Published in final edited form as:
Health Psychol. 2014 July ; 33(7): 628–638. doi:10.1037/hea0000032.

Teaching Children to Cross Streets Safely: A Randomized Controlled Trial

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Abstract

Objective—Child pedestrian injury is a global public health challenge. This randomized controlled trial considered comparative efficacy of individualized streetside training, training in a virtual pedestrian environment, training using videos and websites, plus no-training control, to improve children's street-crossing ability.

Methods—Pedestrian safety was evaluated among 231 seven- and eight-year-olds using both streetside (field) and laboratory-based (virtual environment) trials prior to intervention group assignment, immediately post-training, and six months post-training. All training groups received six 30-minute sessions. Four outcomes assessed pedestrian safety: start delay (temporal lag before initiating crossing), hits/close calls (collisions/near-misses with vehicles in simulated crossings), attention to traffic (looks left and right, controlled for time), and missed opportunities (safe crossing opportunities that were missed).

Results—Results showed training in the virtual pedestrian environment and especially individualized streetside training resulted in safer pedestrian behavior post-intervention and at follow-up. As examples, children trained streetside entered safe traffic gaps more quickly post-training than control group children and children trained streetside or in the virtual environment had somewhat fewer hits/close calls in post-intervention VR trials. Children showed minimal change in attention to traffic post-training. Children trained with videos/websites showed minimal learning.

Conclusion—Both individualized streetside training and training within virtual pedestrian environments may improve 7- and 8-year-olds' street-crossing safety. Individualized training has limitations of adult time and labor. Virtual environment training has limitations of accessibility and cost. Given the public health burden of child pedestrian injuries, future research should explore innovative strategies for effective training that can be broadly disseminated.

Keywords

pedestrian; street-crossing; injury; safety; randomized controlled trial

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Child pedestrian injury is a global public health challenge. 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). Global data are less precise, but alarming. Estimates exceed 30,000 child pedestrians killed annually worldwide (Toroyan & Peden, 2007).

Among the target age group for this research, children ages 7 and 8, there were 37 pedestrian injury deaths and 3,792 pedestrian injuries treated in emergency departments in 2010 (NCIPC, 2013). Several studies document that young children regularly negotiate street environments alone, especially when going to and from school (Macpherson, Roberts, & Pless, 1998; Martin, Lee, & Lowry, 2007; McDonald, Brown, Marchett, & Pedroso, 2011). 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 (Agran, Winn, & Anderson, 1994; DiMaggio & Durkin, 2002; Lightstone, Dhillon, Peek-Asa, & Kraus, 2001) – with mid-block crossings particularly dangerous near schools (Warsh, Rothman, Slater, Steverango, & Howard, 2009) – and typically within a half-mile of the child’s home (Lightstone et al., 2001) or school (Warsh et al., 2009).

A wide range of behavioral and environmental factors contribute to child injury risk. Prominent among them is children’s development. Engaging in street environments safely is a complex intrapsychic task that requires accurate perception of the street environment and the vehicles traveling in it, efficient cognitive processing of that environment to make a decision about the safety of continuously appearing and changing traffic gaps, and initiation and maintenance of motoric movement to traverse the street. Because children are actively learning and developing the perceptual, cognitive, and motoric skills to be safe pedestrians during middle childhood (e.g., Barton, 2006; Schieber & Thompson, 1996; Whitebread & Neilson, 2000), they have higher risk of pedestrian injuries.

A range of programs have been developed and tested to teach children the skills needed for safe pedestrian behavior (see Duperrex, Bunn, & Roberts, 2002; Schwebel, Davis, & O’Neal, 2012 for reviews). Available interventions have varying efficacy, but the existing literature consistently demonstrates that most children have the developmental capacity to learn safe pedestrian behavior with appropriate practice and training by age 7 or 8, and perhaps earlier. Studies of individualized or small-group training by a skilled adult pedestrian at streetside locations, for example, yield improved pedestrian behavior that is retained over time (Barton, Schwebel, & Morrongiello, 2007; Demetre et al., 1993; Rothengatter, 1984; van Schagen, 1988). Early studies of training in non-immersive virtual pedestrian environments indicate promise that training in virtual environments may also be effective at improving pedestrian behavior (Bart, Katz, Weiss, & Josman, 2008; McComas, MacKay, & Pivik, 2002; Thomson et al., 2005). Studies investigating other training tools, including classroom-style education (Berry & Romo, 2006; Cross et al., 2000; Hotz et al., 2004, 2009; Stevenson, Iredell, Howat, Cross, & Hall, 1999), videos (Preusser & Lund , 1988; Zeedyk & Wallace, 2003), and computer software (Glang, Noell, Ary, & Schwarz, 2005; Tolmie et al., 2005), offer mixed results, with many reporting increased knowledge about children exposed to the training but several reporting poor transfer to safer behavior patterns.

What remains untested in large randomized trials is which interventions might teach children necessary components of safe pedestrian behavior most effectively, and whether different interventions may be more effective at teaching different components of pedestrian safety. Identification of pedestrian training programs that are efficacious could play a significant role in intervention dissemination to reduce child pedestrian injury rates nationally and globally.

The present study considered three strategies of pedestrian safety training in a randomized controlled trial with seven- and eight-year-old children. Participating children were randomly assigned to one of four conditions. One group of children received training using widely available video and internet programs on pedestrian safety. These programs represent the most commonly used strategy for child pedestrian safety training in the United States, and have been demonstrated previously to have good efficacy to transfer knowledge to children but limited efficacy to create behavior change (Glang et al., 2005; Preusser & Lund, 1988; Tolmie et al., 2005; Zeedyk & Wallace, 2003). A second group of children received individualized training at streetside locations with an adult researcher. Individualized streetside training has been shown in initial trials to be an effective strategy to train children in safe pedestrian behavior (Barton et al., 2007; Demetre et al., 1993; van Schagen, 1988; Yeaton & Bailey, 1983). A third group of children received individualized training in a semi-immersive, interactive virtual pedestrian environment. Training was tailored to the child's ability and consisted of repeated crossings in the virtual environment with feedback concerning safety of those crossings. Early work with non-immersive virtual environments suggests children might learn pedestrian safety via such strategies (Bart et al., 2008; McComas et al., 2002; Thomson et al., 2005), but largescale randomized trials have not yet been published. The fourth and final group of children was randomly assigned to be in a control group and received no pedestrian safety training as part of the research program. Our focus was on mid-block crossing on two-lane bi-directional roads, without traffic signals. All participating children completed both field and laboratory-based assessments of pedestrian behavior prior to the intervention, immediately following the intervention, and six months after the intervention was completed. Based on the existing literature, we hypothesized that children trained at streetside locations and those trained in the VR would show superior improvement in pedestrian safety skills compared to those trained using videos and internet programs or the control group. We expected this result to be true both for broad pedestrian skills (hits/close calls in simulated crossings) as well as for specific key components of pedestrian safety (attention to traffic, delay entering safe traffic gaps) and for crossing efficiency (crossing when safe opportunities arise).

Methods

Participants

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

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

The Virtual Reality Pedestrian Environment

The virtual reality (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 mid-block and crosses a two-lane bi-directional road. Children are semi-immersed atop a wooden curb with three monitors in front of them. 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, such that the environment switches from first person to third person and allows children to learn whether their crossing was safe or not. The avatar walks at the child's typical walking speed (as assessed previously in a different room across five trials).

The virtual environment includes ambient and traffic noise and has been validated in a trial demonstrating behavior in the virtual world matched behavior in the actual street environment, both among children and adults (Schwebel et al., 2008). A short video demonstrating the virtual environment is available at http://www.uab.edu/psychology/psy-fac/33-primary-faculty/66-dr-david-c-schwebel

General Protocol

Following consent processes, children completed 12 (if randomly assigned to an intervention group) or 6 (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 (field) environments (details below). Following pre-test assessment, children were randomly assigned to one of four groups: the virtual reality training group, the video/computer training group, the streetside training group, or the no-contact control group. Training in all three intervention groups was comprised of six sessions, scheduled bi-weekly over 3 weeks. Soon after intervention sessions were completed, post-training pedestrian safety measures were collected during two visits, one in the laboratory and one in the field. Finally, two follow-up sessions assessed pedestrian behavior in the laboratory and field six months after completion of the intervention. Protocols for each session appear below.

Pre-Training Assessment

Two sessions, one in the laboratory and the other in the field, assessed pre-training baseline measures of children's pedestrian abilities. The laboratory visit was comprised of 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. Prior to virtual reality assessment trials, children completed 8 practice trials and received standardized instructions to cross when they perceived the virtual 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 8 crossings using the "shout" technique, whereby they stood immediately adjacent to the road and shouted "now" when they deemed it safe to cross (Demetre et al., 1992). Children also completed 8 crossings using the "two-step" technique, whereby they stood two steps off the curb, and took two steps toward the road to indicate when they deemed it safe to cross (Demetre et al., 1992). Measures of pedestrian behavior derived from the streetside and virtual road simulations appear below under the header, "Pedestrian Measures".

Virtual Reality Training

Children in the virtual reality training group received six sessions of training in the VR environment, each comprised of three segments of 15 virtual crossings (45 total crossings per session). Each crossing was accompanied by computer-generated feedback concerning safety; this feedback was delivered by a child-friendly cartoon character who cautioned greater safety in the case of a hit or close call, and who provided positive verbal feedback in the case of a safe crossing. Difficulty of crossing, defined by both traffic density and speed of traffic, was tailored to children's abilities, with the goal that children succeed on about 85% of trials and traffic became increasingly difficult as success rates improved.

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. The tools were chosen based on their broad use (e.g., recommended by state Departments of Transportation), broad accessibility (accessible to broad population), and relevance (focused primarily on child pedestrian safety). Each session lasted about 30 minutes. Materials presented, by trial, were:

Training Trial 1: WalkSmart computer software (Oregon Center for Applied Research)

Training Trial 2: I'm no Fool video (Disney) and Willie the Whistle video (National Safety Council/National Highway Traffic Safety Association, US Department of Transportation)

Training Trial 3: Safer Journey website (Federal Highway Association, US Department of Transportation)

Training Trial 4: Step to Safety with Asimo video (National Safety Council/Honda Motor Company) and Otto the Auto School Bus Safety video (AAA Foundation for Traffic Safety)

Training Trial 5: Otto the Auto computer software (California State Automobile Association, American Automobile Association)

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

Streetside Training

Children in the streetside behavioral training group were exposed to six sessions of individualized streetside training from trained 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, chaining) and developed from strategies used by Rothengatter (1984), Young and Lee (1987), and Barton and colleagues (Barton et al., 2007). A semi-structured and flexible approach educated children based on each child's strengths, limitations, and abilities (as judged by the trainer during training sessions), with two primary foci: attending to traffic in both directions and selecting safe traffic gaps. Streetside locations were selected at marked crosswalks that became increasingly more challenging (heavier traffic) across the six 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. At both time points, two sessions were 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). The 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 five weeks after the pre-intervention assessment ended for children in the control group (M=36.2 days, SD = 12.4). Thus, the same amount of time (about 5 weeks) passed between pre-training and post-training across all groups, including the control group, allowing for control of any developmental effects of time passage. The follow-up assessment occurred approximately six 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. Each offered pros and cons. The VR offered a controlled traffic scenario whereby we could standardize speed and volume of traffic across participants; remove potential bias from weather, time of day, and other environmental characteristics; and obtain precise computer-driven measurement of behavior. The field assessment offered a more realistic and ecologically valid measure of behavior with real-world traffic (and the emotions that go along with it). Four outcome measures of pedestrian safety were considered: hits/close calls, attention to traffic, start delay, and missed opportunities (See Table 1).

Hits/close calls were included as a gross outcome measure of pedestrian safety, a count of crossings that are highly risky – the child would either have been hit by a vehicle had it been an actual rather than a simulated crossing, or would have been within 1 second of being hit by a vehicle. The virtual environment records hits and close calls automatically, with close calls tallied any time the child was within one second of collision with an oncoming vehicle. Children crossed the virtual street 30 times, so results are expressed as a count of hits/close calls out of 30 trials in the VR. 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 average walking speed (assessed during the pre-intervention laboratory trial) over the crosswalk distance in the field was less than one second shorter than the time until the next vehicle entered the crosswalk. Inter-rater reliability for the timing was established and adequate ($r > .95$ between independent coders measuring time, masked to condition, on 20% of sample). Children completed 16 trials in the field, and results are expressed as a count out of 16 trials.

Attention to traffic and start delay were included as two critical components of pedestrian safety. Attention to traffic was measured by looks to the left plus looks to the right while waiting to cross the street, divided by waiting time in minutes, and offers an indication of the pedestrian's attention to the traffic environment. Each head turn in either direction was counted as one turn, such that a look to the left, the right, and the left again would be counted as 3 turns. A single look to the left was counted as one turn. 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 videotape. Coders counted head-turns to the left and to the right, and also timed waiting time. Interrater reliability was again adequate ($r > .95$ between independent coders measuring times and counts, masked to condition, on 20% of sample).

Start delay, defined as the temporal lag (in seconds) before initiation of crossing into a traffic gap, is considered an indicator of children's efficiency of cognitive processing in pedestrian situations (Barton, 2006; Plumert, Kearney, & Cremer, 2004). 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, inexperienced child pedestrians apparently do not begin to process the safety of a traffic gap until that gap appears, causing a significant (e.g., 500-2000 milliseconds) temporal delay before children enter a safe gap. That delay increases injury risk.

Start delays were assessed automatically in the VR, defined as the temporal gap between the gap crossed within appearing (that is, the last vehicle passes the crosswalk) and the child initiating crossing by stepping off the curb. Start delays were assessed in field trials via coding of videotaped behavior. Coders watched tapes and used a computer-based stopwatch to record the time between the last vehicle leaving the crosswalk and the child perceiving a safe crossing opportunity by indicating with a shout "now" (shout task) or the first foot landing on the ground (two-step task). Inter-rater reliability was established for the coding and was adequate ($r > .95$ between independent coders measuring times, masked to condition on 20% of sample).

Missed opportunities do not represent a measure of pedestrian safety but rather a measure of the pedestrian's efficiency in pedestrian behavior. Tallied as instances when a traffic gap that was 1.5 or greater times the time needed for the child to cross the street, but the child chose not to cross, a high number of missed opportunities reflects inefficiency in pedestrian behavior. These instances were counted electronically in the VR and by videotape review in the field. There was very low variance of missed opportunities in the field, so the field assessment was dropped from analysis due to poor variance. Results from the VR are expressed as a count out of 30 trials, with multiple missed opportunities possible within a single crossing trial.

All field pedestrian measures were computed separately for the two-step and the shout tasks. Because trends for the two-step and shout tasks were similar across intervention groups, we aggregated behavior across the two assessment strategies to create single field measures of pedestrian behavior.

Other Measures

Basic demographic information was reported by parents at the initial laboratory visit. A verbal intelligence screening was conducted using the Peabody Picture Vocabulary Test-IV (PPVT-4; Dunn & Dunn, 2007). Normed on a large national sample, the PPVT-4 has excellent internal and test-retest reliability, and converges well with other measures of verbal intelligence (Dunn & Dunn, 2007; Pullen, Tuckwiller, Konold, Maynard, & Coyne, 2010).

Children's pedestrian experience was assessed by parent report using the pedestrian behavior questionnaire (Stavrinos et al., 2009), which assesses children's typical weekly walking habits in multiple domains (e.g., to school, to friends' houses, to walk dog, etc.). Responses were summed to yield parent-report of the child's total average weekly distance walked.

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 (categorical variables) and analysis of variance (continuous variables). Primary hypotheses were tested using repeated-measures analysis of variance (ANOVA) with pedestrian behavior, assessed with four measures in the lab and three measures in the field, serving as 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 if so, we performed contrasts to determine which pairs of conditions differed over time. Due to inequality of variances across condition and time for the field measures, as assessed via the Levene (1960) test, we allowed the variance to vary by condition/time combination in the repeated measures model and incorporated this into the tests of the interaction. 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. Both unadjusted and adjusted (*p*-value multiplied by 12) values are presented.

Specifically, we fit the following model:

$$Y_{ijk}=\beta_0+\beta_1 * VISIT+\beta_2 * CONDITION+\beta_3 * VISIT * CONDITION+\varepsilon_{ijk}$$

where Y_{ijk} is the response (as presented in Table 1) measured on the i^{th} subject (i=1,…, 60) within the j^{th} condition (j=control, VR, streetside, video) at the k^{th} visit (k=pre, post, follow-up). In this model formulation, the parameter vector associated with condition has 3 degrees of freedom (due to 4 levels of the variable), and the parameter associated with visit has 2 degrees of freedom (due to the 3 levels of the variables). Thus, the parameter vector associated with the interaction has 3x2 degrees of freedom. For each model, we considered the pre-intervention visit to be the reference visit and the VR condition to be the reference value. Thus, the pre-intervention visit for the VR group was the reference value for the interaction. The parameter estimates and their standard errors from the models for each outcome are presented in Supplemental Table 1. Note that in this table, parameter estimates presented represent differences from that level to the reference.

We assumed sphericity (compound symmetry) for the covariance structure unless we found the variance to differ across combinations of visit and condition, in which case we allowed variance components to be estimated for each visit/condition combination. We assessed symmetry univariately at each visit/condition combination via ocular inspection, and encountered one situation for which the data were not approximately symmetric (missed opportunities in the field). We adjusted the missed opportunities in the field variable by dichotomizing it (0 vs. 1 or more) and assessed that variable via generalized linear mixed model prior to dropping it from consideration due to lack of variation across groups even when dichotomized.

Results

Table 2 presents descriptive data for those children who were randomized, both overall and by intervention group (n=231). As expected, no groups differed statistically on the baseline factors. We also 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 on demographics (age and gender), pedestrian experience, and randomized group assignment. Given this, subsequent analyses were conducted in a pairwise manner, with all available data.

Table 3 presents descriptive data and p-values for the interaction between condition and time for seven repeated-measures ANOVAs. As shown, five of the seven models yielded statistically significant interactions, indicating that the changes over time differed by condition.

Results from the field assessments are presented graphically in Figure 2. The four groups started with similar mean start delays but the streetside group showed a sharp increase in mean start delay post-intervention whereas the other three groups showed a modest decrease, with the VR group showing the sharpest decrease post-intervention. By the follow-up assessment, all four groups returned close to baseline. Contrasts comparing the slopes found that the streetside group changes differed from all three other groups (unadjusted *p*s < .0001, adjusted *ps* < 0.01), suggesting the intervention had influence on the children, and especially on the group trained streetside which may have become more conscious of the decision-making process to cross a street and therefore took slightly longer to make the decision immediately after the training. The children trained in the VR also showed change; those children may have practiced decisionmaking enough that the process became streamlined somewhat post-intervention.

All four groups showed a modest increase in close calls during field trials from pre to post assessment, with the children trained in the video group showing the sharpest, but not statistically different, increase. Three of the four groups then showed a modest decrease upon follow-up, perhaps reflecting six months of development; children trained at streetside locations did not show that decrease as clearly and the contrast was not statistically significant. Data from the attention to traffic assessment during field trials are also shown in Figure 2. Results were not statistically significant but indicate a trend for the children trained in the VR to have less attention to traffic following training, with the other groups staying consistent or showing a slight increase. During the six months from post-intervention to follow-up assessments, the control group showed a sharp decrease in attention to traffic whereas the other three groups maintained similar levels of attention to traffic.

Results from laboratory assessments of pedestrian safety in the VR also appear in Figure 2. For all four outcomes, changes over time varied across the four groups. Results from the assessment of start delay are very similar to those of the same measure from the field assessment. The streetside group showed an increase in start delay immediately post-intervention, followed by a sharp decrease upon follow-up six months later. The other three groups showed a steady decline in start delay over time, with the VR group showing the sharpest decrease post-training. As was found in the field assessment, contrasts comparing the slopes found that the streetside group changes differed from all three other groups (unadjusted *p*s < .0001 and adjusted *p*s < .01 for all contrasts except video vs. streetside groups from post to follow-up, for which unadjusted $p < .05$ and adjusted $p = .53$.

Results from the assessment of hits and close calls in the VR also show parallels to the field measurement assessment. Both the streetside and VR-trained groups showed a decrease in hits/close calls when crossing in the virtual environment post-training; the children trained with videos and internet websites showed a modest increase, and the control group of children showed a notable increase in dangerous crossings during the post-training assessment. The differences between the streetside and control groups and between the VR and the control groups were statistically significant in unadjusted analyses from pre- to post-training (unadjusted *p*s < .05; adjusted *p*, streetside vs. control = .11, VR vs. control = .31). All four groups showed a decrease between post-training and follow-up assessments, perhaps reflecting the six months of development that had occurred.

Results from the assessment of attention to traffic in the VR were quite different from the assessment in the field. In the virtual environment assessment, the group trained in the VR demonstrated a sharp increase in attention to traffic immediately following training, and then a continued increase at follow-up. The children trained with videos/internet and at streetside locations showed little change immediately following training but a sharp increase at follow-up. The control group showed modest increases throughout assessments but minimal change compared to the three groups of children who received training. No contrasts were significant after applying the Bonferroni adjustment. Unadjusted statistically significant contrasts included the following for pre- to post-intervention change: VR vs control groups (unadjusted $p < .05$; adjusted $p = .24$), VR vs. streetside training (unadjusted $p < .01$; adjusted $p = .05$); and the following for post-intervention to follow-up assessment: streetside vs. video groups (unadjusted $p < .05$; adjusted $p = .22$).

Finally, we examined instances of missed opportunities in the virtual reality assessments. Missed opportunity data were skewed with a long positive tail; results examining medians were very similar to those with means and data from means are presented. Children trained at streetside locations showed a large increase in missed opportunities following training, followed by a decrease at follow-up six months later. Children trained in the VR showed the opposite pattern: a sharp decrease following training, followed by a modest increase at follow-up. The children trained with videos/internet showed minimal change across time and the control group of children showed a slight decrease in missed opportunities across the assessments. Post-hoc contrasts found that the streetside group differed from all three other groups at a statistically significant level (unadjusted ps < .001 from pre- to post-intervention, adjusted ps <.05; unadjusted ps < .05 from post-intervention to follow-up, adjusted p, streetside vs. VR=.04; adjusted p, streetside vs. control = .57; adjusted p streetside vs. video = .12).

Discussion

Taken together, results indicate that both individualized streetside pedestrian safety training and training within a semi-immersive and interactive virtual pedestrian environment show promise as effective strategies to train 7- and 8-year-old children to cross streets more safely. Individualized streetside training in particular yielded consistently safer pedestrian behavior compared to children trained for an equal amount of time using widely-available videos and internet websites and compared to children who received no training.

These results are consistent with the existing literature on pedestrian safety training for children (see Duperrex et al., 2002; Schwebel et al., 2012 for reviews). The present results support other research that suggests individualized streetside training is effective to teach children to cross streets more safely (e.g., Barton et al., 2007; Demetre et al., 1993; van Schagen, 1988; Yeaton & Bailey, 1983). They also support initial pilots in non-immersive virtual pedestrian environments that suggest pedestrian safety training in VR may be effective (Bart et al., 2008; McComas et al., 2002; Thomson et al., 2005). Finally, they lend support for the mixed results previously reported concerning training using videos and software (Glang et al., 2005; Preusser & Lund, 1988; Tolmie et al., 2005; Zeedyk & Wallace, 2003), indicating the need to be cautious in assuming children might learn to cross streets more safely based on such educational programs.

The two training strategies that appear to be most effective, individualized streetside training and training within virtual environments, each offer advantages and disadvantages to schools, community centers, and others who may wish to train children in how to cross streets safely. Individualized streetside training is laborious. It requires a competent adult pedestrian to spend at least a few hours with a child, teaching the cognitive-perceptual aspects of safe pedestrian behavior while offering repeated practice, with feedback about success, at the task. One might compare this process to teaching a child to hit a baseball or a tennis ball; repeated practice at the cognitive, perceptual, and motor skills needed helps a child hone the skill, and feedback about the success of trials is valuable. Innovative strategies to accomplish such training, such as the Kerbcraft program that recruits retired older adults to train schoolchildren in the United Kingdom, are available and have empirical support for efficacy (Whelan et al., 2008).

Training in a virtual pedestrian environment also offers the opportunity for repetitive practice at the cognitive, perceptual, and motoric aspects of pedestrian behavior, but requires less intensive individualized attention. In fact, virtual environments can be arranged to permit children's use without adult supervision. A significant disadvantage of training children in virtual pedestrian environments is the lack of accessibility. Most schools and community groups do not have access to virtual pedestrian environments, nor to the financial resources to purchase them. Suitable alternatives that can be offered to large numbers of children at minimal cost via the internet must be identified. One possibility, currently under development in our laboratory (Schwebel & McClure, 2013), is the notion of delivering a VR-type experience over the internet. If, as hypothesized, the key component of pedestrian training is repeated practice at the cognitive-perceptual task of crossing a street, then a sacrifice in realism that occurs from moving VR from a three-dimensional immersive experience to a two-dimensional internet experience may not detriment training, and it could be delivered globally to any school with internet access.

Our results indicate that one of the most widely-used training tools currently, a combination of publicly-accessible videotapes and internet websites, was an ineffective training strategy. Although videos and websites hold appeal due to their accessibility, our results indicate they are a poor choice for interventionists.

We assessed pedestrian safety outcomes with two modalities (streetside and virtual reality assessments) and multiple measures (start delay, hits/close calls, attention to traffic, and missed opportunities). On the surface, it may seem that our results were inconsistent across outcome measures. Pedestrian behavior is multifaceted, however; children do not simply learn to cross streets safely, but rather must learn to attend to traffic, to judge the safety of traffic gaps, and then to initiate movement into the street. Each of those components – and they can be divided further into subcomponents – must be mastered for a child to become a safe pedestrian.

Our results suggest that children trained in the virtual environment had fewer hits/close calls in both field and laboratory assessments post-training. Hits/close calls with vehicles represent a critical outcome of interest, as they reflect potential for serious or fatal injury. The reduction in hits/close calls may be explained in part by the reduction in start delays shown by children trained in the VR; with more efficient cognitive processing of the pedestrian environment, start delays can be reduced and safety improved. Interestingly, children's attention to traffic was inconsistent across measurement domains following training in the VR, with greater attention demonstrated in the VR assessment following training but lesser attention demonstrated in the field. Taken together, we might conclude that training in a virtual pedestrian environment improves children's cognitive processing and safety but that influence on attention to traffic is unclear. Of note is the possibility that children might have adequate attention to traffic prior to training – that is, by age 7 children might typically show adequate attention to traffic in pedestrian settings because they already have the developmental capacity to recognize the importance of looking for traffic when approaching a street-crossing. It may be that the cognitive aspects of pedestrian behavior are deficient and in need of practice and training at age 7 or 8, not the attentional aspects. This possibility is supported by the fact that looks per minute reported in the present sample are comparable to those reported in our previous work with samples of adults (Stavrinos, Byington, & Schwebel, 2011; Schwebel et al., 2012) and adolescents ages 14–15 (Davis, Avis, & Schwebel, in press). In contrast, children's scores on hits/close calls, start delay, and missed opportunities are generally far inferior to those reported among adults and adolescents, even after training. Also of note is the fact that traffic volume and density was consistent, constant and rather thick in the VR but varied much more greatly in the field, where natural traffic patterns, with larger gaps and more irregular density and volume across participants emerged.

Children trained individually at streetside locations showed longer start delays posttraining that became much shorter at follow-up in both field and VR assessments. Thus, there is evidence that streetside training improves children's cognitive processing of pedestrian situations. Our results were somewhat inconsistent across assessment strategies for measures of attention and hits/close calls among children trained streetside, however. Children trained with videos/internet programs demonstrated little improvement in any domains of pedestrian behavior in post-training assessments.

We considered post-training pedestrian behavior on two occasions, both immediately post-training and at a six-month follow-up visit. Individual trends varied somewhat across components of pedestrian behavior and across measurement strategies, but the general trend was for safety improvements to be retained over the six-month follow-up period. Of course, children also experienced six months of development in cognition, perception, and other relevant pedestrian skills during that half-year, as represented by improved scores among the control group on several relevant measures.

Like all research, this study had limitations. One limitation was a measurement issue. Although all participating children were given orientation trials in the VR before data were collected, children in the VR training group had extensive experience in the VR, and that practice may potentially have impacted their performance in the VR assessment trials. Similarly, children trained in streetside locations had more practice deciding when to cross in streetside simulations and therefore may have had elevated performance in field assessment trials (though note that field assessments were deliberately conducted in a different location than streetside training sessions).

A second limitation is specific to the streetside assessment trials. Naturalistic field trials offer advantages. Specifically, they incorporate real traffic patterns, which typically involve clusters of heavy traffic followed by “windows” of light traffic. However, inevitably some children experienced heavier traffic density during field trials than others. Periodic large windows of light traffic provided easy crossing opportunities and reduced variance in some outcome measures. Close call opportunities were rarer in the field trials, and missed opportunities were so rare that we were unable to assess them meaningfully in the field, as a very large portion of the sample had no missed opportunities at all in the field. These inconsistencies in the naturalistic trials may partly explain why results varied somewhat across outcome measurement strategies.

A third limitation is the sample size. Although our *a priori* power analyses indicated a sample of 240, accounting for attrition, would be adequate to detect medium effect sizes, it was not sufficient to detect smaller effect sizes that may be meaningful and important to public health. Several of the findings were statistical trends that may prove significant in larger replications as well as in applied community practice where large numbers of children are trained. Finally, our study focused only on mid-block unsignalled crossings. We did not assess learning or behavior at signaled intersections or other aspects of pedestrian skill that may lead to injury risk.

In conclusion, this RCT suggests 7- and 8-year-old children may gain critical streetcrossing knowledge through training in a VR environment or individualized streetside training. Future research should build from these findings to develop, evaluate, and then implement lowcost methods to train children in pedestrian safety that can be disseminated widely.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Thanks to Elizabeth O’Neal, Anna Johnston, Ksenia Shingareva, and the students of the UAB Youth Safety Lab for their extensive help with data collection, entry, and coding; Jodie Plumert and Kathy Christoffel for consulting advice; Aeron Gault for IT support; and the Digital Artefacts team for VR development and support. The research was supported by Award Number R01HD058573 from the Eunice Kennedy Shriver National Institute of Child Health & Human Development. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Eunice Kennedy Shriver National Institute of Child Health & Human Development or the National Institutes of Health.

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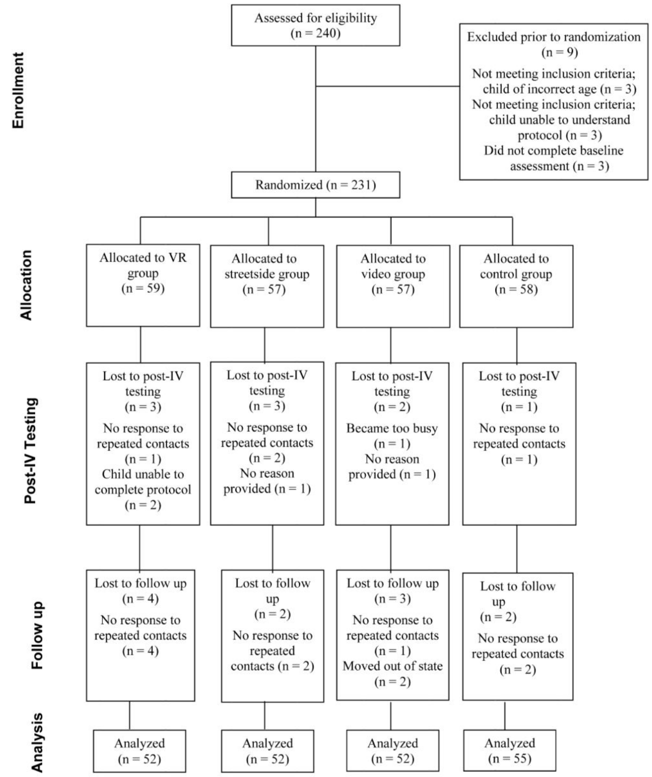

Figure 1.
CONSORT flowchart of study enrollment.

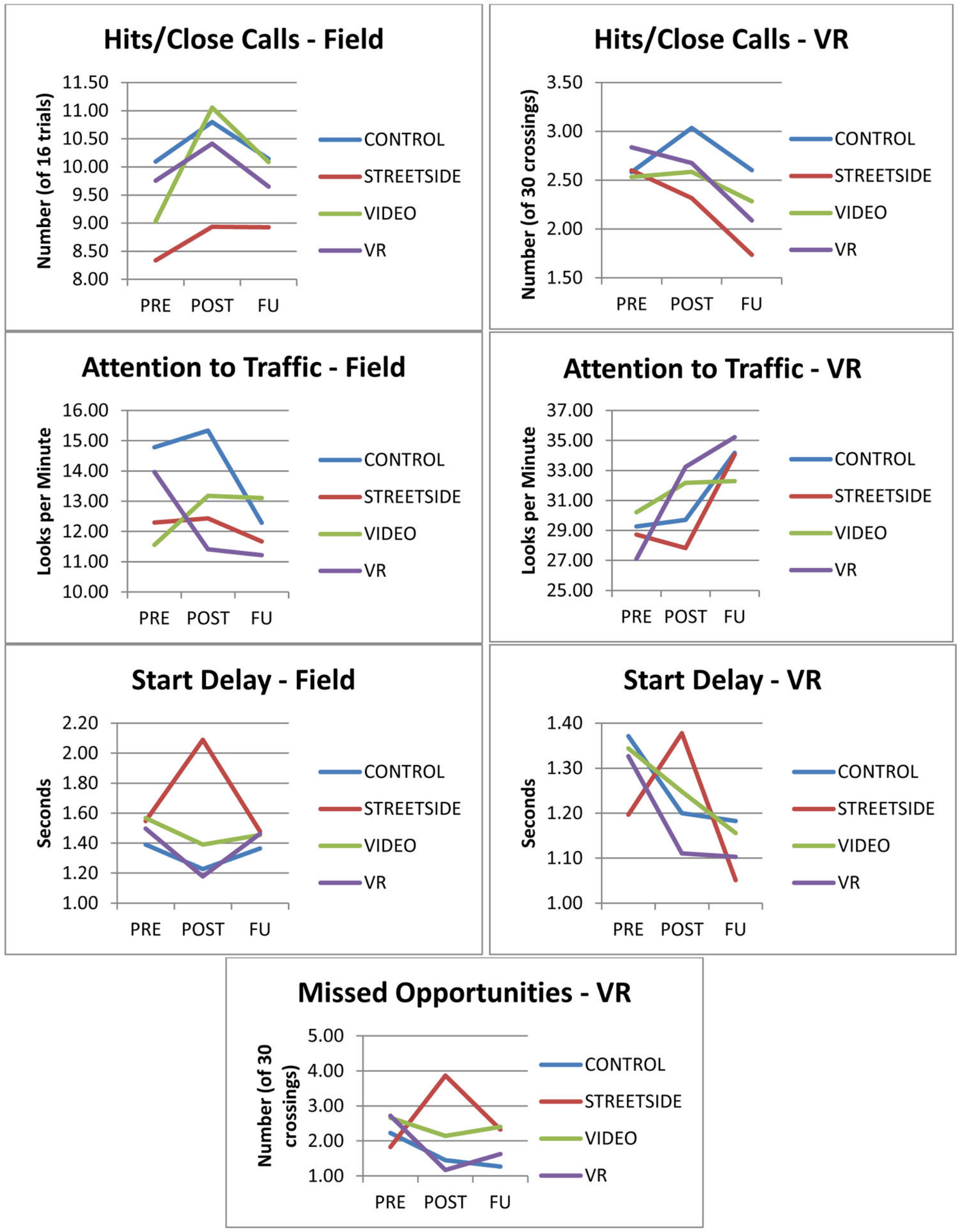

Figure 2.

Results from Field and VR Trial Outcomes: Group Means by Condition and Assessment Point.

Table 1

Summary of Outcome Measures

Variable	Assessing	Type	Units	Possible Range
Field Measures				
Hits/Close Calls	Dangerous Injury Outcomes	Count	Number	0–16
Attention to Traffic	Looking at Traffic Environment	Continuous	Looks/Wait Time	0-∞
Start Delay	Cognitive Processing	Continuous	Seconds	0-∞
VR Measures				
Hits/Close Calls	Dangerous Injury Outcomes	Count	Number	0–30
Attention to Traffic	Looking at Traffic Environment	Continuous	Looks/Wait Time	0-∞
Start Delay	Cognitive Processing	Continuous	Seconds	0-∞
Missed Opportunities	Crossing Efficiency	Count	Number	0-∞

Table 2

Descriptive Data: Percentages and Means(SD)

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)[1]	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					
% < $40k	27	22	26	28	28
% $40k-<$100k	38	27	35	28	38
% >= $100k	35	27	37	40	33
PPVT-4 IQ Screen[1]	106 (16)	107 (16)	108 (16)	104 (18)	105 (15)
Pedestrian Experience[2]	2.5 (0.3, 5.8)	2.1 (0.3, 5.1)	2.1 (0.5, 4.5)	2.5 (0.1, 5.7)	3.3 (0.4, 7.0)

[1] Mean (Standard Deviation) reported for this continuous variable.

[2] Median (25 th percentile, 75 th percentile) reported for this highly skewed continuous variable.

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Table 3

Descriptive Data: Outcome Measure Means (SD)

	VR			Streetside			Video			Control			
	Pre IV	**Post IV**	**FU**	**Pre IV**	**Post IV**	**FU**	**Pre IV**	**Post IV**	**FU**	**Pre IV**	**Post IV**	**FU**	***p*[1]**
Field													
Hits/Close Calls (count over 16 trials)	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)	0.78
Attention to Traffic (looks/wait time)	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
Start Delay (seconds)	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)	<0.001
VR													
Hits/Close Calls (count over 30 trials)	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
Attention to Traffic (looks/wait time)	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
Start Delay (seconds)	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
Missed Opportunities (count over 30 trials)	2.7 (4.2)	1.2 (1.6)	1.6 (1.9)	1.8 (2.0)	3.9 (4.6)	2.3 (2.3)	2.7 (4.3)	2.1 (3.6)	2.4 (5.5)	2.2 (3.5)	1.5 (3.0)	1.3 (1.8)	<0.0001

[1] P-value for interaction between time and condition in ANOVA model.

Note. 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.