An Investigation of Peer Influences on Risky Child and Adolescent Pedestrian Road Crossing

SAFER SIM

SAFEty Research using SIMulation

UNIVERSITY TRANSPORTATION CENTER

Jodie M. Plumert, PhD
Professor
Psychological & Brain Sciences
University of Iowa

Joseph K. Kearney, PhD
Professor
Computer Science
University of Iowa

An Investigation of Peer Influences on Risky Child and Adolescent Pedestrian Road Crossing

Jodie M. Plumert

Professor & Chair

Psychological & Brain Sciences

University of Iowa

Joseph K. Kearney

Professor

Computer Science

University of Iowa

June 2017

Table of Contents

List of Figures

Abstract

Pedestrian injuries and fatalities involving children and adolescents are a significant public health concern in the U.S. In 2013 alone, 236 child pedestrians died and 10,000 were injured in traffic collisions [1]. One factor that may increase the risk of such collisions is peer influence. Although it is well known that having multiple peers in the car dramatically increases risky behavior among teen drivers, little is known about how child, adolescent, and adult pedestrians cross roads with peers, and whether joint road crossing with peers puts pedestrians at heightened risk for collisions with motor vehicles. This project conducted two experiments investigating social influence on road-crossing behavior. The first experiment examined how adults and children jointly cross traffic-filled roadways with a real partner in a pedestrian simulator. The second experiment investigated how people jointly coordinate their decisions and actions with a computer-generated agent that was programmed to be either safe (taking only large gaps) or risky (also taking relatively small gaps).

The results of the two experiments consistently showed that participants were inclined to cross the same gap as their partner, even when not explicitly instructed to do so, and in doing so, they tightly synchronized their movements with their partner. This was true for children and adults, for friendly and unacquainted partners, and for partners that were real or computer-generated agents. The experiments also showed that adult participants often adjusted their gap choices and the timing of their crossing to accommodate their partner – picking bigger gaps that allowed more time for crossing. Children were less likely adjust their choices, leading to riskier road crossing. Lastly, the experiments showed that the riskiness of the partner's gap choices influenced the riskiness of the gaps selected by the participant.

This report presents the design, methods, and results of the two experiments and discusses the implications for future research investigating pedestrian safety.

1   Experiment 1: Perceiving and Acting on Joint Affordances: How Children Cross Roads Together

1.1   Introduction

Children cross streets every single day, both alone and with others. Crossing the street can be a difficult task that requires choosing a sufficient gap size and then coordinating movement with the traffic in order to safely make it across the street. In 2013, 10,000 child pedestrians were injured in traffic collisions and 236 were killed [1]. The task of crossing the street can be even more complicated when it involves a peer. The two children must pay close attention to the traffic and time their movements together. However, nothing is known about whether crossing the street with a peer puts children at a greater risk for injury than crossing alone. The goal of this study was to see if there are differences between child and adult pedestrians crossing the street alone compared to crossing the street with a friend. Additionally, we were interested in whether there were differences in gap choices and movement timing between pairs of adult friends and pairs of 12-year-old friends.

Our main goal was to examine how pairs of friends cross streets compared to how solo crossers cross streets. We also wanted to see if there were differences in gap selection and movement timing between adults and 12-year-olds. In order to test this, we used a large-screen, immersive pedestrian simulator that included a single lane of traffic. Pedestrians had to cross the street by looking at the cars coming from the left and judging when it was safe to cross. When they felt it was safe, they physically crossed the street. We predicted that those in the pair condition would choose larger gaps than those in the solo condition. Specifically, in order for pairs to fit through the gap, bigger gaps must be chosen than when crossing alone. We also expected that pairs would coordinate their movement by entering the roadway at the same time, resulting in less time between the pair member on the right and the lead car in the gap than between the pair member on the left and the lead car in the gap. We also predicted that solo 12-year-old crossers would be more conservative in their gap selection than solo adult crossers. In research by O'Neal et al. [2], 12-year-olds were more conservative in their choices, so we expected that the same pattern would emerge. We wanted to test how the additional task of coordinating movement with a partner would affect their gap choices and movement timing.

1.2   Background Literature

Crossing the street first requires pedestrians to choose a safe gap to cross. Once the gap is chosen, they must coordinate their movement with that of the traffic to cross safely. This requires that children cut in closely behind the lead car and walk at a speed that allows them to reach the other side before the tail car reaches them. O'Neal et al. [2] looked at gap choices and movement timing in 6-, 8-, 10-, 12-, and 14-year-olds, as well as adults. Gap size choices were very similar across all age groups except for 12-year-olds. Twelve-year-olds were more conservative in their choices, choosing bigger gaps than all the rest of the age groups. In addition, 6-, 8-, and 10-year-olds timed their entry into the road less tightly than adults, which led to less time to spare and more collisions than older age groups. Importantly, even though 12-year-olds had poorer timing of entry, their choice of bigger gap sizes led to similar time to spare as the 14-year-olds and adults. By age 14, the children's road crossing looked like that of

adults. Over development, children learn to coordinate their movements correctly in order to cross the street safely. An interesting finding was that the 12-year-old group was more conservative in their gap choices than adults. For the present study, we chose to compare 12-year-olds and adults because we predicted that we would again see differences in solo crossers for both age groups that may also be seen in children and adults crossing with a friend.

Barton and Schwebel [3] also measured road-crossing ability in children ages 5 to 8 and compared the results to those of adults. They had children and adults cross a wooden crosswalk that was placed in the grass next to a crosswalk by a school. They found that the 5- to 6-year-olds took more risks and had more tight fits that could have led to collisions with cars. However, most child crossing behaviors were very similar to adult crossing behaviors. One explanation is that adults also engage in risky behavior, but they can better coordinate their movements in order to cross safely. This can also be seen in findings by Plumert et al. [4]. They had children and adults bicycle across a virtual road with high-density traffic. Children and adults both took risky gaps and timed their entry into the roadway more tightly to compensate for their risky gap choices. However, children taking risky gaps got hit 20% of the time whereas adults never got hit. This suggests that children have more difficulty adjusting their actions to match their risky decisions. Geraghty, Holland, and Rochelle [5] studied road-crossing errors in older adults crossing the street and found that as age increased, so did the number of errors that were made. They also found that walking speed and start-up delay were predictors of unsafe crossing in older adults. These factors could also affect how children cross the road. If children have start-up delays due to slower cognitive processes, it could create more unsafe crossing. We could also see decreases in motor coordination that lead to unsafe crossing as well.

Crossing with a peer requires joint action in gap choices and movement timing. Not only do pair members have to cross the road safely, they have to understand and anticipate what their partner is going to do. Jiang et al. [6] studied how two unfamiliar partners cross a single lane of virtual traffic together and how they differ from solo crossers. They found that pairs were highly likely to cross together and tightly synchronized their entry into the roadway. They chose larger gaps than solo crossers, presumably to allow both members of the pair to cross the roadway safely. Because they entered the roadway at the same time, pair members on the left had more time between themselves and the lead vehicle in the gap than pair members on the right. This synchronous timing occurred between pedestrians who did not know each other and who provided few verbal and gestural cues to their partner. At present, it is unknown whether gap decisions and movement timing differs when pairs of friends cross roads together.

1.3   The Current Investigation

The main goal of this study was to examine how pairs of friends cross streets compared to how solo crossers cross streets. We also wanted to see if there were differences in gap selection and movement timing between adults and 12-year-olds. In order to test this, we used a large-screen, immersive pedestrian simulator that included a single lane of traffic. Pedestrians had to cross the street by looking at the cars coming from the left and judging when it was safe to cross. When they felt it was safe, they physically crossed the street. We predicted that those in the pair condition would choose larger gaps than those in the solo condition. Specifically, in order for pairs to fit through the gap, bigger gaps must be chosen than when crossing alone. We also expected that pairs would coordinate their movement by entering the roadway at the same

time, resulting in less time between the pair member on the right and the lead car in the gap than between the pair member on the left and the lead car in the gap. We also predicted that solo 12-year-old crossers would be more conservative in their gap selection than solo adult crossers. In research by O'Neal et al. [2], 12-year-olds were more conservative in their choices, so we expected that the same pattern would emerge. We wanted to test how the additional task of coordinating movement with a partner would affect their gap choices and movement timing.

1.4   Methods

1.4.1   Apparatus

The experiment was conducted in a large-screen pedestrian simulator (see Figure 1.1), consisting of three screens that are placed at right angles to each other. This created a three-walled room that was 10 ft. wide x 14.2 ft. long x 8 ft. tall. Stereo projectors were used to back-project images onto the side screens. A fourth stereo projector front-projected images onto the floor. There were 17 Flex 13 infrared motion-tracking cameras mounted to the virtual environment (VE)[1]. Participants wore Volfoni ActiveEyes stereo shutter glasses that were synchronized with the displays so that images were alternately visible in the left and right eyes. This permitted us to show stereo images with the correct perspective for each participant (see Figure 1.2). An OptiTrack motion capture system was used to determine the position and orientation of the participants' heads based on the marker locations viewed from 17 Flex 13 cameras surrounding the volume. Each participant's eye point was estimated from the head data and used to render the scene correctly for their viewpoint (in an image stream that only they could see). The VE software is based on the Unity3D gaming platform. In-house code generated traffic and recorded the positions and orientations of vehicles and the pedestrians during the experiment for later analysis.

Figure 1.1.- The Hank Large Screen Pedestrian Simulator.

---

[1] The terms "simulator" and "virtual environment" both refer the graphically simulated world used in our experiments. We use the two terms interchangeably through the report.

Figure 1.2 - Solo and joint road crossing in the pedestrian simulator. Images are shown from the camera viewpoint for clarity. In the real experiment, each participant saw a separate image stream rendering in non-stereo for their eyepoint.

1.4.2   Data Recording and Performance Variables

The master computer recorded the position and orientation of all movable entities in the VE, including the locations of the pedestrians' heads and all vehicles on every time step. This method of data recording allowed us to reconstruct key aspects of the experiment off-line. A 3D visualizer was developed in-house in Unity 3D to graphically replay trials. This application enabled researchers to visualize the pedestrian motion and traffic from different viewpoints (e.g., top-down, first-person, or third-person views) and navigate through the entire recorded experiment using the play, pause, stop, fast-forward, and rewind buttons. In addition, the visualizer automatically produced a record of the following performance variables:

Number of gaps seen: the number of gaps seen before crossing the roadway, including the gap crossed (a measure of waiting).
Gap size: the temporal size of the gap selected for crossing.
Timing of entry: the time between the moment the rear of the lead vehicle in the gap passed the participant and the moment the participant entered the path of the vehicles.
Road-crossing time: the time it took the participant to cross the road (from the moment they entered the road to the moment they exited the road).
Time to spare: the time between the moment the participant cleared the path of the vehicles and the moment the front of the tail vehicle in the gap passed the participant.
Close call: a road crossing was classified as a close call if the time to spare was less than or equal to 0.5 s.

1.4.3   Participants

There was a total of 96 participants in four groups: 12-year-old pairs of friends (mean age: 12 years, 9 months; 16 females), 12-year-old solo crossers (mean age: 12 years, 2 months; 8 females), adult pairs of friends (mean age: 20 years, 5 months; 18 females), and adult solo crossers (mean age: 19 years, 7 months; 8 females). Fifteen additional participants were excluded from the analyses for the following reasons: 10 participants had videos that did not

record or contained no sound, two participants had the data overridden, two participants had simulators that froze and would not restart, and the members of one pair were different genders. The sample was 91.70% Caucasian, 4.2% Asian, 2.1% African American, and 2.1% biracial. Participants were recruited through the Psychological and Brain Sciences Child Research Participant registry or from mass-emails sent to the University of Iowa community. Participants were each paid $15 for participating in the study.

1.4.4   Procedure

The session began with familiarization with the VE and task. The experimenter explained that there would be a stream of traffic coming from the left-hand side. The participant would stand on the sidewalk in the back of the simulator and would have to wait to cross the street until the first car, always colored purple, had passed. Once the purple car passed, participants could wait as long as they needed before crossing the street. Once they reached the other side, the traffic ceased being generated and the participant could walk back to the other side. The goal of the task was to cross the street without getting hit by the car.

Participants had two practice trials where the experimenter would follow the participant's lead and walk across the street with them. In the pair condition, after the first practice, participants swapped sides. After the practice trials, participants crossed the road 30 times. In the pair condition, participants switched sides after 15 trials so that each member of the pair crossed on both the right and the left.

1.5   Results

1.5.1   Data Analysis Strategy

We analyzed trials separately when the pair crossed the gap together and when the pair chose different gaps. A majority of the gaps were taken together in the pair (M=82%, SD=3). It was slightly higher for adults (M=89%, SD= 31%) compared to 12-year-olds (M=73%, SD=44%). When they crossed the same gap, we were interested in how gap selection in the pair compared to that of solo crossers, and how the left and right crossers in the pair timed their movements relative to each other and to solo crossers. When pairs crossed separate gaps, we were interested to see how gap selection and movement timing differed between the first and second crosser. Trials crossed together comparing left and right crossers were analyzed in repeated measures analyses of variance (ANOVAs) with standing position (left, right) and order (first, second) as within-subjects factors and age (12, adult) as a between-subjects factor. Separate ANOVAs were conducted comparing left pair members to solo crossers, right pair members to solo crossers, and left pair members to right pair members. When pairs crossed different gaps, repeated measures ANOVAs were used with role (1st crosser, 2nd crosser) as a within-subjects factor and age (12, adult) as a between-subjects factor. Separate ANOVAs were conducted for 1st crossers compared to solo crossers, 2nd crossers compared to solo crossers, and 1st crossers compared to 2nd crossers. For both types of trials, an ANOVA was used to compare the pair condition to solo crossers. We also used a mixed effects logistic regression to determine whether the likelihood of choosing a certain size gap was different for solo crossers compared to left pair members and right pair members. We also wanted to test the likelihood of choosing a gap depending on the age group.

### 1.5.2   Crossing through the Same Gap

1.5.2.1   Gap Selection

Mean gap size. We expected pairs to choose bigger gaps to allow both crossers to fit through safely. However, there was no significant difference in mean gap size between the left crossers and the solo crossers, $F_{(1,63)}$= .001, ns, or between right and solo crossers, $F_{(1,63)}$= 1.12, ns. Likewise, there was no effect of age for left compared to solo crossers, $F_{(1,63)}$=1.12, ns, or right crossers compared to solo crossers, $F_{(1,63)}$=1.04, ns.

Likelihood of taking a gap. We analyzed the likelihood of taking a gap using gap size, condition (solo, pair), and age (12-year-olds, adults) as predictors. As expected, participants in both conditions were more likely to take larger than smaller gaps, z = 15.56, $p < .001$, with the average odds of choosing a gap increasing by 19.98 with each .5 s increase in gap size. The gap acceptance thresholds of those in the pair and solo conditions were not significantly different from one another, z = 1.51, ns. Similarly, there were no significant differences in gap acceptance thresholds between the age groups.

However, condition moderated gap size acceptance, z = 2.39, p = .02, indicating that pairs were more discriminating in their gap selection than solo crossers (Figure 1.3). Those in the solo condition, z = 15.19, $p < .001$, had 18.93 increased odds of accepting a given gap with each .5 s increase in gap size. Those who crossed in pairs, z = 13.01, $p < .001$, had 51.94 increased odds of accepting a given gap with each .5 s increase in gap size. Additionally, age group moderated gap size slope differences, z = -2.30, p = .02 (Figure 1.4). Children, z = 21.97, p = .02, were less sensitive in their gap selection; they took a higher proportion of small gaps and a larger proportion of larger gaps compared to adults, z = 21.42, p = .02. Further, adults had 25.37 increased odds of gap acceptance with each .5 s increase in gap size, while 12-year-olds only had 12.01 increased odds of accepting a gap with each .5 s increase in gap size.
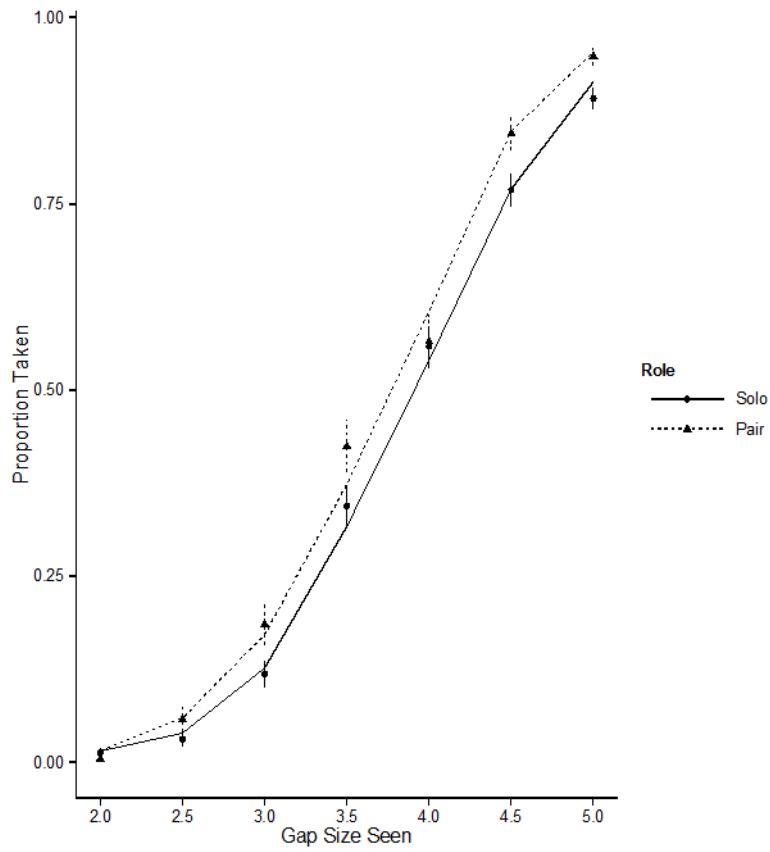
Figure 1.3 - Logistic regression curves representing the likelihood of taking a gap in the solo condition and pair condition.
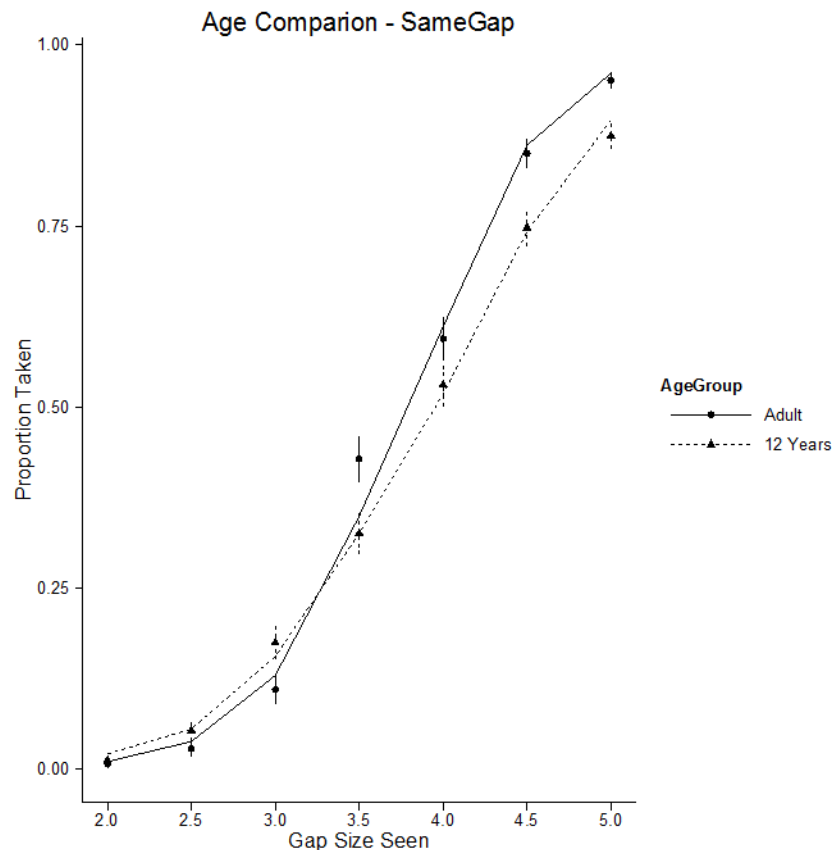
Figure 1.4 - Logistic regression curves representing the likelihood of taking a gap when pairs crossed the same gap by age.

To test our hypothesis that adults and 12-year-olds would choose different gap sizes, we conducted separate logistic regression analyses for each age group. Adults showed a preference for larger rather than smaller gaps, $z = 15.77$, $p < .001$, with the odds of taking a gap increasing by 19.52 with each .5 s gap increase. Additionally, condition moderated gap size slope differences, $z = 2.50$, $p = .01$. Adults in the solo condition, $z = 14.59$, $p < .001$, were more discriminating in their gap choices than those in the pair condition, $z = 12.10$, $p < .001$, taking more of the small gaps and fewer of the large gaps. Twelve-year-olds also showed a preference for larger rather than smaller gaps, $z = 13.74$, $p < .001$, with the odds of taking a gap increasing by 11.46 with each .5 s gap increase. However, condition did not moderate gap size slope differences.

1.5.2.2   Movement Timing

Timing of entry. There was no significant difference in timing of entry for the pair member on the left and solo crossers, $F(1,63)=.37$, ns. However, those on the right (M= .63 s, SD=.15) cut in more tightly behind the lead car than solo crossers (M= .75 s, SD=.17), $F(1,63)= 10.894$, $p=.029$, and than pair members on the left (M= .78 s, SD=.15), $F(1,30)= 101.331$, $p<.001$. There was no effect of age for left pair members compared to solo crossers, $F(1,63)=.32$, ns, right pair

members compared to solo crossers, F(1,63)=.12, ns, or left pair members compared to right pair members, F(1,30)=1.76, ns.

Variability in timing of entry. There was a significant effect of standing position on variability of timing of entry for left pair members, (M= .23, SD=.09), F(1,63)= 18.75, p<.001, and right pair members, (M= .22, SD=.07), F(1,63)=17.00, p<.001, compared to solo crossers (M= .15, SD=.06). Both left and right pair members were more variable in their timing of entry than solo crossers. When comparing left to right pair members, there was no effect of standing position, F(1,30)=2.13, ns. There was no effect of age for left pair members compared to solo crossers, F(1,63)=2.09, ns, right pair members compared to solo crossers, F(1,63)=2.34, ns, or left pair members compared to right pair members, F(1,30)=.02, ns.

Road-crossing time. There was a significant Age x Standing Position interaction for both left (M= 2.13, SD=.20), F(1,63) = 5.00, p=.03, and right crossers (M= 2.13, SD=.22), F(1,63)= 6.08, p=.02, compared to solo crossers (M= 2.16, SD=.18). Simple effects tests revealed no effect of standing position for adults who crossed on the left (M= 2.19, SD=.18), F(1,31)=1.03,ns, and for those who crossed on the right (M= 2.21, SD=.18), F(1,31)= 1.76, ns, compared to solo crossers (M= 2.11, SD=.21). However, there was a significant effect of standing position for 12-year-olds crossing on the left (M= 2.07, SD=.22), F(1,31)=5.28, p=.029, and for those crossing on the right (M= 2.06, SD=.24), F(1,31)= 4.82, p=.04, compared to solo crossers (M= 2.20, SD=.11). Twelve-year-olds in the pair condition crossed the road more quickly than 12-year-olds in the solo condition.

Time to spare. There was no effect of standing position on time to spare for left pair members compared to solo crossers, F(1,63)= .000, ns. However, there was a marginally significant effect of standing position for right pair members compared to solo crossers, F(1,63)=3.67, p=.06, with right pair members (M= 1.63 s, SD=.30) having more time to spare than solo crossers (M= 1.48 s, SD=.33). We also found a significant effect of standing position between left and right pair members, F(1,30)= 68.45, p<.001, with right pair members (M= 1.63, SD=.30) having more time to spare than left pair members (M= 1.48, SD=.29). Order also had a significant effect on time to spare, F(1,30)= 18.94, p=.01. Participants in the pair condition had more time to spare during the second 15 trials than the first 15 trials. There was no effect of age for left pair members compared to solo crossers, F(1,63)=.79, ns, right pair members compared to solo crossers, F(1,63)=.35, ns, or left pair members compared to right pair members, F(1,30)=.01, ns.

Collisions. There was a significant effect of standing position on collisions for solo crossers (M= .20, SD=.14) compared to left pair members (M= .021, SD=.03), F(1,63)=49.09, p=.000, and right pair members (M= .004, SD=.01), F(1,1)=63.99, p<.001. Solo crossers were hit more often than those crossing in the pair condition. There was no effect of age for left pair members compared to solo crossers, F(1,63)=.72, ns, or for right pair members compared to solo crossers, F(1,63)=.09, ns. For left pair members compared to right pair members, there was a significant Standing Position x Age interaction for collisions, F(1,30)=5.42, p=.03. Simple effects tests revealed no effect of standing position for adults, F(1,30)=1.0, ns. However, there was a significant effect of standing position for 12-year-olds, F(1,30)= 9.19, p=.008, with left pair members (M= .034, SD=.04) having more collisions than right pair members (M= .004, SD=.02). There was also a significant effect of order on collisions, F(1,30)=4.49, p=.04, with those crossing

in the first half of the trials having fewer collisions than those crossing in the second half of trials.

### 1.5.3   Crossing Through the Different Gaps

The pairs only crossed through different gaps 18% of the time. However, when analyzing these gaps, we were interested to see how 1st and 2nd crossers differed in their gap size selection. We hypothesized that when the pair did not cross the same gap, first crossers would likely be crossing a riskier gap than the second crosser was willing to take.

1.5.3.1   Gap Selection

Mean gap size. As predicted, those crossing first (M= 3.55 s, SD=.59) chose smaller gaps than solo crossers (M= 4.38 s, SD=.23), $F(1,54)= 49.41$, $p<.001$. They also chose significantly smaller gaps than second crossers (M= 4.20 s, SD=.54), $F(1,20)=35.98$, $p<.001$. However, there was no effect of standing position for first or second crossers, $F(1,20)= 2.47$, ns. There was no effect of age for first crossers compared to solo crossers, $F(1,54)=.20$, ns, second crossers compared to solo crossers $F(1,54)=1.67$, ns, or first crossers compared to second crossers, $F(1,20)=.49$, ns.

Likelihood of taking a gap. As would be expected, mixed effects logistic regression analyses showed that first, second, and solo crossers preferred larger over smaller gaps, $z = 15.11$, $p < .001$, with the average odds of taking a given gap increasing by 19.12 per .5 s increase in gap size (Figure 1.5). Additionally, compared to solo crossers, first crossers had lower gap acceptance thresholds, $z = 3.52$, $p < .001$, with the first crossers having 8.88 increased odds of taking a gap. Conversely, second crossers, $z = -1.88$, $p = .06$, had .77 decreased odds of accepting a gap compared to solo crossers, albeit this finding was marginal. The model also revealed a three-way interaction between age, role, and gap size, $z = -2.40$, $p = .02$, when comparing first vs. solo crossers. When broken down by age, adults showed no interaction of role and gap acceptance. First crossers had 8.52 increased odds of accepting a gap of a given size. For 12-year-olds, role moderated gap size slope differences for 1st crossers, $z = -4.89$, $p < .001$, compared to solo crossers. First crossers, $z = 2.44$, $p = .01$, were less discriminating in their gap choices than solo crossers, $z = 13.42$, $p < .001$.
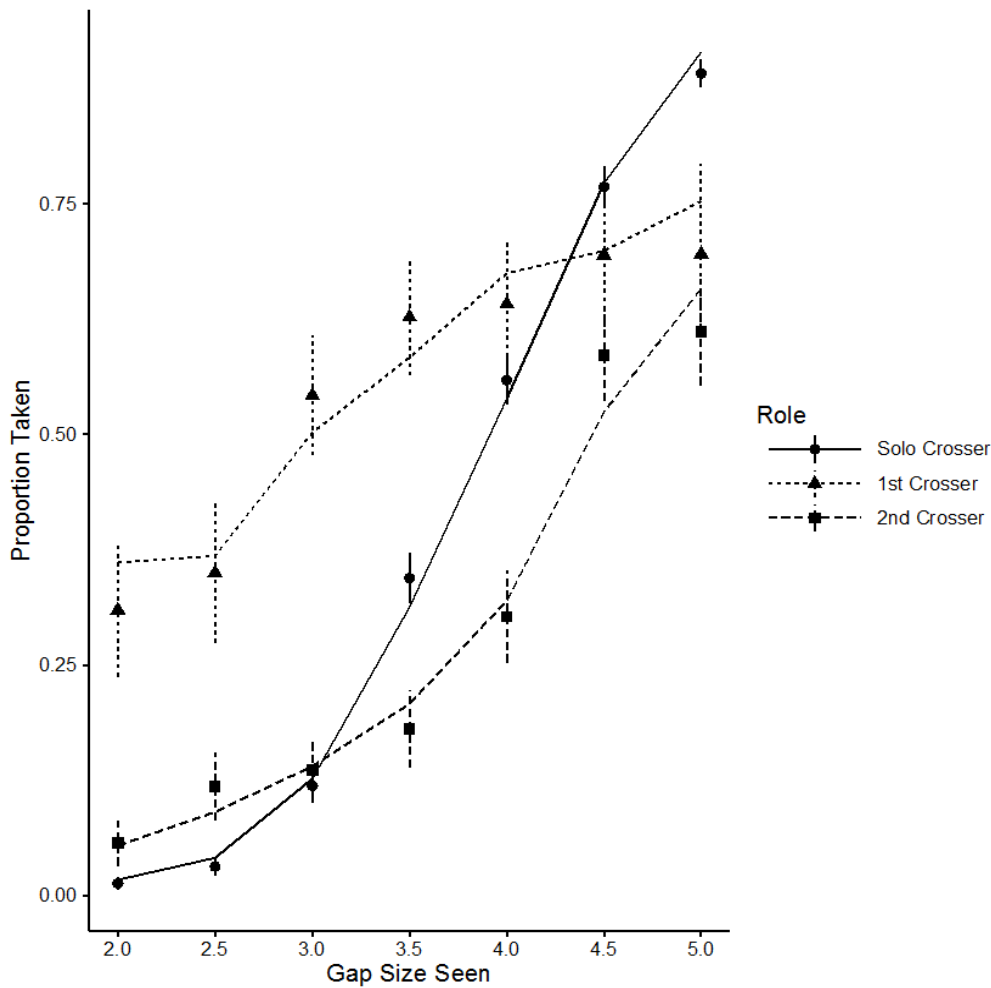
Figure 1.5 - Logistic regression curves depicting the likelihood of taking a gap for first crossers, second crossers, and solo crossers.

1.5.3.2   Movement Timing

Timing of entry. There was no effect of role for solo crossers compared to first crossers, $F(1,54)=1.80$, ns, or first crossers compared to second crossers, $F(1,20)=.34$, ns. There was a significant effect of role on timing of entry for second crossers compared to solo crossers, $F(1,54)= 4.50$, $p=.04$. Those crossing second (M= .662, SD=.13) cut in more closely behind the lead car than those crossing solo (M= .75, SD=.17). There was no effect of age for first crossers compared to solo crossers, $F(1,54)=1.12$, ns, second crossers compared to solo crossers, $F(1,54)=1.67$, ns, or first crossers compared to second crossers, $F(1,20)=.02$, ns.

Variability in timing of entry. Those crossing first (M= .28, SD=.12) had more variability in their timing of entry than solo crossers (M= .15, SD=.06), $F(1,54)= 23.681$, $p<.001$, but 12-year-olds and adults did not differ in variability of timing of entry, $F(1,54)=1.34$, ns. There was a main effect of age, with 12-year-olds being more variable than adults, $F(1,54)=6.53$, $p=.014$. There was also a significant Standing Position x Age interaction when comparing solo (M= .152,

SD=.06) to second crossers (M= .20, SD=.15), F(1,54)=5.93, p=.019. Simple effects tests showed that adults did not differ in their variability due to standing position, F(1,1)= .80, ns. However, 12-year-old second crossers exhibited more variability in timing of entry (M= .26, SD=.18) than solo crossers (M= .15, SD=.04), F(1,27)=5.62, p=.025. When comparing first to second crossers, those crossing first (M= .28, SD=.12) were more variable in their timing of entry than those crossing second (M= .20, SD=.15), F(1,20)=20.00, p=.008; further, there was a marginal effect of age, F(1,20)=3.96, p=.061, with adults exhibiting less variability than 12-year-olds.

Crossing time. There was a significant effect of role on crossing time. Pair members crossing first (M= 1.95, SD=.26) crossed significantly more quickly than solo crossers, (M= 2.16, SD=.18), F(1,54)=12.11, p=.001. Pair members crossing second (M= 2.04, SD=.21) also crossed more quickly than solo crossers F(1,54)=5.142, p=.028. Those crossing first also crossed significantly more quickly than those crossing second, F(1,20)=5.48, p=.03. There was no effect of age for first crossers compared to solo crossers, F(1,54)=.13, ns, or second crossers compared to solo crossers, F(1,54)=2.74, ns.

Time to spare. There was a significant effect of role between solo crossers and first crossers, F(1,54)=28.44, p<.001. This is expected because 1st crossers choose smaller gaps than both 2nd and solo crossers. Those crossing first (M= .93, SD=.43) had significantly less time to spare than solo crossers (M= 1.48, SD=.33) and second crossers (M= 1.50, SD=.51). There was no effect of role when comparing second crossers to solo crossers, F(1,54)= .07. There was a significant effect of role when comparing first crossers to second crossers, F(1,20)= 31.91, p<.001. There was no effect of age for first crossers compared to solo crossers, F(1,54)=.61, ns, second crossers compared to solo crossers, F(1,54)=1.850, ns, or first crossers compared to second crossers, F(1,20)=.41, ns.

Collisions. Analysis showed that those crossing solo (M= .20, SD=.14) were hit more often than those crossing first (M= .08, SD=.14), F(1,54)= 9.94, p=.003, and those crossing second (M= .02, SD=.04), F(1,54)=37.09, p<.001. We would expect pair crossers to get hit more often due to the riskier gaps chosen; however, we see the opposite in this case. Additionally, those who crossed first were hit more often than those who crossed second, F(1,20)= 4.48, p=.047. This is likely due to the fact that those crossing first chose smaller gaps than those crossing second. There was no effect of age for first crossers compared to solo crossers, F(1,54)=.14, ns, second crossers compared to solo crossers, F(1,54)=.58, ns, or first crossers compared to second crossers, F(1,20)=.43, ns.

1.6   Discussion

The goal of this study was to compare pedestrian road-crossing behavior in pairs of friends vs. solo crossers of the same age. We also wanted to examine potential differences between adults and children in road-crossing behavior. We found that pairs and solo crossers chose similar gaps sizes to cross and that overall behavior looked very similar between the two age groups. Pairs also synchronized their movements very closely. The timing of entry for those on the left was similar to solo crossers, but right pair members cut in more tightly behind the lead car. In order to cross safely, pairs crossed more quickly than solo crossers. That led to left crossers and solo crossers with similar times to spare, and those on the right with good timing entry had more time to spare. We also did not find many differences between 12-year-olds and adults in gap

choices or movement timing. The only differences in movement timing between the two age groups was that 12-year-olds walked more quickly than adults and were more variable in their timing of entry.

In contrast to our expectations, there were not many differences between pairs of friends and solo crossers. We would expect pairs of friends to choose larger gaps to allow both pedestrians to safely cross through the gap. However, in this study they chose gaps very similar to those of solo crossers. Jiang et al. [6] found that pairs of unfamiliar peers chose larger gaps than solo crossers. This leads to the conclusion that, when crossing with a friend, pedestrians take more risks. We also found that, in the pair condition, those crossing on the right cut in more tightly behind the lead car and had more time to spare than solo and left crossers. Given that gap choices were relatively tight and that the pair walked in synchrony, the pair member on the right had to enter the road more tightly behind the lead car. In other words, the right pair member had to adjust his or her crossing actions in order to match the pair's risky gap decisions. We also saw that 12-year-olds in the pair crossed the road more quickly than solo crossers. Again, we see that those in the pair condition are not adjusting their decisions in order to cross safely, but rather they are adjusting their movement to compensate for their riskier gap choices.

We also observed a greater number of risky choices when pairs chose to take different gaps. Those who crossed the street first chose smaller gaps and had less time to spare than solo and second crossers. In order for first crossers to make it across safely, they adjusted their movement timing by crossing the street more quickly. Second crossers likely found the gap crossed by the first crosser too small and therefore waited for a larger gap to cross. By choosing a bigger gap, second crossers were able to walk more slowly and still have more time to spare than first crossers.

One unexpected finding between pairs and solo crossers was that solo crossers were hit significantly more often than pedestrians in the pair. We would expect that the riskier behavior in choosing a smaller gap size would have led pedestrians in the pairs to be hit more often. However, because of the adjustment in timing of entry and walking speed, pedestrian pairs were hit less often than solo pedestrians.

We were also surprised to find that there were not very many differences in crossing behavior in adults and 12-year-olds. The only differences we found were that 12-year-olds overall crossed the road more quickly than adults. Twelve-year-olds were also more variable in their timing of entry compared to adults, which matches results from O'Neal et al. [2]. We hypothesized that 12-year-old solo crossers would be more conservative in their gap choices than adult solo crossers. O'Neal et al. [2] found that 12-year-olds chose bigger gaps than adults, and we expected to see the same results. Perhaps the age of the child isn't as important as how mature they are. It could be that we had younger 12-year-olds and less-mature 12-year-olds that crossed the street much more like 6- to 10-year old children instead of the 12-year-olds in the O'Neal et al. study.

From this study we can conclude that pairs of friends who cross the road together take more risks than solo crossers. The pairs chose gaps similar in size to those chosen by solo crossers when they should have chosen larger gaps that allowed both pedestrians to safely cross. Their poor gap choices led them to adapt their movement timing to allow for safe crossing. They

crossed the road more quickly, and those on the right cut in more tightly behind the lead car. Parents should be aware that their children may take more risks when with a peer and that it may be beneficial to teach them how to make better gap choices when crossing with a friend. More research needs to look at how different age groups cross the road with a peer and how that compares to crossing alone. By understanding the behavior of children, we can teach them more effectively and keep them safer.

2 Experiment 2: Action Coordination with Agents: Crossing Roads with a Computer-Generated Agent in a Virtual Environment

2.1 Introduction

We spend much of our active lives surrounded by other people: on city sidewalks, in malls, at sporting events, and in museums. Both observational studies and laboratory experiments have found that the actions of others around us influence our behavior, often in subtle and inconspicuous ways. Observers anticipate the actions of others, leading to a priming of motor activation systems in the observer [7, 8, 9]. Merely watching others perform an action increases an observer's tendency to perform the action even when the observer did not intend to perform the action themselves [10]. One everyday manifestation of this effect happens at street corners. Studies of pedestrian road crossing show that the likelihood of a person crossing against a red light is increased when someone nearby starts to cross against the red light [11, 12, 13, 14]. This tendency to follow the leader can lead to an increased risk of injury from a collision.

Virtual environments provide a powerful medium in which to conduct controlled experiments on how people are influenced by the behaviors of others [15]. We can populate VEs with computer-generated (CG) characters (also called agents) and study how the agent behavior influences human participants. Moreover, we can conduct these studies in a safe environment where the risk of injury to participants is minimal. A key question is whether people respond to CG characters in the same way they respond to a real person.

Our earlier work examined how two real people cross through traffic in a co-occupied, large-screen VE [6]. Each participant was presented with independent, viewpoint-correct non-stereo images of the VE. We found that pairs often crossed together, even with no instructions to do so, and closely synchronized their movements when crossing. Pairs also chose larger gaps than solo crossers, presumably to accommodate the joint action of crossing the road together.

Three terms are frequently used to describe computer-generated graphic characters in VR and AR: Characters, agents, and avatars. We use the terms CG character and agent interchangeably to mean animated characters that are computer controlled. We reserve the term avatar to refer to animated characters that mimic the real-time motions of a real person in a shared virtual environment.

In this project we conducted an experiment comparing road crossing with a real person to road crossing with a CG character programmed to be risky or safe (see **Error! Reference source not found.**). The experiment had two purposes. One was to examine how the risky or safe road-crossing behavior of a CG character influences the behavior of a participant. The second was to assess the degree to which people interact similarly with a real person vs. a CG character.

Figure 2.1 - Photograph of street crossing with another person or a computer-generated agent in the pedestrian simulator (the visual angles are correct from the viewpoint of the pedestrian).

2.1   Background Literature

2.1.1   Joint Action and Road Crossing

Joint action has been intensely studied by psychologists using both behavioral and neuro-physiological methods. What this work reveals is that we are wired to coordinate our actions with others [16]. Watching others perform an action increases the tendency to perform the action even when the observers did not intend to perform the action themselves [10]. Observers also anticipate the actions of others, leading to a priming of motor activation systems in the observer [7, 8, 9].

The impulse to "do as your companion does" has important implications for tasks in which timing is critical, such as road crossing. In particular, following the lead of another person into a tight gap in traffic could lead to a collision. Field studies and surveys have shown that pedestrians have an increased willingness to cross against a red light when another pedestrian starts to cross first [11, 12, 13, 14].

Joint action frequently involves making judgments about affordances, or possibilities for action that depend on the relationship between the characteristics of the individual and the properties of the environment [17]. In the case of an individual making judgments about whether a gap in traffic affords crossing, he or she must take into account the relationship between how long it will take to cross the road and the size of the temporal gap between the vehicles [18]. Making judgments about affordances becomes more complex when two people are crossing the road because they must take into account the time needed for both people to cross through the temporal gap between the cars. There is evidence that when two people perform a joint action they act as a unit, making decisions that take into account the impact of their actions on their partner [19]. For example, using functional magnetic resonance imaging (fMRI), Radke et al. [20] found increased brain activation in the medial prefrontal cortex following errors that had consequences for their co-actor in a cooperative computer-gaming task. Similarly, when two people are asked to walk side-by-side through an aperture, they are sensitive to the fit required for the pair to pass through the aperture [21]. Also, we found in our previous study that when

pairs cross a virtual road, as compared to singletons, they tend to act together, pick larger gaps, and synchronize their movement when crossing together [6].

2.1.2   Interactions with Agents in Virtual Reality

A growing body of research has examined social interactions mediated through conversational interactions with CG characters in VEs, focusing on how the fidelity of agent appearance and movement influences co-presence in conversational activities [22-27]. However, there is relatively little research examining how people interact with CG characters while performing full-body activities such as bicycling in large-scale environments. One study that involved full-body motion of the participant (but not the agent) examined the influence of behavioral realism on interpersonal distance in VEs [28]. The researchers found that people exhibit patterns of interpersonal distance between themselves and virtual agents similar to what has been reported in previous studies with real people.

We have examined social influences on children's road crossing using a CG character as a virtual peer in a bicycling simulator (see Figure 2.2) [29]. Specifically, we looked at whether 10- and 12-year-olds chose tighter gaps after riding with a virtual peer who selected smaller versus larger gaps. Participants were instructed to watch the virtual peer cross each intersection before attempting to cross on their own. After crossing a gap in traffic, the virtual peer waited on the other side of the intersection for the participant to cross. They then jointly rode to the next intersection. After six intersections, the peer said goodbye to the rider and rode off down a side street. Child riders then continued on their own for the next six intersections. We found that children in the risky (small gap) peer condition were more likely to cross 3.5 and 4.5 s gaps than were children in the safe (large gap) peer condition. These gaps are ambiguous in the sense that they are neither too small to cross nor are they easily crossable.

Figure 2.2 - A child rider with the virtual peer.

In this report, we present the results of an experiment that examined how people cross roads as pedestrians in a VE with a CG character who took either risky or safe gaps. We compared their road-crossing behavior with the CG character to a control condition in which people crossed roads with another person.

2.2   Methods

2.2.1   Task

We used a pedestrian road-crossing task to examine the effects of a real vs. a CG partner on joint decision-making and action coordination. Two previously unacquainted participants or a single participant and a CG character stood next to each other at the edge of a one-lane road and watched continuous traffic coming from the left. Participants were asked to cross the road without being hit by a car. They were given no instructions about whether or not they should cross together. Once both participants had crossed the road, the traffic ceased to be generated. Participants then walked back across the empty road to the starting point, and a new trial commenced.

The traffic traveled at a constant speed of 25 MPH, with randomly ordered, uniformly distributed temporal gaps between cars that ranged in size from un-crossable to easily crossable (2-5 s gaps, including half-second intervals). The traffic was composed of different models of compact cars with random colors, all similar in size.

2.2.2   Virtual Environment

The experiment was conducted in a large-screen VE similar to a CAVE [30], consisting of three screens placed at right angles relative to each other. The screens formed a three-walled room that was 10 ft. wide x 14.2 ft. long x 8 ft. tall. Three DPI MVision 400 Cine 3D high-resolution projectors were used to back-project images onto the side screens. A fourth projector front-projected images onto the floor. Stereo surround sound with the Doppler Effect was used to generate ambient traffic sounds.

We used an OptiTrack motion capture system to track the movements of the participants. The tracking system consisted of 17 Flex 13 infrared cameras mounted on the top and the back of the VE. Participants wore a helmet with reflective markers mounted on it to track their head position and orientation.

A real participant (which we call the target participant) was paired with either another real participant or a CG character (in both cases, we call the second entity the crossing partner). Our analysis focuses on the target participant. At the start of each trial, the target participant stood at the edge of a virtual one-lane road to the right of the crossing partner. The target participants in all conditions viewed stereo images based on the estimated position and orientation of their eyes. A fixed inter-pupillary distance of 6.5 cm was used to render images for the left and right eyes. Active shutter glasses were used to split the left- and right-eye image streams to create a stereo effect. Non-target participants, who served as crossing partners in the real condition, saw the same stereo images that the target participants saw.

The VE software is based on the Unity3D gaming platform. A detailed description of the hardware and software is presented by Rahimian et al. [31]. The simulation frame rate was about 30 fps without noticeable lag or jitter. Images were displayed at a rate of 120 Hz.

2.2.3   Experiment Design

The experiment used a between-subjects design with three conditions: real, safe, and risky. In the real condition, the road-crossing partner was a real person. In the safe and risky conditions, the road-crossing partner was a stereo CG character that mimicked the crossing motion of a real partner.

2.2.4   Character Design

The character's standing location and crossing motion were designed to match observations of real partners from our previous work [6]. The character motion was created by the Mecanim animation engine, using full-body, motion-captured walking and turning motions blended and controlled by a state machine. The risky agent was programmed to cross any gap that was larger than or equal to 3.5 s, while the safe agent crossed any gap that was larger than or equal to 4.5 s. We know from our previous study that gaps around the size of 3.5 s are crossable but tight for people crossing in pairs, and that gaps of 4.5 s and above are safe and easy to cross. The agent stood to the left of the participants. When the agent crossed the road, its time of entry relative to the lead car in the gap was the same as the average time of entry we observed for the left member of the pair in our previous study of two real crossers (M=0.80 s, SD=0.16). The crossing time of the agent was approximately 2.08 s, which was also similar to the left member in a pair observed from our previous study (M=2.09 s, SD=0.25). Thus, the agent basically replicated the crossing motion of a real partner standing on the left. Only the gap acceptance criterion level varied across the risky and safe CG characters.

As a check on the decision-making and movement timing of the virtual partners, we compared the gap selection and crossing motions of the virtual partners to the gap selection and crossing motions of the left person (the real partner) in the control condition of this experiment. The safe agent crossed significantly larger gaps than the real partner, M=4.76 s (SD=0.05) vs. M= 4.48 s (SD=0.27), p<.001. The risky agent crossed significantly smaller gaps than the real partner, M= 4.26 s (SD=0.09) vs. M= 4.48 s (SD=0.27), p=.025. This verified our agent design.

The safe agent (M=0.83 s, SD=0.81), p=.015, and the risky agent (M=0.81 s, SD=0.02), p=.034, entered the road more slowly than the real partner (M=0.67 s, SD=0.20), but the road-crossing times of the safe agent, (M=2.07 s, SD=0.04), the risky agent (M=2.08 s, SD=0.03), and the real partner (M=2.05 s, SD=0.23) were nearly identical. As shown in Figure 2.3, the agents' crossing trajectory was similar to that of the real partner, but the slight delay when entering the road caused a slight overall delay in crossing. We will return to this difference when we look at how the targets synchronized their crossing motion with the partner.

Because of the immersive stereo display, the CG character actually appeared to be standing inside the simulator volume, at the location where the real partner stood in our previous study. Participants sometimes even reached out to touch the character.
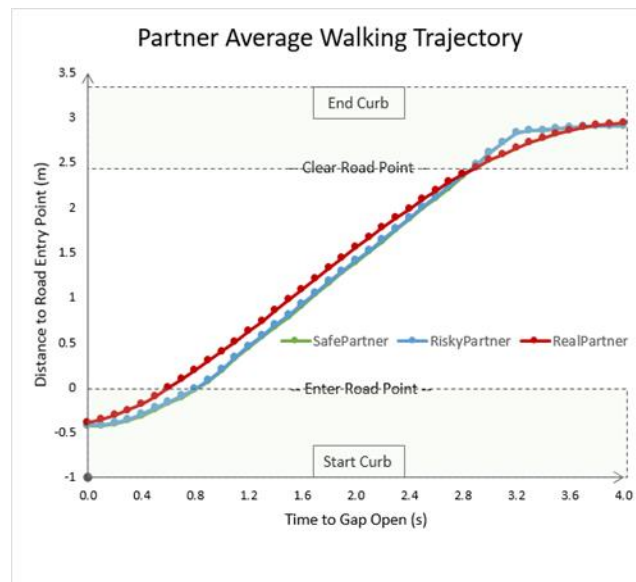
Figure 2.3 - Partner average walking trajectory in 3 conditions. The safe and risky agent partner's walking path were the same.

2.2.5   Procedure

The session began with the experimenter obtaining informed consent from participants in an adjoining room. Participants were then taken to the simulator room and fitted with the tracking helmet, shutter glasses, and a harness that was connected to a post at the back of the VE to prevent them from walking into the front screen. In the real condition, one of the two participants was randomly selected to serve as the crossing partner and the other as the target participant. The partner always stood on the left side of the target as the pair waited to cross through the stream of traffic.

After a brief introduction to the virtual neighborhood, target participants performed a single practice road-crossing trial with the partner. The experimenter instructed participants to watch the traffic and to cross without getting hit by a car. Participants then completed 20 road-crossing test trials with their partner. After finishing the road-crossing task, participants filled out a demographics questionnaire and were debriefed about road-crossing safety. The experiment took approximately 30 min. to complete.

2.2.6   Data Recording and Performance Variables

With respect to the target's road-crossing performance, we focused on two main aspects of road crossing: gap selection and movement timing. We also examined how the target interacted with the partner in terms of movement synchrony and standing distance. Participants in all three conditions rarely talked or gestured to their partners. Scores for each measure represented the average across the 20 test trials.

2.2.6.1   Gap Selection

Waiting time represented how long participants waited from the start of a trial until crossing.

Gap size was the temporal size of the gap selected for crossing.

2.2.6.2   Movement Timing

Timing of entry was the time between the back of the lead vehicle and the participant at the moment the participant entered the road. This measure describes how tightly participants timed their movement relative to the lead vehicle in the gap.

Crossing time was the amount of time that the participant took to cross the road.

Time to spare was the time between the participant and the front of the tail vehicle at the time the participant cleared the path of the cars. This measure describes how close the participants were to getting hit by the tail vehicle.

Hits were extremely rare. In only 3 of nearly 900 crossings did a vehicle virtually collide with a participant (one in the safe agent condition and 2 in the risky agent condition). While there were no physical consequences to being hit, participants did seem to be aware of very close calls and hits – they would sometimes do a jump at the end of a crossing to avoid being hit. The number of hits was too small to statistically analyze.

All measures were averaged across the 20 road-crossing trials to arrive at aggregate scores. We also computed a variability of timing of entry score by calculating the standard deviation of each participant's timing of entry across all 20 test trials.

2.2.7   Partner interaction

Interpersonal distance. We also measured the distance between the target and the partner when the first car of the traffic stream crossed the middle of the simulator. At that time, both the target and the partner were waiting for a gap. This measure reflects how much interpersonal distance the target maintained from the partner.

Movement synchrony. We examined two aspects of movement synchrony between the target and partner. One was how closely they started moving together, and the other was how closely they finished the crossing together.

2.2.8   Participants

The participants were 64 undergraduate students enrolled in an elementary psychology course at the University of Iowa. There were 16 participants (8 male, 8 female) who crossed with the risky agent (risky condition), 16 participants (8 male, 8 female) who crossed with the safe agent (safe condition), and 16 participants (8 male, 8 female) who crossed with a real partner (real condition). An additional 16 participants served as the partners in the real condition. One pair in the real condition had to be dropped due to tracking errors. Participants received course credit for their participation.

2.3   Results

There were two primary questions of interest. First, how did the risky and safe agents influence the participants' gap selection and movement timing? Second, how did participants interact with the agents as compared to a real partner?

Group differences were analyzed in one-way ANOVAs with partner type (real, safe, risky) as a between-subjects factor. As a complement to the ANOVAs, mixed-effects logistic regression analyses were conducted to evaluate gap size and partner type as predictors of gap choices.

2.3.1 How did the risky and safe agents influence participants?

2.3.1.1 How did the safe and risky agents influence gap selection?

Participants in all three conditions preferred to cross with their partner. Participants crossed with the safe agent on 64% of the trials, with the risky agent on 72% of the trials, and with the real partner on 76% of the trials. The likelihoods of crossing with the partner were not significantly different across the three conditions, and were all significantly different from chance (50%), $p=.009$, $p<.001$, $p<.001$, respectively.

We first analyzed gap choices on all trials, combining trials on which the participants crossed the same gap as their partner and trials on which they crossed a different gap than their partner. As shown in Figure 2.4, mixed-effects logistic regression analyses showed that participants in all conditions were more likely to take larger than smaller gaps, $p < .001$. Additionally, the gap acceptance thresholds of those in the risky condition were significantly less conservative than of those in the real partner condition, $p = .01$; they were 3.51 times more likely to accept a given gap compared to those in the real partner condition. Further, the gap acceptance thresholds of those in the risky condition were significantly less conservative than those in the safe condition, $p = .04$, with those in the risky condition having 2.72 increased odds of accepting a gap compared to those in the safe condition.
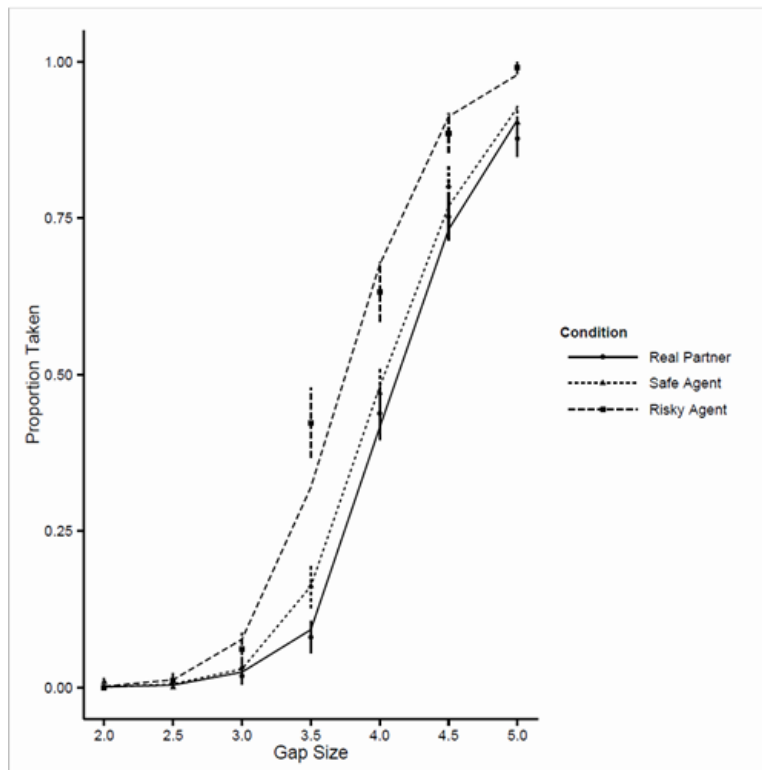
Figure 2.4 - Logistic regression curves depicting the likelihood of participants taking gaps of each size with a Real Partner, Safe Agent, or Risky Agent.

We then analyzed gap choices on the trials in which the participants crossed the same gap with their partner. As would be expected, targets in the risky agent condition (M=4.43 s, SD=0.14) chose significantly smaller gaps than targets in both the safe agent condition (M=4.74 s, SD=0.07), $p<.001$, and the real partner condition (M=4.61 s, SD=0.20), $p<.029$. Those in the real partner condition chose marginally smaller gaps than those in the safe agent condition, $p=.066$.

Finally, we analyzed gap choices on the trials in which the participants did not cross the same gap with their partner. When crossing different gaps, targets in the safe agent condition were highly likely to cross before the agent (80%), significantly different from chance (50%), $p<.001$, and taking gaps that were smaller than the safe agent would take, M=4.00 s (SD=0.18) vs. M=4.75 s (SD=0.13). In contrast, targets in the risky condition rarely crossed before the agents (4%), significantly different from chance (50%), $p<.001$, preferring to wait for a larger gap than the risky agent took, M=4.33 s (SD=0.43) vs. M=3.83 s (SD=0.18). As a consequence, when crossing by themselves, targets in the safe agent condition (M=4.00 s, SD=0.18) picked significantly smaller gaps than those in both the risky agent condition (M=4.33 s, SD=0.43), $p=.022$, and the real partner condition (M=4.48 s, SD=0.31), $p=.001$.

2.3.1.2   How did the safe and risky agents influence movement timing?

a.   When crossing together

Timing of entry. The targets' timing of entry when crossing with the partners did not differ significantly between the three groups: safe agent condition M=0.69 s (SD=0.14), risky agent condition M=0.64 s (SD=0.20), real partner condition M=0.57 s (SD=0.13).

Crossing time. When crossing the same gap, targets paired with safe agents (M=2.29 s, SD=0.15), p<.001, and risky agents (M=2.24 s, SD=0.17), p=.015, took significantly longer to cross the road than those who crossed with a real partner (M=2.07 s, SD=0.16).

Time to spare. Participants who crossed with a real partner (M=1.97 s, SD=0.35) had more time to spare than those who crossed with a risky agent (M=1.55 s, SD=0.29), p=.001. The time to spare in the safe agent condition (M=1.77 s, SD=0.20) did not differ from the risky partner condition, nor from the real partner condition.

b.   When crossing separate gaps

Timing of entry. The entry timing was not significantly different among the three groups: safe agent condition, M=0.58 s (SD=0.10), risky agent condition, M=0.57 s (SD=0.18), real partner condition M=0.61 s (SD=0.14).

Crossing time. As was the case when they crossed the same gap as the partner, targets in the safe agent (M=2.27 s, SD=0.20) and risky agent (M=2.24 s, SD=0.23) conditions crossed more slowly than did targets in the real partner condition (M=2.04 s, SD=0.18), even when they crossed different gaps than the partner, p=.008 and p=.031, respectively.

Time to spare. Targets in the safe agent condition (M=1.14 s, SD=0.19) had less time to spare than targets in both the risky agent (M=1.52 s, SD=0.50), p=.031, and real partner (M=1.83 s, SD=0.50), p=.001, conditions. As noted in the gap selection section (4.1.1), when targets in the safe condition did not cross with the agent, they tended to cross smaller gaps. Given the smaller gap size and longer crossing time, targets in the safe agent condition naturally ended up with less time to spare when they crossed different gaps than their partner.

2.3.2   How did participants interact with agents vs. real partners?

2.3.2.1   Interpersonal distance

To what degree did participants keep similar interpersonal distance between themselves and real partners vs. agent partners? A comparison of interpersonal distance across the three conditions showed that interpersonal distance did not differ significantly across the three conditions: safe agent condition M=.13m (SD=0.08), risky agent condition M=.10m (SD=0.09), real partner condition M=.10m (SD=0.07).

2.3.2.2   Movement Synchrony

Entering the road. Targets in all three groups entered the road in close synchrony with their partner when crossing through the same gaps, with an average difference in entry time of *M*=0.24 s (*SD*=0.11) in the safe agent condition, *M*=0.24 s (*SD*=0.08) in the risky agent condition, and *M*=0.24 (*SD*=0.17) in the real partner condition.

Clearing the road. Likewise, targets in all three groups cleared the road together with their partners in very tight synchrony, with an average difference in clear time of M=0.28 s (SD=0.13) in the safe agent condition, M=0.29 s (SD=0.16) in the risky agent condition, and M=0.28 (SD=0.14) in the real partner condition.

The small enter and clear road time difference between the two members of the pair showed that in all three conditions participants synchronized their crossing with the partner. This finding is further confirmed by Figure 2.5 where the average walking path of the partner and target in the three conditions is shown.
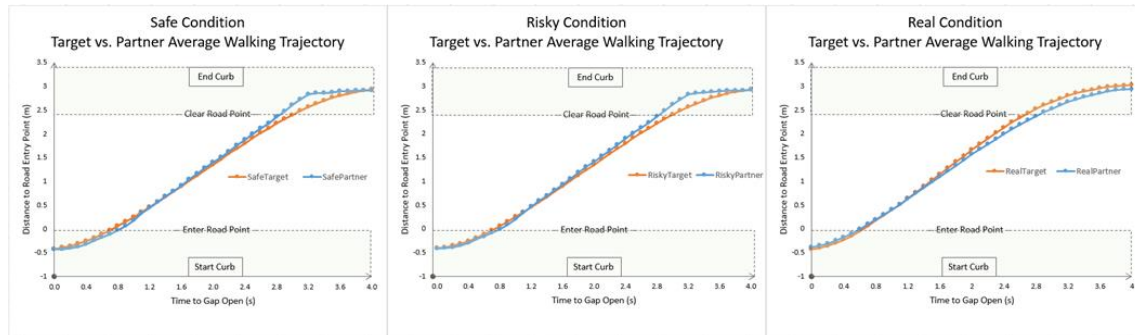
Figure 2.5 - Average walking trajectory in 3 conditions showing that participants synchronized their movement with their partners.

This tight synchronization between targets and partners may explain why targets who were crossing with an agent had longer crossing times than targets who were crossing with a real partner. It appears that targets who crossed with an agent slightly slowed their motion to synchronize with the agent (which timed its entry slightly later relative to the lead vehicle).

2.4   Discussion

This report presents the results of an experiment investigating how people jointly coordinate their decisions and actions with a CG character in a large-screen VE. We focused on two main questions: How does the riskiness of a CG character's road-crossing behavior influence the behavior of a participant? To what degree do people interact similarly with a real person vs. a CG character?

In many respects, participants treated CG characters similarly to real partners in the joint road-crossing task. Participants in all three conditions were more likely to cross the same gap as the partner than not, and kept a similar interpersonal distance between themselves and their partner. In addition, they coordinated their crossing movement with both real and CG agent partners, entering and exiting the roadway in tight synchrony. Notably, targets paired with CG characters appeared to slow their crossing movement to allow the later starting agents to catch up with them and then continued the crossing in synchrony with the agent.

When paired with the risky partner, targets were willing to take more borderline gaps (3.5 and 4 s) than they took with the safe or real partner. This is consistent with our previous work showing that child cyclists are more likely to take riskier gaps after experience riding with a risky CG peer

than a safe CG peer [29]. Interestingly, the safe partner seemed to exert a less powerful influence on targets than did the risky partner. Targets were less likely to cross with the safe peer, most often crossing smaller gaps before a gap arrived that was sufficiently large for the safe partner to accept.

The group differences in the target participants' willingness to accept risky gaps when paired with risky agents are likely due, at least in part, to the targets coupling their decisions and actions with the decisions and actions of their partner. This tendency to "do what the partner is doing" results in targets taking more small gaps when the partner took small gaps. That this happened with the risky agent shows that the pull to couple motions can lead to greater risk taking and demonstrates that this pull holds for CG characters. Both observations are important: (1) that pedestrians will adjust their gap threshold to take greater risk in response to greater risk taking by a nearby pedestrian, and (2) that this behavior can be elicited with a relatively crude CG agent.

The story is even more interesting when combined with the asymmetry of the effect – targets were less willing to wait for the safe agent when a large gap came late in the sequence. Overall, this may suggest that actual movement is a necessary component for partner influence (i.e., the motion of the risky agent triggered action in the target, but the presence of the safe peer waiting for a large gap was not enough to hold the target in place). Alternatively, it may reflect a greater willingness to adjust gap acceptance thresholds downward (taking more small gaps) than to wait for larger gaps. It would be interesting to test the limits of this coupling to see how tight of gaps participants would take with an agent. It would also be interesting to use human confederates as partners who could be instructed to be more or less risky in their gap choices.

This study demonstrates the potential for using large-screen VEs to study how people interact with CG characters. Our characters were realistic in many respects: they appeared plausibly human; their movements were based on real human motions; they had idle motions that gave some sense of liveness; and their gaze tracked the motion of the lead car in the gap to be crossed. However, it was very evident that they were simulated entities: their clothes and hair were stiff; their motions were highly repetitive; the transitions between motions were somewhat abrupt; and the agent neither acknowledged nor engaged with the participants. Other work might explore how different levels of fidelity in both the appearance and behavior of the character influence participant behavior. The road-crossing task also provided robust behavioral measures for examining how people adjust their behavior in the presence of animated characters. The wide field of view allowed participants to keep the agent in their peripheral vision even when they were attending to the traffic, something that would be more difficult in a head-mounted display system.

This study also provides a foundation for future studies examining joint action in physically separated, shared VEs where participants are represented by graphic avatars in their partner's VE. Such shared VEs have been investigated for teleconferencing [32, 33], task performance [22, 34], and rehearsal [35]. This research has largely focused on how the fidelity of self-avatars impacts an individual's perception, performance, and sense of body ownership [36, 37], and on how avatar fidelity influences conversational interactions [22, 26, 38]. However, little is known about what levels of motion and appearance fidelity are needed to effectively represent other actors and to support full-body joint actions in a shared virtual space. Road crossing is an excellent model system for studying coordinated action in complex perceptual-motor tasks that involve making decisions and timing movement. The results of this experiment provide a baseline which

could be compared to similar data collected with avatars of various levels of fidelity. In future work, we plan to investigate how the fidelity of both avatar appearance and movement influences interactions between participants in road crossing.

References

1. National Highway Traffic Safety Administration (2014). Traffic Safety Facts 2014. DOT HS 812 261, U.S. Department of Transportation, Washington, DC.

2. O'Neal, E. E., Jiang, Y., Franzen, L., Rahimian, P., Yon, J. P., Kearney, J. K., & Plumert, J. M. (2017). Changes in perception-action tuning over long time scales: How children and adults perceive and act on dynamic affordances when crossing roads. *Journal of Experimental Psychology: Human Perception and Performance. http://doi.org/10.1037/xhp0000378.*

3. Barton, B. K. & Schwebel, D. C. (2007). The roles of age, gender, inhibitory control, and parental supervision in children's pedestrian safety. *Journal of Pediatric Psychology, 32(5)*, 517-526.

4. Plumert, J. M., Cremer, J., Kearney, K., Recker, K., & Strutt, J. (2011). Changes in children's perception-action tuning over short time scales: Bicycling across traffic-filled intersections in a virtual environment. *Journal of Experimental Child Psychology*, *108*, 322-337

5. Geraghty, J., Holland, C., & Rochelle, K. (2015). Examining links between cognitive markers, movement initiation and change, and pedestrian safety in older adults. *Accident Analysis and Prevention, 89*, 151-159.

6. Jiang, Y., O'Neal, E., Yon, J.P., Frazen, L., Rahimian, P., Plumert, J., & Kearney, J. (in press). *Acting Together: Joint Pedestrian Road Crossing in an Immersive Virtual Environment.* ACM Transactions on Applied Perception.

7. Cisek, P. & Kalaska, J. F. (2004). Neural correlates of mental rehearsal in dorsal premotor cortex. *Nature*, 431, 7011, 993–996.

8. Kilner, J. M., Vargas, C., Duval, S., Blakemore, S.-J., & Sirigu, A. (2004). Motor activation prior to observation of a predicted movement. *Nature Neuroscience*, 7, 12, 1299–1301.

9. Van Schie, H. T., Mars, R. B., Coles, M. G. H., & Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience*, 7, 5, 549–554. http://doi.org/10.1038/nn1239

10. Lakin, J. L. & Chartrand, T. L. (2003). Using nonconscious behavioral mimicry to create affiliation and rapport. *Psychological Science*, 14, 4, 334–339.

11. Faria, J. J., Krause, S., & Krause, J. (2010). Collective behavior in road crossing pedestrians: The role of social information. *Behavioral Ecology*, 21, 6, 1236–1242.

12. Guéguen, N. & Pichot, N. (2001). The influence of status on pedestrians' failure to observe a road-safety rule. *The Journal of Social Psychology*, 141, 3, 413–415.

13. Lefkowitz, M., Blake, R. R., & Mouton, J. S. (1955). Status factors in pedestrian violation of traffic signals. *Journal of Abnormal Psychology*, 51, 3, 704–706.

14. Zhou, R. & Horrey, W. J. (2010). Predicting adolescent pedestrians' behavioral intentions to follow the masses in risky crossing situations. *Transportation Research Part F: Traffic Psychology and Behaviour*, 13, 3, 153–163. http://doi.org/10.1016/j.trf.2009.12.001

15. Blascovich, J., Loomis, J., Beall, A. C., Swinth, K. R., Hoyt, C. L., & Bailenson, J. N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry*, 13, 2, 103–124.

16. Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in Cognitive Sciences*, 10, 2, 70–76.

17. Gibson, J. J. (1979). The ecological approach to visual perception. Hillsdale, NJ:Erlbaum. http://doi.org/10.1080/08838158409386516

18. Young, D. S. & Lee, D. N. (1987). Training children in road crossing skills using a roadside simulation. *Accident Analysis and Prevention*, 19, 5, 327–341.

19. Marsh, K. L., Johnston, L., Richardson, M. J., & Schmidt, R. C. (2009). Toward a radically embodied, embedded social psychology. *European Journal of Social Psychology*, 39, 7, 1217–1225. http://doi.org/10.1002/ejsp.666

20. Radke, S., De Lange, F. P., Ullsperger, M., & De Bruijn, E. R. A. (2011). Mistakes that affect others: An fMRI study on processing of own errors in a social context. *Experimental Brain Research*, 211, 3-4, 405–413. http://doi.org/10.1007/s00221-011-2677-0

21. Davis, T. J., Riley, M. A., Shockley, K., & Cummins-Sebree, S. (2010). Perceiving affordances for joint actions. *Perception*, 39, 12, 1624–1644. http://doi.org/10.1068/p6712

22. Bailenson, J. N., Beall, A. C., & Blascovich, J. (2002). Gaze and task performance in shared virtual environments. *Journal of Visualization and Computer Animation*, 13, 5, 313–320.

23. Bailenson, J. N., Yee, N., Merget, D., & Schroeder, R. (2005). The effect of behavioral realism and form realism of real-time avatar faces on verbal disclosure, nonverbal disclosure, emotion recognition, and copresence in dyadic interaction. *Presence: Teleoperators and Virtual Environments*, 15, 4, 359–372. http://doi.org/10.1162/pres.15.4.359

24. Garau, M. (2006). Selective fidelity: investigating priorities for the creation of expressive avatars. Avatars at Work and Play SE - 2, 34, 17–38. http://doi.org/10.1007/1-4020-3898-4_2

25. Garau, M., Slater, M., Bee, S., & Sasse, M. A. (2001). The impact of eye gaze on communication using humanoid avatars. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems CHI 01*, 309–316. http://doi.org/10.1145/365024.365121

26. Garau, M., Slater, M., Vinayagamoorthy, V., Brogni, A., Steed, A., & Sasse, M. A. (2003). The impact of avatar realism and eye gaze control on perceived quality of communication in a shared immersive virtual environment. *New Directions in Video Conferencing*, pp. 529–536.

27. Welbergen, H. Van, Basten, B. J. H. Van, Eggers, A., Ruttkay, Z. M., & Overmars, M. H. (2010). Real time animation of virtual humans: a trade-off between naturalness and control. *Computer Graphics Forum*, 29, 8, 2530–2554.

28. Bailenson, J. N., Blascovich, J., Beall, A. C., & Loomis, J. M. (2003). Interpersonal Distance in Immersive Virtual Environments. *Personality and Social Psychology Bulletin*, 29, 7, 819–833. http://doi.org/10.1177/0146167203253270

29. Babu, S. V., Grechkin, T. Y., Chihak, B., Ziemer, C., Kearney, J. K., Cremer, J. F., & Plumert, J. M. (2011). An immersive virtual peer for studying social influences on child cyclists' road-crossing behavior. *IEEE Transactions on Visualization and Computer Graphics*, 17, 1, 14–25.

30. Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM*, *35*(6), 64-73.

31. Rahimian, P., Jiang, Y., Yon, J. P., Franzen, L., Plumert, J. M., & Kearney, J. K. (2015). Designing an immersive pedestrian simulator to study the influence of texting and cellphone alerts on road crossing. In *2015 Road Safety and Simulation International Conference*.

32. Greenhalgn, C. & Benford, S. (1995). MASSIVE: A collaborative virtual environment for teleconferencing. *ACM Transactions on Computer-Human Interaction*, 2, 3, 239–261.

33. Isbister, K., Nakanishi, H., Ishida, T., & Nass, C. (2000, April). Helper agent: Designing an assistant for human-human interaction in a virtual meeting space. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 57-64). ACM.

34. Slater, M., Sadagic, A., Usoh, M., & Schroeder, R. (2000). Small-group behavior in a virtual and real environment: A comparative study. *Presence*, 9, 1, 37–51. http://doi.org/10.1162/105474600566600

35. Normand, J.-M., Spanlang, B., Tecchia, F., Carrozzino, M., Swapp, D., & Slater, M. (2012). Full body acting rehearsal in a networked virtual environment — a case study. *Presence*, 21, 2, 229–243.

36. McManus, E. A., Bodenheimer, B., Streuber, S., De La Rosa, S., Bülthoff, H. H., & Mohler, B. J. (2011, August). The influence of avatar (self and character) animations on distance estimation, object interaction and locomotion in immersive virtual environments. In *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization,* (pp. 37-44). ACM.

37. Ries, B., Interrante, V., Kaeding, M., & Phillips, L. (2009). Analyzing the effect of a virtual avatar's geometric and motion fidelity on ego-centric spatial perception in immersive virtual environments. *Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology*, 1, 212, 59–66.

38. Raij, A. B., Johnsen, K., Dickerson, R. F., Lok, B. C., Cohen, M. S., Deurson, M., Pauly, R. R., Stevens, A. O., Wagner, P, & Lind, D.S. (2007). Comparing interpersonal interactions with a virtual human to those with a real human. *IEEE Transactions on Visualization and Computer Graphics*, 13, 3, 443–57.