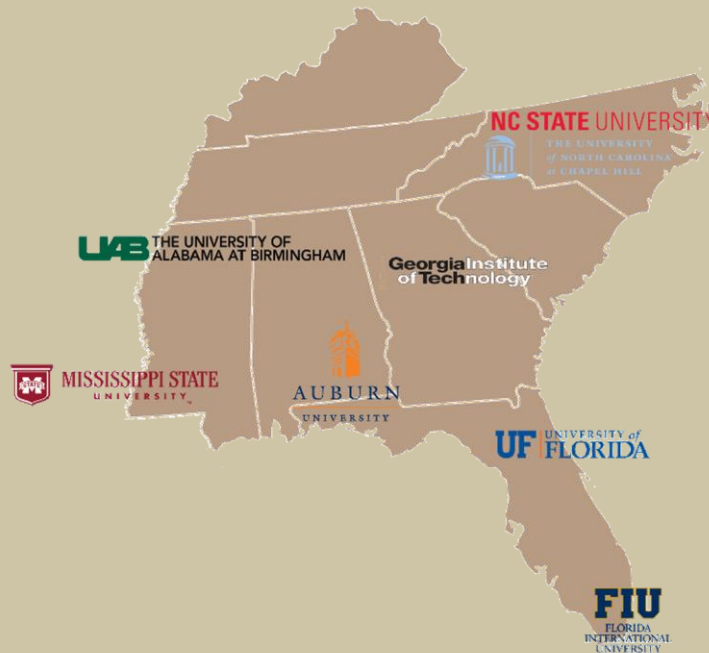2015

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Final Report

Community-Based Pedestrian Safety Training in Virtual Reality: A Pragmatic Trial

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Abstract

Child pedestrian injuries are a leading cause of mortality and morbidity across the United States and the world. Repeated practice at the cognitive-perceptual task of crossing a street may lead to safer pedestrian behavior. Virtual reality offers a unique opportunity for repeated practice without the risk of actual injury. This study conducted a pragmatic pre-post within-subjects trial of training children in pedestrian safety using a semi-mobile, semi-immersive virtual pedestrian environment placed at schools and community centers. Pedestrian safety skills among a group of 44 seven- and eight-year-old children were assessed in a laboratory, and then children completed six 15-minutes training sessions in the virtual pedestrian environment at their school or community center over the course of three weeks. Following training, pedestrian safety skills were re-assessed. Results indicate improvement in delay entering traffic following training. Safe crossings did not demonstrate change. Attention to traffic and time to contact with oncoming vehicles both decreased somewhat, perhaps an indication that training was incomplete and children were in the process of actively learning to be safer pedestrians. The findings suggest virtual reality environments placed in community centers hold promise for teaching children to be safer pedestrians, but future research is needed to determine the optimal training dosage.

Executive Summary

Almost 5,000 American pedestrians are killed annually, and 207,000 others injured. About one-fifth of injured pedestrians are children. One major reason children have increased pedestrian injury risk compared to adults is because crossing a street requires sophisticated cognitive and perceptual processing, skills that develop during childhood.

Previous research suggests children can learn to be safer pedestrians. In particular, interventions offering repeated practice at crossing a street hold promise to teach children the complex cognitive-perceptual skills required. Such training was traditionally delivered by adults at streetside locations, but recently scholars have explored the use of virtual reality (VR). VR features several advantages for pedestrian safety training: a safe computer-generated environment with realistic images and sounds, a feeling of immersion without risk of actual injury, systematic delivery and control of stimuli to customize training to individual skill, and an engaging and fun learning environment. Further, VR training can be administered with minimal adult supervision and monitoring.

The present study extended previous research using VR to teach children pedestrian safety in two primary ways. First, previously-tested VR environments were not mobile. A system that is fixed to a given location curtails broad dissemination of the intervention. By contrast, a mobile system can be transferred to different schools or community centers where children receive intense training over the course of a few weeks. We therefore refined a previously-developed and validated system to a more mobile VR environment. Second, we sought to conduct a pragmatic trial by testing VR training in a field environment under the usual circumstances of its potential implementation. Rather than training children in a sterile and artificial laboratory environment, we trained children in their schools and community centers, with the inevitable circumstances that arise in community environments.

Using a within subjects pre-post research design, we evaluated children's pedestrian safety at baseline, exposed them to six 15-minute VR training sessions, and re-evaluated pedestrian safety. We hypothesized pedestrian performance would improve across four performance measures: attention to traffic, delay in entering safe traffic gaps, time to contact with oncoming traffic while crossing, and unsafe simulated crossings.

As hypothesized, children's delays to enter traffic decreased slightly and significantly, implying the possibility of more rapid decision-making about gap safety following training. Children's attention to traffic and time to contact by oncoming vehicles both decreased slightly but significantly following training, implying the possibility of slightly greater risk of pedestrian injury following training. There were no significant changes in the rate of unsafe crossings following training. A possible explanation for the pattern of results is that post-training, children made crossing decisions more confidently and more efficiently without sacrificing safety. They may have chosen equally safe but tighter gaps rather than waiting for obviously safe gaps. Post-hoc analyses support this possibility.

This study supports use of VR to teach child pedestrian safety and extends previous findings by installing a semi-mobile VR reality into community settings and implementing a pragmatic trial to test learning. The trial, which used six 15-minute training sessions, seemed to improve children's efficiency in pedestrian crossings but not safety. More intense training, and more replication of the cognitive-perceptual process of crossing streets and receiving feedback about crossing safety, may be required to train children fully. Future research should consider dosage affects – how much training is required to teach children pedestrian skill? Development of VR systems that offer cost and portability for broad dissemination also should be prioritized.

CHAPTER 1. BACKGROUND

Almost 5,000 American pedestrians are killed annually, and 207,000 others injured. About one-fifth of injured pedestrians are children (*1*). One major reason children have increased pedestrian injury risk compared to adults is because crossing a street requires sophisticated cognitive and perceptual processing, skills that develop during childhood. Previous risk assessment work suggests that most 5- to 6-year-olds and some 8-year-olds fail in judging the speed of traffic and choosing safe traffic gaps accurately and consistently when crossing a road (*2, 3*).

Despite cognitive and perceptual challenges, training appears to improve children's skills for safe crossings. A recent systematic review suggests children can learn to be safer pedestrians with appropriate training (*4*). In particular, behavioral interventions that offer individualized repeated practice at crossing a street hold promise toward teaching children the complex cognitive-perceptual skills required to be safe pedestrians. Traditionally, this sort of repeated practice was offered live, at streetside locations, with training closely monitored by competent adult pedestrians (*5-8*). More recently, scholars have explored the use of virtual reality to provide children with repeated practice crossing a street (*4, 9*).

Virtual reality offers several advantages over individualized streetside pedestrian safety training. It provides a safe computer-generated environment with realistic images and sounds that offer a feeling of immersion without the risk of actual injury. It can provide systematic delivery and control of stimuli, customized training to individual skill levels, and an engaging and fun learning environment. Further, virtual reality training can be administered with minimal adult supervision and monitoring. In the most extensive published evaluation of virtual reality

pedestrian safety training, Schwebel and colleagues (*4*) implemented a randomized controlled trial to 240 seven- and eight-year-olds who were randomly assigned to receive pedestrian safety training in a series of six 30-minute sessions within a virtual pedestrian environment, through individualized streetside training, through a series of computer-based games and videos, or to be in a no-contact control group. Results varied somewhat across outcome measures, but generally children trained individually by an adult at streetside locations or through the virtual reality environment demonstrated greater learning than those trained through games/videos or those in the no-contact control group. Specifically, children trained in the virtual environment showed decreases in unsafe crossings and delays entering traffic gaps (start delays) as measured in the virtual environment, increases in attention to traffic while waiting to cross in the virtual environment, and decreases in attention to traffic in field assessments.

The present study was designed to extend previous findings in two primary ways. First, previously-tested virtual reality environments were not mobile. A system that is fixed to a given location curtails broad dissemination of the intervention. By contrast, a mobile system can be transferred to different schools, community centers, or other institutions where children can receive intense training over the course of a few weeks. We therefore refined a previously-developed and validated system to a more mobile environment that could be transported to different settings. Second, we sought to conduct a pragmatic trial by testing virtual reality training in a field environment under the usual circumstances of its potential implementation (*10-12*). Rather than training children in a sterile and artificial laboratory environment, we trained children in their schools and community centers, with the inevitable circumstances that arise in community environments. A pragmatic trial is important because it allows researchers to

understand how the intervention would work in a more realistic situation, closer to what would represent a scaled-up intervention.

Using a within subjects pre-post research design, we evaluated children's pedestrian safety at baseline, exposed them to six 15-minute training sessions within a mobile virtual pedestrian environment, and re-evaluated children's pedestrian safety. We hypothesized pedestrian performance would improve across four performance measures, which we detail below: greater attention to traffic, shorter delay in entering safe traffic gaps, greater time to contact with oncoming traffic while crossing, and fewer unsafe simulated crossings.

CHAPTER 2. RESEARCH APPROACH

PARTICIPANTS

Forty-four 7- and 8-year-old children (mean age = 8.01 years; SD = 0.56; range = 6.8-9) were recruited in 2014 from three sites in the Birmingham, Alabama area: Hemphill Elementary School (n=11), Bluff Park Elementary School (n=28), and the YMCA Downtown Youth Center (n=5). The sample was 52% African-American, 48% Caucasian, and 51% female. Those sites were selected because they have a high proportion of children who walk to school and they were geographically convenient and amenable to collaboration. About one-quarter (26%) of children came from a household with parent-reported annual income of less than $20,000, 21% with household income between $20,000 and $39,999, 23% with household income between $40,000 and $99,999 and 31% with household income greater than $100,000. Based on parent reports, 30% of the sample walked to school regularly (at least once/week and usually considerably more often) and 95% walked on streets regularly (at least once/week and usually considerably more often) for transportation, commuting, or recreation. The sample had a pre-test mean body mass index (BMI) of 17.65 (SE = 0.74, range = 12.24 to 24.98) for girls and 17.83 (SE 0.94, range = 10.69 to 31.11) for boys.

The study protocol was approved by the IRBs at University of Alabama at Birmingham and University of North Carolina Chapel Hill. All parents of study participants provided informed consent and children provided developmentally-appropriate informed assent. All schools and all parents of participants were compensated for their time participating in the study.

SPECIFICATIONS OF THE VIRTUAL ENVIRONMENT

The virtual reality environment was based on a previous semi-immersive virtual environment that was validated to represent real-world behavior among samples of both children

and adults (*13*). It used identical scenery, sound, and responding as the previous system. The

software was upgraded to utilize the Unity gaming platform and runs on a single Windows 7 PC

with an Intel Core i5-3330 3.0GHz Quad-Core desktop processor and GeForce GT 640 video

card. The three screen displays are comprised of 3 vertically mounted Samsung MD55C 55"

Direct-lit LED displays (See Figure 2-1 for photo of system).

Figure 2-1. Photograph of Virtual Reality System Placed in a School

To ease transportability and security, the casing that houses the virtual environment was

constructed of museum-quality materials. It is durable enough to handle heavy use by

intermittently supervised children and frequent transport to different sites, but light enough to be transported. It breaks into 5 parts to fit onto a small truck. The CPU and monitors are situated inside locked cabinets for secure use and storage at schools and community centers. A wireless tablet and keyboard drive the simulator and can be locked in the cabinets when not in use.

USER EXPERIENCE IN THE VIRTUAL ENVIRONMENT

In the virtual environment, children are asked to stand on a simulated curb approximately 3 feet from semi-circular monitors. Children are semi-immersed into the virtual world so they feel a part of the virtual world but have external stimuli in peripheral vision to reduce motion sickness. The stimuli are adjusted to eye-level and provide accurate perspective so the user feels immersed into the environment. While immersed, children view a bi-directional roadway with vehicle traffic modeled after an actual street environment near a local school. The virtual modeling represented all aspects of the actual roadway precisely; the crosswalk span was just under 26 feet long. When children deem it safe, they step off the curb and trigger a pressure plate. The virtual world then changes from an immersive first-person perspective to third-person, permitting children to view their own crossing. This switch from first to third person happens seamlessly; most children report not noticing it.

Vehicle traffic density and volume are adjustable; for training, we used progressively more challenging traffic (faster speed and greater density) over the six sessions, with children exposed to the lightest level of traffic at the first two sessions, a medium level the next two, and a harder level the last two sessions. Vehicle types – selected from over 2 dozen vehicles (including cars, SUVs, pick-ups, ambulances, school buses, etc.) – appeared in random order at a frequency comparable to that seen on the actual crossing site. Ambient and Doppler-accurate traffic noise were delivered through speakers. Following crossings, a cartoon character informed

children of the safety of the crossing using positive reinforcement for successes and cautionary feedback for dangerous crossings. In cases of collisions, the screen froze just before impact and then the cartoon character appeared.

OVERARCHING STUDY PROTOCOL

Children participated in structured assessment sessions prior to the intervention and after the intervention. Both these sessions were held in a university laboratory. Between pre- and post- sessions, children engaged in six 30-minute virtual reality training sessions at their school or community center. Session details appear below.

PRE-TRAINING ASSESSMENT PROTOCOL

The pre-intervention assessment used the less mobile laboratory-based virtual environment (*13*) to assess children's pedestrian skills. Walking speed was assessed based on the average of several 26-foot walks in a separate location (the same distances as the crosswalk span) and measured in miles per hour. With the instruction to cross the virtual street when they thought it was safe, children completed 30 virtual crossings in three sets of 10 crossings set at light (10 vehicles/minute), moderate (12 vehicles/minute) and heavier (16 vehicles/minute) traffic volume. The sets were presented in randomized order across participants. Traffic travelled in both directions and at 30 miles/hour for all crossings.

TRAINING SESSIONS PROTOCOL

Following pragmatic trial standards, training occurred at schools and community centers with the newly developed mobile virtual environment. Each of the six sessions lasted about 15 minutes and consisted of 25 crossings; they were scheduled biweekly for three weeks. Children were given the instructions to cross the virtual street in each trial when they thought it was safe

and engaged in the virtual environment largely on their own, although an adult researcher was present in the room to assist if needed.

POST-TRAINING ASSESSMENT PROTOCOL

Post-training assessments mirrored pre-training identically.

PEDESTRIAN PERFORMANCE MEASURES

Four pedestrian performance measures were considered: attention to traffic, gap before initiating crossing, time to contact, and unsafe crossings. *Attention to traffic* reflects children's attention to oncoming vehicles, assessed by looks to the left and right while deciding to cross, divided by waiting time in seconds. These data are computed automatically in the virtual environment using head-tracking equipment (Trackir4:Pro, NaturalPoint, Inc, Corvallis, OR). The head-tracking equipment consists of a small electronic device situated above the virtual environment that tracks head movements of the participant, who wears a monitoring device above his/her head that is affixed using a headband. The tracker is synchronized with the virtual reality software to determine the number of times participants look left and right during each crossing. Previous work established reliability of the automated data collection compared to hand-coded data from videotapes ($r > .95$ between independent coders; *4*). In rare cases of equipment failure (<10%; most often due to particular hair styles that interfere with wearing the monitoring device properly), videotaped data were coded by hand. Note that we label this variable "attention to traffic", but we are unable to verify that children were actually looking at traffic and not something else in that direction as the construct is assessing looking behavior, not attention. We also are unable to demonstrate that vehicles which are "looked at" are processed and considered from a safety perspective; looking does not necessarily equate to cognitive processing.

The temporal gap before crossing initiation is measured as the time in seconds between a safe traffic gap appearing (i.e., the last, most recent car departs the crosswalk before the child will enter the roadway) and the child stepping down to enter the road during a crossing. Labeled *start delay* in this study, it is considered a proxy for cognitive processing of pedestrian situations because it measures the "thinking time" before the pedestrian accepts a traffic gap (*14, 15*). *Time to contact* (TTC) refers to the shortest time (in seconds) between an oncoming vehicle (in either direction) and the child pedestrian's presence at any point in the crosswalk while the child was crossing. Shorter TTCs imply more dangerous crossings. Last, *unsafe crossings* were tallied when a child was hit by a virtual vehicle in either lane, or within one second of being hit. Data for these variables were recorded electronically by the virtual environment and reported as the percentage of unsafe crossings.

Pedestrian performance measures were computed based on performance across the 10 trials at each difficulty level at pre-training and at post-training. As continuous measures, attention to traffic, start delay, and TTC were computed based on the average across the trials attempted at each difficulty level. Unsafe crossings was operationalized as the percentage of crossings attempted that were unsafe. On rare occasions, missing data emerged due to experimenter error, software failure, or child inattention to complete trials validly; the average of available trials was used in those instances. After data cleaning, we had valid data on 54 children. We excluded 10 of those children for failing to complete at least one session (i.e., failed to complete at least 8 trials) in the pretest and the posttest. Failure to complete a session emerged for various reasons, including software error, experimenter error, child behavior, and attrition during training or at post-intervention assessment. This resulted to a final valid sample size of 44 children.

OTHER MEASURES

Parents reported basic demographic data (e.g., child gender, race/ethnicity, birthdate; family SES) in a short questionnaire.

DATA ANALYSIS PLAN

Data analysis was completed in four steps. First, we considered descriptive data for potential covariates and performance measures at the individual level. Second, we conducted bivariate correlation analyses to examine relations between potential covariates and pedestrian performance measures. Third, we constructed independent mixed effects repeated measures regression models predicting three of the four pedestrian performance measures: mean attention to traffic, mean start delay, and mean TTC at the session level. Predictors included in the regression models were the primary variable of interest, time (pretest vs. posttest), crossing difficulty (light vs. moderate vs. heavy traffic), and child-level attributes that had significant associations with the variable of interest in bivariate analyses (walking speed in miles per hour and child sex). We use repeated measures because each individual completed up to three sessions in each test. Last, we constructed a regression model using ordinary least squares with subject-level clustering to examine the fourth performance measure: unsafe crossings. Unsafe crossings were examined at the test (pre/post) level instead of at the session level to avoid using a repeated measures count model which would have required significant degrees of freedom. Again, predictors for the unsafe crossings model were those that had significant associations in bivariate analysis (walking speed) plus time (pretest vs. posttest). All models were estimated using Stata SE 13.

CHAPTER 3. FINDINGS

Table 3-1 presents descriptive raw data (untransformed) for the pedestrian performance measures. Outcome measures appear first, followed by the continuous covariate measure of walking speed (shaded). Given significant skew, start delay was transformed using square root transformation for subsequent analyses.

Table 3-1. Descriptive Data (N=44)

Variable	Pre-intervention		Post-intervention	
	Mean (SD)	Range	Range	Range
Attention to traffic (looks/sec)	0.51 (0.18)	0-1.10	0.46 (0.20)	0-1.08
Start delay (sec)	1.24 (0.50)	0.19-2.93	0.96 (0.50)	0.14-2.44
Time to contact (sec)	3.37 (1.97)	0.32-8.28	3.19 (1.59)	0.48-6.99
Unsafe crossings (%)	26.49 (12.58)	3.33-60.00	23.03 (12.47)	6.67-56.67
Walking speed (miles/hour)	2.97 (0.47)	1.88-4.21	3.08 (0.50)	2.10-4.42

Table 3-2 presents bivariate tests between potential covariates and pedestrian performance measures. Of the covariates examined, only walk speed and child sex had consistent and significant associations with safety outcomes. Faster walkers were more attentive to traffic, had longer time to contact, made fewer unsafe crossings, and spent less time waiting to enter a gap in traffic. Female participants were also more attentive to traffic, had longer time to contact, and waited less time to enter a traffic gap. Sex was not significantly associated with unsafe crossings.

Table 3-2. Bivariate Associations between Potential Covariates and Pedestrian Performance Measures

	Attention to traffic (looks/sec)		Start delay square root (sec)		Time to contact (sec)		Unsafe crossings; count/test (%)	
Walkspeed[1]	0.34	**	-0.24	**	0.51	**	-0.50	**
Height[1]	0.10		0.00		0.06		0.02	
Weight[1]	-0.04		0.03		-0.17		-0.01	
Body mass index[1]	-0.11		-0.02		-0.01		-0.00	
Age[1]	0.07		-0.07		0.02		-0.03	
Sex (male=0; female=1)[2]	2.19	*	-2.92	**	2.27	*	-1.24	
Race (white=0; nonwhite=1)[2]	-1.23		-0.74		-1.15		0.10	

[1] Correlation coefficient
[2] t-statistic
* $p<.01$; ** $p<.001$.

Table 3-3 presents results of the regression models predicting attention to traffic (Model 1), start delay (Model 2), and TTC (Model 3). As shown in Model 1, after controlling for crossing difficulty, walking speed and sex, children were slightly but significantly less attentive after training than before. Stated quantitatively, we found an average decrease of 0.06 looks/second of waiting from pretest to posttest. For a male participant with a mean walking speed of 3 mph walking in moderate traffic, this implies a predicted decrease from 0.54 to 0.48 looks/second of wait time; for a female walking in moderate traffic at 3 mph, the models predict a decrease from 0.49 to 0.43 looks/second.

Child participants also exhibited slightly but significantly shorter start delays after training. For a child walking 3 mph in moderate traffic, this corresponds to a predicted decrease

in start delay of nearly three tenths of a second, from 1.06 seconds before training to 0.80

seconds after training for males and 1.32 seconds to 1.02 seconds for females.

TTC decreased slightly after training (Model 3, Table 3). After controlling for crossing

difficulty and walking speed, children allowed just over one quarter of a second closer to

oncoming traffic while crossing, on average, in the posttest than in the pretest. The model

predicts a decrease in time to contact from 3.49 to 3.23 seconds for an average male participant

in moderate traffic, and a decrease from 3.34 to 3.07 seconds for an average female.

Table 3-3. Repeated Measures Mixed Effect Regression Models Predicting Continuous
Pedestrian Performance Measures

	Model 1 Attention to traffic			Model 2 Sqrt(Start delay)			Model 3 Time to contact (TTC)		
	Coef	SE		Coef	SE		Coef	SE	
time (pre-training=0; post-training=1)	-0.06	(0.03)	*	-0.14	(0.03)	**	-0.26	(0.11)	*
traffic (moderate)	-0.00	(0.02)		-0.08	(0.03)	**	-2.17	(0.14)	**
traffic (heavy)	-0.02	(0.02)		-0.12	(0.03)	**	-3.46	(0.14)	**
Walk speed (mph)	0.10	(0.03)	**	-0.06	(0.04)		0.86	(0.15)	**
sex (male=0; female=1)	-0.06	(0.03)		0.12	(0.04)	**	-0.15	(0.16)	
Constant	0.25	(0.10)	*	1.28	(0.13)	**	2.78	(0.49)	**
Observations		263			263			263	
Log-likelihood		91.2			32.9			-366.1	
AIC		-164.4			-47.71			750.2	
BIC		-132.2			-15.56			782.4	

Standard errors in parentheses
* p<0.05, ** p<0.01

Table 3-4 presents results of an ordinary least squares regression model with subject-level

clustering to predict unsafe crossings. No significant relationship between training and unsafe

crossings emerged.

Table 3-4. Linear Regression Model Predicting Unsafe Crossings

	Model 4 Unsafe crossings		
	Coef	SE	
Time (post-training=1; pre-training=0)	2.87	(2.07)	
Walk speed (mph)	-13.03	(2.40)	**
Constant	65.26	(7.78)	**
Observations		88	
R^2		0.26	
AIC		672.4	
BIC		679.8	

Robust standard errors in parentheses
** $p<0.01$

CHAPTER 4. CONCLUSIONS, RECOMMENDATIONS, AND SUGGESTED RESEARCH

This study examined the influence of six 15-minute training sessions in a community-based virtual pedestrian environment on 7- and 8-year-old children's pedestrian safety. It was conducted using pragmatic trial strategies, such that the virtual environment was placed in a community setting for children to train. Evaluation of children's pedestrian safety was assessed in a different virtual environment based at a university laboratory both pre- and post-intervention on the basis of four performance measures: attention to traffic, gap before initiating crossing, time to contact, and unsafe crossings.

Children's delays to enter traffic gaps decreased slightly and significantly, implying more rapid decision-making about the safety of traffic gaps following training. Children's attention to traffic and time to contact by oncoming vehicles both decreased slightly but significantly following training, implying slightly greater risk of pedestrian injury following the training. There were no significant changes in the rate of unsafe crossings following training.

The drop in start delay was consistent with our hypotheses and with previous research findings (*4*). Children entered traffic gaps more quickly following training, indicating quicker processing speed to make decisions about traffic safety after practicing street-crossing repeatedly in the virtual environment. This finding, consistent with laboratory-based findings from pedestrian safety training in virtual reality (*4*), supports the possibility that training in virtual reality can help children improve their pedestrian safety decision-making.

We did not discover the anticipated results with respect to attention to traffic, TTC, and unsafe crossings. Instead, we found slightly shorter TTC and attention to traffic values following training and no significant change in unsafe crossing rates. One possible explanation for these

results is that following training, children made crossing decisions more confidently and more efficiently (less attention to traffic and faster speed) without sacrificing safety. Children may have chosen equally safe but tighter gaps rather than waiting for obviously safe gaps (shorter TTC created by reduction in very large gap selections and preference for smaller gaps that appeared sooner). To test these hypotheses, we conducted a post-hoc analysis of raw time waiting to cross (time waiting from when virtual vehicles began moving until children entered the road) and discovered a drop in waiting time of nearly a full second (0.96 seconds) from pre-intervention to post-intervention after controlling for difficulty, walk speed, and child sex ($p <$ .001). A plausible conclusion, therefore, is that the training children received (six 15-minute sessions) in this study may have helped the children become more confident and efficient pedestrians but was insufficient to achieve full pedestrian safety. The children may have been still actively learning and improving their safety, and results may have been stronger with more substantial training. Previous work in a laboratory virtual environment (*4*) utilized six 30-minute sessions of training, twice the amount of practice as used in this study, and found a decrease in unsafe crossings as well as a decrease in start delay following training in the virtual environment. Further research is recommended to evaluate more fully the process and slope of improved cognition as children learn to cross streets safely.

There are other possible explanations for our results. In the driver education literature, for example, there is some evidence that training programs actually increase risk of injury because they encourage earlier licensing (*18*). Although we saw no anecdotal or statistical evidence that our training actually increased risk among children and the parallel to adolescent driver training is inexact, it is plausible that using virtual reality to train children in pedestrian safety could cause iatrogenic effects and increase injury risk. Another possible explanation is

that some children became bored with the pedestrian environment by the end of the study and began displaying impatient or impulsive crossing behavior in the context of increased skill. Such behavior could lead to shorter start delays, less attention to traffic, shorter times to contact, and a combined lack of change in unsafe crossings. The effect of traffic volumes on children's pedestrian behavior is a topic that has not been examined carefully in the existing literature. However, the results from this study were largely as expected: children had shorter start delays (needed to cross safely in tighter gaps) and shorter TTCs (smaller gaps yield less safety margin) in moderate and especially heavier traffic compared to lighter traffic. Interestingly, children's attention to traffic did not change when exposed to heavier versus light traffic. Future work might continue to explore how traffic volume and density influence child pedestrian decisions and safety.

Previous work suggests boys take somewhat greater risks in pedestrian situations (*16*) and have higher rates of pedestrian injuries (*1*). Therefore, it was not surprising to us that girls showed higher attention to traffic, shorter start delays, and larger TTCs in bivariate analyses. The gender effect of start delay following training was most interesting, as it emerged also in the regression model after controlling for effects of other variables. We therefore conducted post-hoc analyses examining the interaction between gender and time on start delay. Curiously, boys showed minimal improvement in start delay following training, partly because their pre-intervention start delays averaged 1.02 sec (SE = 0.06), close to the start delay reported in adult samples (e.g., 1.06 seconds in (*17*); 0.84 seconds in (*13*). Girls, on the other hand, demonstrated highly significant improvement in start delays in this sample, moving from an average of 1.37 seconds (SE = 0.07) pre-intervention to 0.88 seconds (SE = 0.08) post-intervention. Future

research should replicate and examine more carefully the possibility of gender-related differences in pedestrian safety training programs.

IMPLICATIONS, STRENGTHS, AND WEAKNESSES

The present results contribute to our early understanding of how children learn the complex visual-perceptual skills required to be safer pedestrians, and whether virtual reality offers an appropriate medium for training in pedestrian safety. Early research supported the fact that virtual reality holds promise (*9, 19*), and the largest randomized trial to date supported early findings (*4*). The current trial extended previous research by installing a semi-mobile virtual reality into community settings and implementing pragmatic trial strategies to test whether learning could be accomplished outside a sterile laboratory environment. Results support and extend previous work suggesting the possibility that virtual reality may be an effective and efficient means to teach children pedestrian safety, but also imply training cannot be done quickly. This trial, which used six 15-minute training sessions, seemed to improve children's efficiency in pedestrian crossings but did not significantly improve their rate of unsafe crossings. It may be that more intense training, and more replication of the cognitive-perceptual process of crossing streets and receiving feedback about crossing safety, is required to train children fully in the skills required. Prior to broad-based implementation of child pedestrian safety training by virtual reality, further trials are recommended. Those trials should work to understand what aspects of pedestrian safety are learned via training in virtual environment, and at what pace. Randomized clinical trials and other rigorous research designs are recommended.

The research discussed in this study offers several strengths. It addresses a critical public health problem, uses novel and innovative technology, and applies pragmatic trials methodology. Further, the work represents translation of basic research findings into practice (*20, 21*). Despite

these strengths, the study also has limitations. Scientists recognize a completely pragmatic trial is not practical to implement (*11*), so we implemented a research design that incorporated many pragmatic components but still offered valid data. Our sample was diverse and offered sufficient power to test our hypotheses, but was drawn from just three community sites in Alabama, and with a specific age group. Future research should seek larger samples from other geographic areas and with other ages. Finally, we implemented a within-subjects pre-post design and did not include active comparison groups (e.g., streetside training) or a no-contact control group. Future research should incorporate more rigorous research designs to evaluate the influence of pedestrian safety training in virtual reality.

CONCLUSIONS

This pragmatic pre-post within-subjects trial found that children's pedestrian safety ability improved modestly following six 15-minute training sessions within a virtual pedestrian environment located at their school or community center. Efficiency in making a decision to enter the road was improved (shorter start delays), leading to somewhat less attention to oncoming traffic and selection of gaps that placed children closer to oncoming traffic while crossing the street. Safety of crossing was not changed significantly after training. Future research is recommended to continue to explore the effectiveness and dosage required to effectively train children in pedestrian safety using virtual reality environments.

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