic, but was subject to varying traffic conditions across participants. Three outcome measures of pedestrian safety were considered: hits/close calls, attention to traffic, and start delay.

Hits/close calls were included as a gross outcome measure of pedestrian safety, a count of crossings that are highly risky—that is, the child would either have been hit by a vehicle had it been an actual crossing, or would have been within one second of being hit. The virtual environment records hits and close calls automatically. Children crossed the virtual street 30 times, so VR results are expressed as a count of 30 trials (possible range = 0–30). Hits/close calls were assessed in the field by videotape review. A hit/close call was recorded when the time between the child's initiation into the crosswalk, plus their previously-assessed average walking speed over the crosswalk distance, was less than one second shorter than the time before the next vehicle entered the crosswalk. Inter-rater reliability was established and adequate ($r > 0.95$ between independent coders masked to condition on 20 % of the sample).

Children completed 16 field trials, so results are expressed as a count of those trials (possible range = 0–16).

Attention to traffic and start delay were included as two critical components of pedestrian safety. Attention to traffic was measured by the number of looks to the left plus looks to the right while waiting to cross, divided by waiting time in minutes. Head-tracking equipment monitored children's visual attention to traffic from the left and right in the virtual world. Field trial data was coded from videotapes. Coders counted head-turns to the left and to the right, and also timed waiting time. Interrater reliability was again adequate ($r > 0.95$). Attention to traffic is expressed as a continuous measure.

Start delay, defined as the temporal lag (in seconds) before initiation of crossing into a traffic gap, is considered an indicator of the efficiency of children's cognitive processing in pedestrian situations (Barton, 2006; Plumert, Kearney, & Cremer, 2004). Start delays were assessed automatically in the VR based on the temporal gap between the appearance of the entered gap (that is, the time the last vehicle passes the crosswalk) and when the child initiated crossing. In the field, start delays were assessed via videotape coding of the time between the last vehicle leaving the crosswalk and the child indicating intention to cross. Inter-rater reliability was adequate ($r > 0.95$). Start delays are expressed in seconds.

All field pedestrian measures were computed separately for the two-step and the shout tasks but because trends for the two tasks were consistently similar, we aggregated behavior across them to create single field measures of pedestrian behavior.

Analysis Plan

Descriptive data were considered first, both for the full sample and within randomly-assigned groups. We tested for balance across the groups using Chi square tests of association for categorical variables and analysis of variance for continuous variables. Data pertinent to the first hypothesis—that children would gain pedestrian safety knowledge via training using videos, software and the internet as well as from individualized streetside training but less so from training in the virtual environment—were assessed using repeated-measures analysis of variance (ANOVA), in which pedestrian knowledge served as the dependent variables and time (pre vs. post vs. follow-up) and condition (VR vs. streetside vs. video vs. control) as independent variables. We assessed the interaction between time and condition to determine if the changes in condition over time differed, and when they did we performed contrasts using t tests to determine which pairs of conditions differed over time. Similar analyses of changes in pedestrian safety behavior were also performed (see also Schwebel et al., in press). We report only statistically significant contrasts. For models in which the interaction was significant, we used a Bonferroni adjustment to the p value for the 12 pairwise comparisons to account for multiple comparisons, and report these as the adjusted p values.

The second hypothesis concerned correlations between knowledge and behavior prior to and after training. We used Pearson correlations to test this hypothesis both for the overall sample and within randomly-assigned groups. The third hypothesis was that increases in pedestrian safety knowledge would be associated with increases in pedestrian safety behavior among children trained individually at streetside locations, but not among the other randomly-assigned groups. This hypothesis was tested using Pearson correlation of change scores within randomly-assigned groups.

Results

Table 1 provides descriptive data about the sample, both overall and within the randomly-assigned treatment groups. Among children randomized to condition, we compared the 211 children who completed the full study with the 20 who did not complete all assessments. The non-completers were more likely to be African-American and to come from families with lower socioeconomic status, but otherwise the two groups were comparable as to age and gender and randomized group assignment. Given this, subsequent analyses were conducted in a pairwise manner, using all available data.

We turned next to pedestrian behavior and knowledge. At baseline, there were no significant differences in any of the measures among children randomly assigned to different groups. Table 2 displays descriptive data for pedestrian safety knowledge and pedestrian behavior, as measured both in the field and in the VR environment. The p value for the interaction effect in repeated-measures ANOVAs appears in the final column. There was a significant interaction effect for knowledge for all three pedestrian safety behaviors assessed in the VR, and for the start delay measure in the field.

Results concerning knowledge are shown graphically in Fig. 2. As hypothesized, children in the video/software/internet and the individualized streetside condition showed a sharp increase in knowledge following training, as indicated by the steep slope between pre- and post-intervention assessments. Children in the other two groups showed relatively flat slopes, or minimal change. At 6-month follow-up, children in the video/software/internet seemed to retain their knowledge but children who had received individualized streetside conditions tended to gain even further knowledge. The other two groups of children showed a modest increase in knowledge, perhaps reflecting 6 months of development and learning. Statistically significant differences from pre- to post-test included: streetside versus the VR group (unadjusted $p = 0.0009$, adjusted $p = 0.01$), streetside versus the control group (unadjusted $p = 0.007$, adjusted $p = 0.08$), the video versus the VR group (unadjusted $p < 0.0001$, adjusted $p < 0.0005$), and the video versus the control group (unadjusted $p < 0.0001$, adjusted $p < 0.0005$). Contrasts between the video group and the VR group (unadjusted $p = 0.008$, adjusted $p = 0.10$) and between the streetside and the VR groups (unadjusted $p < 0.001$, adjusted $p = 0.01$) were also statistically different in follow-up to pre-test comparisons.

Results of pairwise comparisons concerning behavior suggest the streetside training improved children's performance in start delays post-intervention relative to the VR group, the video group and the control group both in the field (all unadjusted ps < 0.0001, adjusted ps < 0.005) and in the VR (all unadjusted ps < 0.0001, adjusted ps < 0.005); both the streetside and VR groups had fewer hits/close calls post-training than the control groups in the VR (unadjusted ps < 0.05; adjusted p, streetside vs. control = 0.11, VR vs. control = 0.31); and the VR group showed more attention to traffic post-intervention than either the control (unadjusted $p < 0.05$, adjusted $p = 0.24$) or streetside training groups (unadjusted $p < 0.01$; adjusted $p = 0.05$).

Table 3 displays correlations between pedestrian safety knowledge and pedestrian behavior for the full sample at each time of assessment. Just two correlations were significant, both from VR measurement (start delay at pre-intervention, $r = -0.15$, $p < 0.05$, and hits/close calls at post-intervention, $r = -27$, $p < 0.01$), and both indicated associations between safer pedestrian behavior and greater knowledge. Correlation matrices were computed within randomized groups and results (not shown) were similar.

Table 4 displays correlations between changes in knowledge and behavior from pre- to post-intervention, both for the full sample and within randomly-assigned groups. No correlations were significant. Thus, improvement in knowledge was not related to improvement in pedestrian behavior in any of the four experimental groups.

Discussion

Our first hypothesis was confirmed. Children randomly assigned to pedestrian safety training using videos, software, and internet programs gained pedestrian safety knowledge but their behavior did not improve, as measured both in field and virtual settings. Children randomly assigned to individualized streetside training—a laborious but effective training strategy—showed improvement in both pedestrian knowledge and behavior, and their improvement tended to be retained over a 6-month period. As expected and critical for intervention development, children randomly assigned to training within a virtual environment showed improvement in pedestrian behavior but not in knowledge about pedestrian safety.

Our second hypothesis concerned whether children's knowledge about pedestrian safety was related to pedestrian behavior in simulated mid-block crossings, either at baseline or following training. Surprisingly, few of the correlations were statistically significant, indicating that children's broad knowledge about pedestrian safety was not closely associated with their performance in simulated mid-block crossings. Although our knowledge survey tapped broad pedestrian safety knowledge and our behavioral assessment assessed only mid-block crossings at two-lane bi-directional streets, we anticipated stronger associations between children's knowledge and behavior.

Our third hypothesis assessed whether children's improvement in knowledge following training was associated with improvement in their behavior following training. We expected statistically significant correlations among the children trained at streetside locations, as they were exposed to lessons both in knowledge and behavior. We anticipated more modest or no associations among the other groups, which were exposed primarily to training in knowledge (videos/software/internet) or behavior (VR), or to the no training control. Results suggested poor correlations among all four groups, failing to support this hypothesis.

One must always be cautious about interpreting null results, but we speculate several possible explanations for the findings pertaining to the second and third hypotheses. First, we recognize that our measures may have been inadequate. We used a fairly short self-report instrument to assess knowledge. We used two measures of pedestrian behavior, both simulated in realistic circumstances but not representing actual crossings. The results of our first hypothesis provide some validity to the measure, and the behavioral measures are both well-validated in previous studies, but our null findings should be replicated. Second, our results may have been anomalous and we again advise replication in future studies.

Last, and perhaps most plausible, our measures of pedestrian safety knowledge and pedestrian behavior may have been too disparate to be associated. Our knowledge questionnaire covered a range of pedestrian situations. Our behavior assessment focused only on gap selection at two-lane bi-directional mid-block locations. Perhaps we were unjustified in hypothesizing correlations between the two measures at baseline, or between how well children learned knowledge and gained safer behavior in the streetside training condition, because pedestrian safety knowledge and behavior are actually independent constructs without the same cognitive, perceptual, or educational origins. If this is the case, it reinforces the notion that pedestrian safety is a multifaceted and complex construct that must be both researched by scholars and taught to children in the context of its many components rather than as a single entity. Children must gain a wide range of skills and knowledge before they can engage safely in street environments. These include the cognitive-perceptual aspects of gap selection and crossing decisions that our behavioral assessment tapped, the basic knowledge of route selection and handling street hazards that our knowledge assessment tapped, and others. These multiple components may be orthogonal to each other, suggesting that effective research must carefully define what is being assessed and effective training programs must address all the various components to prepare children successfully for independent pedestrian engagement.

What do our findings mean for practitioners? Early evidence suggests that VR may be an effective tool to teach children safe street crossing behavior at mid-block crossings. However, if VR is to be used as a pedestrian safety training tool that reduces adult time and labor required to train children—and this seems a valuable direction to consider based on current evidence— then practitioners must recognize that existing VR programs do not teach children other components of pedestrian safety that are also critical for safe engagement in street environments. Perhaps most obviously, we are unaware of pedestrian VR simulators that are designed to teach children to handle obstructed vision from parked cars, to select safe routes across intersections, or to handle unusual situations such as approaching emergency vehicles. Until VR simulations are broadened to handle other aspects of pedestrian safety—something that seems feasible in the future—VR training should be combined with tools such as videos or internet training sites to provide children with the broad and comprehensive pedestrian safety knowledge needed to cross streets independently.

Our study had several limitations. We relied on archival data from a randomized controlled trial, and therefore were limited to the measures available from that study. Our analysis omitted relevant aspects of pedestrian safety (e.g., route selection) and were limited to behavioral assessments from mid-block crossings. Relatedly, our streetside training protocol was strong, but was conducted only at mid-block locations and therefore may not have adequately addressed crossings at intersections or in other locations. Our intervention also was individualized, but there is some evidence to suggest that small-group training may be equally or more effective (Tolmie et al., 2005). Our study may also have suffered from methodological bias. The group of children trained in the VR condition benefitted from repeated practice that may have artificially improved children's behavioral performance when assessed in the VR following training. The group of children trained streetside may have had a similar methodology bias when assessed in the field. Of course, our results may also reflect actual learning, as children may have gained pedestrian knowledge through repeated practice during training and then manifested that increase in post-training assessments.

In conclusion, our findings suggest that a combination of videos, software, and internet training is effective at teaching children basic knowledge about pedestrian safety, and that these strategies may supplement behavioral training in virtual pedestrian environments.

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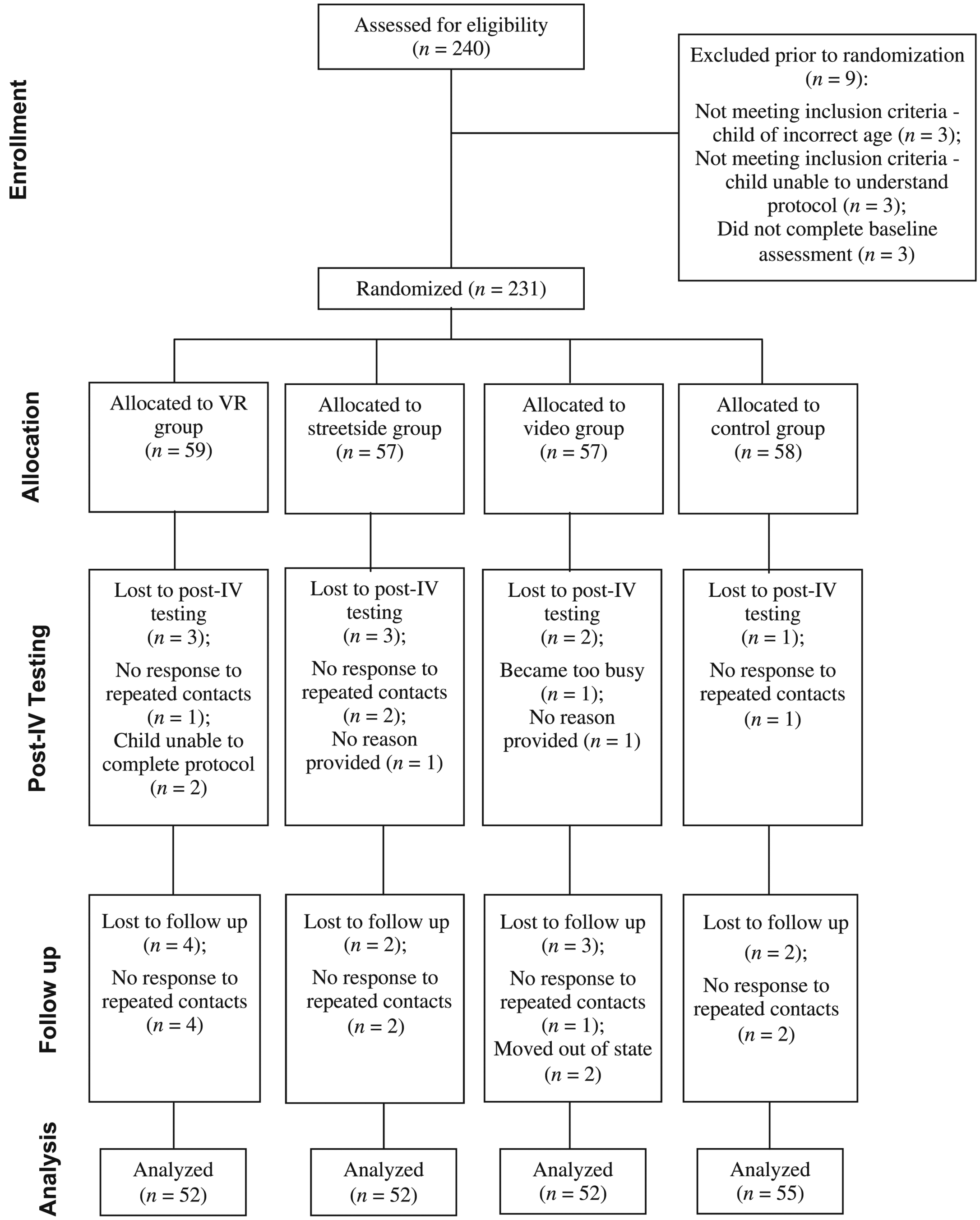

Fig. 1.

CONSORT diagram. Consort flow diagram illustrating enrollment in the study. *VR* virtual reality; *IV* intervention

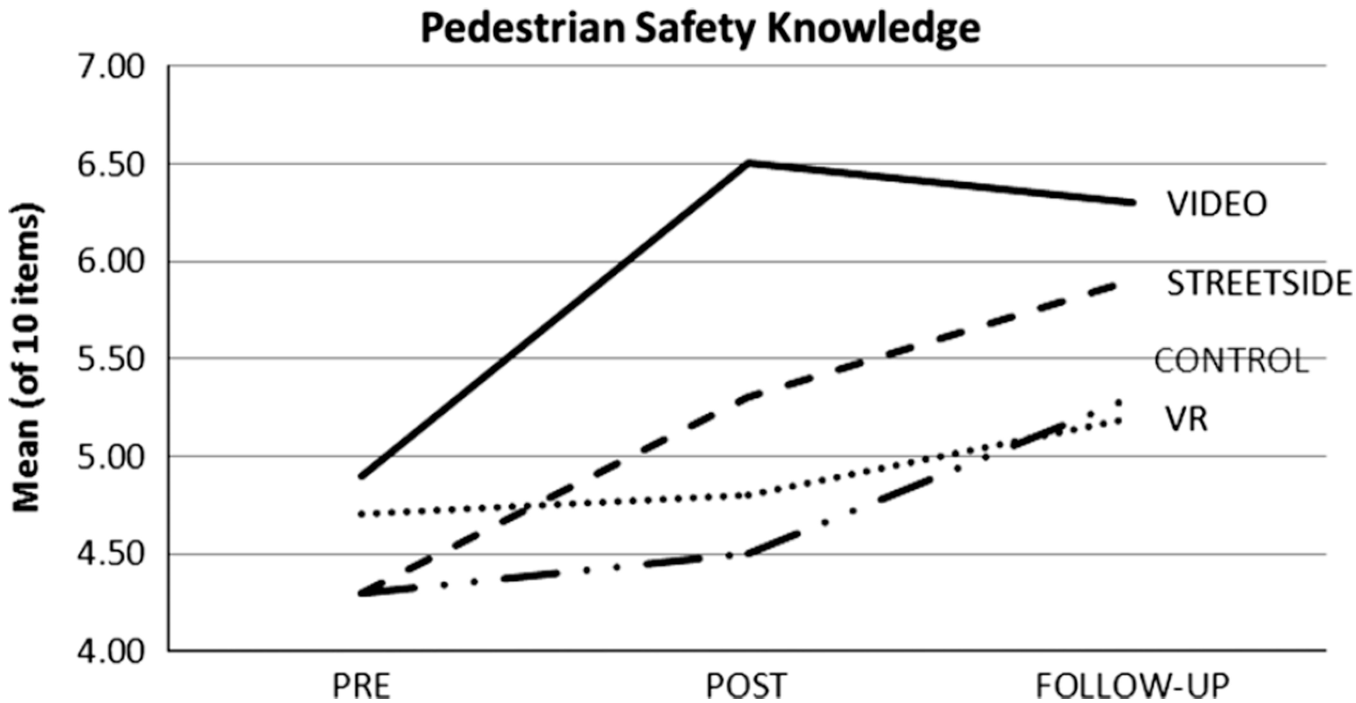

Fig. 2.

Results from field and VR trial outcomes: group means by condition and assessment point. Mean pedestrian safety knowledge scores at pre-intervention, post-intervention, and follow-up, across the four intervention conditions

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Table 1

Descriptive data

Variable	Overall (*N* = 231)	VR (*n* = 59)	Streetside (*n* = 57)	Video (*n* = 57)	Control (*n* = 58)
Sex					
Male (%)	43	46	39	39	48
Ethnicity					
White (%)	53	59	53	53	47
African American (%)	40	39	39	40	43
Other/biracial (%)	7	2	9	7	10
Age (years)[a]	8.0 (0.65)	7.9 (0.67)	7.9 (0.68)	8.1 (0.63)	8.1 (0.63)
Mother's education					
≤HS (%)	10	10	9	11	10
Some college (%)	29	27	35	28	24
College grad (%)	34	32	30	33	38
>College grad (%)	27	29	25	28	24
Father's education					
≤HS (%)	19	20	16	12	24
Some college (%)	21	19	25	18	19
College grad (%)	29	29	25	33	22
>College grad (%)	30	27	23	33	29
Household income					
<$40 k (%)	27	22	26	28	28
$40–$99.99 k (%)	38	27	35	28	38
≥$100 k (%)	35	27	37	40	33

VR virtual reality

[a]Mean (standard deviation) reported for this continuous variable

Table 2

Average outcome measures (standard deviations)

	VR			Streetside			Video			Control			p[a]
	Pre IV	Post IV	FU	Pre IV	Post IV	FU	Pre IV	Post IV	FU	Pre IV	Post IV	FU	
Pedestrian knowledge													
Knowledge (mean correct of 10 items)	4.7 (1.8)	4.8 (1.4)	5.2 (1.3)	4.3 (1.7)	5.3 (1.5)	5.9 (1.5)	4.9 (1.6)	6.5 (1.5)	6.3 (1.7)	4.3 (1.7)	4.5 (1.4)	5.3 (1.6)	<0.0001
Field—Ped. behavior													
Hits/close calls	9.8 (3.5)	10.4 (4.6)	9.7 (4.6)	8.3 (3.3)	8.9 (4.3)	8.9 (4.1)	9.0 (3.9)	11.1 (3.5)	10.1 (3.4)	10.1 (4.1)	10.8 (4.5)	10.1 (3.9)	0.56
(count over 16 trials)													
Attention to traffic	14.0 (11.8)	11.4 (3.3)	11.2 (4.3)	12.3 (9.4)	12.4 (4.9)	11.7 (4.7)	11.6 (6.7)	13.2 (5.1)	13.1 (9.2)	14.8 (11.1)	15.3 (11.1)	12.3 (4.2)	0.25
(looks/wait time)													
Start delay (s)	1.5 (0.70)	1.2 (0.59)	1.5 (0.63)	1.5 (0.66)	2.1 (0.99)	1.5 (0.62)	1.6 (0.78)	1.4 (0.74)	1.5 (0.59)	1.4 (0.59)	1.2 (0.61)	1.4 (0.67)	<0.0001
VR—ped. behavior													
Hits/close calls	2.8 (1.6)	2.7 (1.6)	2.1 (1.4)	2.6 (1.6)	2.3 (1.2)	1.7 (1.1)	2.5 (1.7)	2.6 (1.6)	2.3 (1.5)	2.6 (1.5)	3.0 (1.6)	2.6 (1.6)	0.04
(count over 30 trials)													
Attention to traffic	27.1 (11.4)	33.2 (10.6)	35.2 (11.4)	28.7 (9.7)	27.8 (10.0)	34.1 (9.2)	30.2 (12.1)	32.2 (11.6)	32.3 (12.3)	29.3 (10.7)	29.7 (9.8)	34.2 (10.0)	0.02
(looks/wait time)													
Start delay (s)	1.3 (0.44)	1.1 (0.46)	1.1 (0.43)	1.2 (0.40)	1.4 (0.45)	1.1 (0.31)	1.3 (0.57)	1.2 (0.51)	1.2 (0.38)	1.4 (0.47)	1.2 (0.43)	1.2 (0.45)	<0.01

VR virtual reality; *Ped*. pedestrian; *IV* intervention; *FU* follow-up. Hits/close calls are count. Attention to traffic represents looks left and right divided by waiting time. Start delay is seconds after safe gap appears before child enters roadway

[a] *p* value for interaction between time and condition in ANOVA model

Table 3

Correlations between pedestrian safety knowledge and pedestrian behavior, full sample ($N = 231$)

Variable	Knowledge		
	Pre-IV	Post-IV	Follow-up
Hits/close calls—field	−0.05	−0.03	0.01
Attention to traffic—field	−0.09	0.01	0.00
Start delay—field	0.02	0.06	0.01
Hits/close calls—VR	−0.13	−0.27**	0.12
Attention to traffic—VR	0.03	0.06	0.01
Start delay—VR	−0.15*	−0.05	0.05

Note Knowledge is sum of 10 items. *IV* intervention; *VR* virtual reality. Hits/close calls represent a count over 30 trials in the field and a count of 16 trials in the VR. Attention to traffic represents ratio of looks over wait time. Start delay is time

* $p < 0.05$,

** $p < 0.01$

Table 4

Correlations between change in pedestrian safety knowledge and change in pedestrian behaviors, from pre-intervention to post-intervention

Δ Knowledge correlated with Δ:	**VR (*n* = 59)**	**Streetside (*n* = 57)**	**Video (*n* = 57)**	**Control (*n* = 58)**	**Overall (*N* = 231)**
Field measures					
Hits/close calls	−0.07	−0.04	−0.07	−0.07	−0.04
Attention to traffic	−0.25	0.06	0.20	−0.25	0.01
Start delay	−0.10	−0.17	−0.02	0.10	0.07
VR measures					
Hits/close calls	−0.18	−0.05	0.05	−0.10	−0.09
Attention to traffic	−0.23	0.07	0.20	0.02	−0.03
Start delay	0.08	0.06	−0.23	−0.00	0.05

Note Δ Delta, or Change in; Knowledge is sum of 10 items; *VR* virtual reality. Hits/close calls represent a count over 30 trials in the field and a count of 16 trials in the VR. Attention to traffic represents ratio of looks over wait time. Start delay is time