Action Coordination with Agents: Crossing Roads with a Computer-Generated Character in a Virtual Environment

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Figure 1: Joint road crossing with a real (left) or virtual partner (right). In the actual experiments, the images were rendered from each pedestrian's perspective (not from the camera's perspective).

Abstract

We investigated how people jointly coordinate their decisions and actions with a computer-generated character (agent) in a large-screen virtual environment. The task for participants was to physically cross a steady stream of traffic on a virtual road without getting hit by a car. Participants performed this task with another person or with a computer-generated character (Fig.1). The character was programmed to be either safe (taking only large gaps) or risky (also taking relatively small gaps). We found that participants behaved in many respects similarly with real and virtual partners. They maintained similar distances between themselves and their partner, they often crossed the same gap with their partner, and they synchronized their crossing with their partner. We also found that the riskiness of the character influenced the gap choices of participants. This study demonstrates the potential for using large-screen virtual environments to study how people interact with CG characters when performing whole-body joint actions.

Keywords: Immersive virtual environments, virtual character, stereo displays, joint action, pedestrian road crossing, co-occupied virtual environments, large screen VE.

Concepts: • Human-centered computing ~ Virtual reality
• Human-centered computing ~ Empirical studies in HCI
• Applied computing ~ Psychology

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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 [Cisek and Kalaska, 2004; Kilner et al., 2004; van Schie et al., 2004]. 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 [Lakin and Chartrand, 2003]. 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 [Faria et al., 2010; Guéguen and Pichot, 2001; Lefkowitz et al., 1955; Zhou and Horrey, 2010]. 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 [Blascovich et al., 2002]. We can populate virtual environments with computer-generated (CG) characters¹ (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 virtual environment [Jiang et al., 2016]. Each participant was presented with independent, viewpoint-correct non-stereo images of the virtual environment. 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,

¹ 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.

Figure 2: A child rider with the virtual peer [Babu et al., 2011].

presumably to accommodate the joint action of crossing the road together.

In this paper we present an experiment comparing road crossing with a real person to road crossing with a CG character programmed to be risky or safe. 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.

2 RELATED WORK

2.1 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 [Sebanz et al., 2006]. Watching others perform an action increases the tendency to perform the action even when the observers did not intend to perform the action themselves [Lakin and Chartrand, 2003]. Observers also anticipate the actions of others, leading to a priming of motor activation systems in the observer [Cisek and Kalaska, 2004; Kilner et al., 2004; van Schie et al., 2004].

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 an increased willingness to cross against a red light when another pedestrian starts to cross first [Faria et al., 2010; Guéguen and Pichot, 2001; Lefkowitz et al., 1955; Zhou and Horrey, 2010].

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 [Gibson, 1979]. 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 [Young and Lee, 1987]. 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 [Marsh et al.,

2009]. For example, using functional magnetic resonance imaging (fMRI) Radke et al. [2011] 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 [Davis et al., 2010]. And 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 [Jiang et al., 2016].

2.2 Interactions with Agents in VR

A growing body of research has examined social interactions mediated through conversational interactions with CG characters in virtual environments, focusing on how the fidelity of agent appearance and movement influences co-presence in conversational activities [Bailenson et al., 2002, 2005; Garau, 2006; Garau et al., 2003, 2001; Welbergen et al., 2010]. 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 virtual environments [Bailenson et al., 2003]. They 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 Fig. 2) [Babu et al., 2011]. 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.

In this paper, we present the results of an experiment that examined how people cross roads as pedestrians in a virtual environment 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.

3 METHOD

3.1 The Road-Crossing Task

We used a pedestrian road-crossing task to examine the effects of a real vs. a computer-generated partner on joint decision making and action coordination. Two previously unacquainted participants or a single participant and a computer-generated 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.

Figure 3: Hank virtual environment simulator.

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 (2-5s gaps, including half-second intervals). The traffic was composed of different models of compact cars with random colors, all similar in size.

3.2 Virtual Environment

The experiment was conducted in a large-screen virtual environment (VE) similar to a CAVE [Cruz-Neira et al., 1992] (see Fig. 3), 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/right eye image streams to create a stereo effect. Non-target participants, who serve as crossing partners in the real condition, saw the same stereo images that the target participants saw.

The virtual environment software is based on the Unity3D gaming platform. A detailed description of the hardware and software can be found in [Rahimian et al., 2015]. The simulation frame rate was about 30 fps without noticeable lag or jitter. Images were displayed at a rate of 120 Hz.

Figure 4: Partner average walking trajectory in 3 conditions. The safe and risky agent partner's walking path were the same.

3.3 Experimental Design

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

3.4 Character Design

The character's standing location and crossing motion were designed to match observations of real partners from our previous work [Jiang et al., 2016]. 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 or equal to 3.5s, while the safe agent crossed any gap that was larger or equal to 4.5s. We know from our previous study that gaps around the size of 3.5s are crossable but tight for people crossing in pairs, and that gaps of 4.5s 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 ($M=0.80s$, $SD=0.16$). The crossing time of the agent was approximately 2.08s, which was also similar to the left member in a pair observed from our previous study ($M=2.09s$, $SD=0.25$). 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 real partner, $M=4.76s$ ($SD=0.05$) vs. $M= 4.48s$ ($SD=0.27$), $p<.001$. The risky agent crossed significantly smaller gaps than real partner, $M= 4.26s$ ($SD=0.09$) vs. $M= 4.48s$ ($SD=0.27$), $p=.025$. This verified our agent design.

The safe agent ($M=0.83s$, $SD=0.81$), $p=.015$, and the risky agent ($M=0.81s$, $SD=0.02$), $p=.034$, entered the road more slowly than the real partner ($M=0.67s$, $SD=0.20$), but the road crossing times of safe agent, ($M=2.07s$, $SD=0.04$), risky agent ($M=2.08s$, $SD=0.03$), and real partner ($M=2.05s$, $SD=0.23$) were nearly identical. As shown in Fig. 4, 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 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 of the simulator volume, at the location where the real partner stood in our previous study. Participants sometimes even reached out to touch the character.

3.5 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 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 they 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.

3.6 Measures

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.

3.6.1 Gap selection

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

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

3.6.2 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 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.

3.6.3 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 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.

3.7 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

Figure 5: Logistic regression curves depicting the likelihood of participants taking gaps of each size in three conditions, with a Real Partner, Safe Agent, or Risky Agent.

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.

4 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 Analyses of Variance (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.

4.1 How did the risky and safe agents influence participants?

4.1.1 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 likelihood of crossing with the partner were not significantly different across 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 Fig. 5, 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 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.

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 risky agent condition ($M=4.43s$, $SD=0.14$) chose significantly smaller gaps than targets in both the safe agent condition ($M=4.74s$, $SD=0.07$), $p<.001$, and real partner condition ($M=4.61s$, $SD=0.20$), $p<.029$. 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, $M=4.00s$ ($SD=0.18$) vs. $M=4.75s$ ($SD=0.13$). 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,

$M=4.33s$ ($SD=0.43$) vs. $M=3.83s$ ($SD=0.18$). As a consequence, when crossing by themselves, targets in the safe agent condition ($M=4.00s$, $SD=0.18$) picked significantly smaller gaps than those in both the risky agent condition ($M=4.33s$, $SD=0.43$), $p=.022$, and in the real partner condition ($M=4.48s$, $SD=0.31$), $p=.001$.

4.1.2 How did the safe and risky agents impact 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 $M=0.69s$ ($SD=0.14$), risky agent condition $M=0.64s$ ($SD=0.20$), real partner condition $M=0.57s$ ($SD=0.13$).

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

Time to spare. Participants who crossed with a real partner ($M=1.97s$, $SD=0.35$) had more time to spare than those who crossed with a risky agent ($M=1.55s$, $SD=0.29$), $p=.001$. The time to spare in the safe agent condition ($M=1.77s$, $SD=0.20$) 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, $M=0.58s$ ($SD=0.10$), risky agent condition, $M=0.57s$ ($SD=0.18$), real partner condition $M=0.61s$ ($SD=0.14$).

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

Time to spare. Targets in the safe agent condition ($M=1.14s$, $SD=0.19$) had less time to spare than targets in both the risky agent ($M=1.52s$, $SD=0.50$), $p=.031$, and real partner conditions ($M=1.83s$, $SD=0.50$), $p=.001$. 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.

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

4.2.1 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

Figure 6: Average walking trajectory in 3 conditions. Participants synchronized their movement to the partners.

across the three conditions: safe agent condition $M=.13m$ ($SD=.08$), risky agent condition $M=.10m$ ($SD=.09$), real partner condition $M=.10m$ ($SD=.07$).

4.2.2 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 $M=0.24s$ ($SD=.11$) in safe agent condition, $M=0.24s$ ($SD=.08$) in risky agent condition, and $M=0.24$ ($SD=.17$) in 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 $M=0.28s$ ($SD=.13$) in safe agent condition, $M=0.29s$ ($SD=.16$) in risky agent condition, and $M=0.28$ ($SD=.14$) in 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 Fig. 6 where the average walking path of the partner and target in three conditions is shown.

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).

5 DISCUSSION

This paper presents the results of an experiment investigating how people jointly coordinate their decisions and actions with a computer-generated character in a large-screen virtual environment. 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 4s) 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 [Babu et al., 2011]. 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 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 virtual environments 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 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 virtual environment. Such shared virtual environments have been investigated for teleconferencing [GreenHalgN and Benford, 1995; Isbister et al., 2000], task performance [Bailenson et al., 2002; Slater et al., 2000], and rehearsal [Normand et al., 2012]. This research has largely focused on how the fidelity of self-avatars impacts an individual's perception, performance, and sense of body ownership [Mcmanus and Rosa, 2011; Ries et al., 2009], and on how avatar fidelity influences conversational interactions [Bailenson et al., 2002; Garau et al., 2003; Raij et al., 2007]. 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.

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