J Exp Criminol (2012) 8:29–47
DOI 10.1007/s11292-011-9132-x

Examining context-specific perceptions of risk: exploring the utility of "human-in-the-loop" simulation models for criminology

Andrew Park · Joseph Clare · Valerie Spicer · Patricia L. Brantingham · Tom Calvert · Greg Jenion

Published online: 23 August 2011
© Springer Science+Business Media B.V. 2011

Abstract

Objectives To utilize a "human-in-the-loop" simulation methodology to examine the impact of high-risk environmental contexts on perceptions of victimization risk.

Methods Fifty-nine participants navigated a virtual environment and encountered five two-alternative forced-choice decision points, with one alternative representing a high-risk environmental context in each case.

Results Participants risk-aware decision-making was examined as a function of sex and age, both for their decisions overall and also at each specific decision point. Overall differences in total risk-aware decisions were observed for sex (with females more risk-aware) but not age. In addition to this, variation in perceived risk was also observed across the range of high-risk environmental contexts and there was also some indication of varying influence of age and sex on specific types of risk-aware decisions.

Conclusions These results have interesting implications for research into context-specific perceptions of risk. These findings also support a stance that "human-in-the-loop" simulation modeling has good potential to contribute to criminology more broadly.

Keywords Human-in-the-loop simulations · Perceptions of risk · Decision-making · Movement

A. Park
Thompson Rivers University, Columbia, BC, Canada

J. Clare (✉)
Crime Research Centre, University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia 6009, Australia
e-mail: joe.clare@uwa.edu.au

A. Park · V. Spicer · P. L. Brantingham · T. Calvert
Simon Fraser University, Columbia, BC, Canada

G. Jenion
Kwantlen Polytechnic University, Langley, BC, Canada

Introduction

As outlined by Groff and Mazerolle (2008), recent research activity within criminology and criminal justice has indicated growing support for the utility of computer-based simulations (as emphasized by the 2008 special issue of the *Journal of Experimental Criminology* that focused explicitly on these techniques). To date, simulation has examined a broad range of techniques and a wide spectrum of criminological issues. However, one variation that requires experimental subjects to interact with virtual environments, termed "human-in-the-loop" simulation, remains largely unexplored by criminologists. This paper initiates an assessment of the potential for human-in-the-loop research to make a contribution to contemporary criminological theory. Specifically, the simulation in this case utilizes a virtual environment to examine the impact of high-risk environmental contexts on movement decision-making. This paper outlines the methodology involved with conducting this type of simulation and then explores the results with respect to key demographic characteristics of the simulation participants. Importantly, this simulation demonstrates (1) differences between males and females with respect to risk-aware decision-making, and (2) variation between specific environmental contexts with respect to the impact they have on movement. Extrapolating beyond this particular simulation context, the outcome of this process indicates that human-in-the-loop simulation has the potential to contribute to the broader progression of criminological theory.

Simulation modeling within criminology

Simulations and criminology to date Groff and Mazerolle (2008, p. 188) summarize the fundamental principles that underlie simulation models as follows: (1) distillation of "a phenomenon into its most important elements" and in its simplest form, (2) theoretically-grounded model development, with formal specification within a computer program, which is "able to accommodate dynamic, non-linear interactions that play out over time," and (3) concretely articulated model assumptions that make hypothesis testing possible and replication of results achievable across contexts. The origins of simulation techniques within criminology range back over 25 years, and to date the simulation models produced within a criminological context can be classified into two broad categories: agent-based models and dynamic systems models. Groff and Mazerolle (2008, p. 188) describe agent-based modeling as relying "on a bottom-up approach to computer simulation, where a few, simple, theory based rules are developed for the individual agents" and the "interactions of individuals in the model produce macro-level patterns that *emerge* from the simulation." In contrast to this, dynamic systems models require researchers to identify the inputs, outputs, and internal relationships of a system. The purpose of defining systems in this way is to enable predictions to be made about the likely impact alterations to the internal conditions of the system would have on the outputs.

Human-in-the-loop simulations A third type of simulation modeling has been utilized in non-criminological contexts. This alternative, which examines real-time human decision-making through the use of three-dimensional computer-generated graphic models, is referred to by a range of names including "human-in-the-loop" (HITL), "man-in-the-loop," and "immersive virtual environments" simulation.[1] HITL is the term used within this paper to capture these types of models. These types of simulations, which incorporate virtual reality technology, have the capacity to address a range of methodological concerns involved with examining human behavior. Working within a social psychological context, Blascovich and colleagues (e.g., Blascovich et al. 2002; Hoyt et al. 2003) have proposed that HITL simulation can "ameliorate, if not solve" "at least three methodological problems [that] have dogged experimental social psychology: the experimental control-mundane realism trade-off, lack of replication, and unrepresentative sampling" (Blascovich, et al. 2002, p. 103). These authors conclude with suggestion that HITL simulations have benefits for a range of psychological research areas including visual perception, spatial cognition, education/training, psychotherapy, and social influence. This position is reflected in the range of topics currently being addressed by the Research Center for Virtual Environments and Behavior (University of California, Santa Barbara), which is dedicated to using state of the art immersive virtual environment technology to examine social psychology, spatial cognition, societal impact, vision, education, virtual sound, avatar creation, and eyewitness testimony. Furthermore, these types of simulations have displayed high utility for testing aspects of aviation (e.g., Cummings 2004; Smith et al. 2004; Sollenberger et al. 2005), driving (e.g., Chen and Peng 2000), marine activity (e.g., Bronaugh 2007), as well as the effects of plan-layout complexity, physical differentiation, and gender on acquired spatial knowledge in large-scale, outdoor physical environments (e.g., Cubukcu and Nasar 2005).

It is important to emphasize some of the important reasons that HITL simulations differ from agent-based and dynamic-systems simulations. First, HITL can produce highly variable results across trials despite maintaining constant modeling parameters. This occurs as a direct consequence of the involvement of the human in the outcome. In addition to this, although HITL simulations do provide an experimentally-controlled environment within which the impact of specific elements can be examined, a dynamic feedback loop between the human participant and the simulation does not always exist. This is significant, as it means that the overarching behavior of the simulation model is not influenced by earlier decisions that the participant has made because the design of the HITL simulation is pre-programmed.

To date, there are no HITL simulations that these authors are aware of that have been utilized to test criminological theory. This paper seeks to introduce HITL simulation modeling to criminology with a view to demonstrating the value this technique should have for criminological theory and crime prevention. The focus of this demonstration is an examination of the relationship between environmental contexts that are assumed to increase perceived risk and risk-aware decision-making. The following section outlines the status of research into high-risk environmental contexts as a precursor to explaining the results of this HITL simulation.

[1] For a review of human-in-the-loop simulations, see Dudfield and Butt (2003).

Environmental contexts that increase perceptions of risk

A focus on awareness of risk of victimization This current study focuses on individuals' context-specific (time and space), cue-focused assessments of victimization risk rather than a general fear of crime. Gabriel and Greve (2003) suggested this perception of risk consists of three elements: (1) an individual's cognitive awareness of threat, (2) a subsequent affective experience arising from the cognition, and (3) an appropriate behavior, consistent with the underlying motive or action tendency. According to this three-stage process, the presence of the first and second components could be logically inferred from the observation of the third: that is, behaving in a manner that reduces risk of victimization is consistent with a perception of risk and an associated concern of victimization. Consequently, from this point onwards, this paper focuses on awareness of context-specific risk of victimization.

Environmental contexts that enhance perceptions of risk Brantingham and Brantingham (1997) developed a typology for categorizing characteristics of the environment that could increase the sense of risk.[2] The assumption of this typology is that these characteristics emerge as a consequence of the interaction between the individual and their immediate environment. These are dynamic factors and are directly related to the situational-dependent concerns about the context-specific risk of victimization. These categories of characteristics can be summarized as: (1) inadequate/incomplete environmental knowledge, (2) presence of threatening people, (3) physical signs of trouble, (4) inadequate choices with respect to movement, and (5) isolation. Given this causal assumptions about the links between cognition, affect, and behavior (Gabriel and Greve 2003), it is reasonable to assume that these context-specific perceptions of risk could be inferred by monitoring risk-aware decisions individuals make to avoid these types of environments.

Various combinations of these high-risk contexts form the bases of the HITL simulation model that is the focus of this study. Although research to date has not examined the relationship between risk-aware decision-making and high-risk contexts within a HITL simulation, there are examples of studies that have utilized a range of methodologies to assess the impact of a range of high-risk environmental contexts on behavior and cognition. Outlined below are the summary findings from previous research into the impact of (1) alley width, (2) lurk lines and hidden spaces, and (3) physical and social incivilities. These studies provide a methodological overview about how this research question has been approached prior to the use of HITL simulations, and these findings are discussed because they motivate the hypotheses that were tested within the current study.

Alley width A range of factors associated with alleys were examined by Herzog and Flynn-Smith (2001), including examination of alley curvature, length, and width. In their study, participants examined of a set of 60 pictures of alleys and made a range

[2] These categories were originally termed 'fear generators'; however, to maintain the clear focus on risk of victimization within this paper, this term has been dropped.

of judgments about each one, including an estimate of the case-specific danger (framed in terms of the likelihood of victimization in the depicted setting). Amongst other results, Herzog and Flynn-Smith demonstrated that ratings of alley width produced a significant negative correlation with danger, such that as alley width decreased, perceived danger increased. A significant, positive correlation was observed between estimates of alley length and perceived danger. Moving into an undeveloped natural setting, similar patterns of results were produced for estimates about the relationships between fear and alley width, and fear and path length (Herzog and Kirk 2005). With respect to the categories of high-risk environmental contexts summarized by Brantingham and Brantingham (1997), these findings are directly related to the raised concerns that stem from inadequate choices with respect to movement.

Lurk lines and hidden spaces Building on the influence of alley width on the estimated likelihood of experiencing danger/victimization in a specific setting, specific structures that produce spatial zones which obscure individuals' lines of sight also impact on estimates of risk. Objects such as dumpsters, parked vehicles, dense vegetation, and signage (as discussed by Warr 1990) can all result in a restricted capacity to monitor a specific context for signs of danger. Goffman (1971) discussed the impact of these micro-level physical cues in terms of their potential to produce 'lurk lines'.

The impact of these environmental stimuli on context-specific judgments about risk of victimization have been demonstrated through a series of studies undertaken by Fisher and Nasar (e.g., 1992; 1995), whose formalized model assumed that increased safety concerns would be produced by contexts which: (1) offered refuge for potential offenders, (2) limited potential victims' views of the immediate environment (which they termed 'limited prospect'), and (3) restricted the potential for escape in the event of an attempted victimization. Using a university campus as the specific context, Fisher and Nasar examined the impact of the immediate site on perceptions of safety in three ways: a site-specific questionnaire about feelings of safety at specific sites, ratings gathered on site, and unobtrusive observation of on-site behavior. With respect to the site-specific questionnaire, female respondents indicated greater concerns about safety relative to males. Overall, Fisher and Nasar (1992) concluded that the combination of prospect, escape, and refuge at any specific location have a significant effect on the perceived risks of victimization at those locations.

The work of Fisher and Nasar was extended by Wang and Taylor (2006), who combined the impact of hidden spaces/lurk lines with those focused on alleys within a single methodology. In a series of studies, participants viewed a series of still-photograph slides designed to simulate journeys through dangerous urban alleys. Each photograph in the series simulated a progression down the alley. At each of these points, participants were required to respond to questions about perceived risk and sense of safety with respect to continuing their journey. Overall, this process displayed variations in perceived risk at specific points in the simulation that coincided with the variations in contextual information about prospect, refuge, and escape (as theorized by Fisher and Nasar).

This pattern of results has also been mirrored in a natural environment context. For example, Andrews and Gatersleben (2010, p. 1) asked participants to rate a series of photographs of country park areas for their perceptions of danger, fear, and preference, and concluded that, "walks with higher levels of prospect-refuge (higher visibility, fewer hiding places and more accessibility) were perceived as less dangerous and fearful and more preferred." Within a criminological context, Cozens et al. (2003) utilized a similar methodology to examine fear of crime at railway stations. With respect to Brantingham and Brantingham's (1997) categories of high-risk environmental contexts, lurk lines and micro-level physical cues operate to increase context-specific perceptions of risk by contributing to an individual's sense of possessing inadequate/incomplete environmental knowledge. By extension, this knowledge gap exposes the possibility of the presence of threatening people and offers inadequate choices with respect to movement.

Physical and social incivilities "Incivilities" in this context are considered to be "low-level breaches of community standards that signal erosion of conventionally accepted norms and values" (LaGrange et al. 1992, p. 312). These fall below the threshold for even relatively minor criminal offenses such as petty theft and assault. Physical incivilities are a category label used to define disorderly physical surroundings such as vandalism, graffiti, and abandoned cars. Social incivilities directly relate to disruptive social behaviors including public drunkenness, loitering youth, and the presence of threatening people (LaGrange, et al. 1992).

Based on the analysis of a large phone-based sample (the *Fear of Crime in America Survey*), LaGrange et al. (1992) undertook an examination of the relationship between perceptions of risk and a range of physical incivilities (including trash and litter, loose dogs, vacant houses, and abandoned cars) and social incivilities (represented by bad neighbors, unsupervised youth, excessive noise, and drunks in public). Survey respondents were asked to report the extent to which each of these types of incivility were problems in their neighborhoods, and the results were summed to produce separate indices for social and physical incivility. Initial examination revealed respondent age (amongst other socio-demographic factors) to be a significant correlate with both incivility indices. Multivariate logistic regression was also undertaken, combining the socio-demographic variables with each incivility index in isolation in an attempt to predict risk of victimization. Paralleling Fisher and Nasar's (1992) findings discussed previously, respondent sex, but not age, was amongst the variables identified by this process to be a significant predictor of risk (with males less concerned about risk than females). Overall, LaGrange et al. concluded that this analysis provided evidence of a direct significant effect of social and physical incivilities on perceptions of risk. Fitting within the Brantingham and Brantingham (1997) framework for classifying categories of high-risk environmental contexts, these types of factors relate broadly to the presence of threatening people and the physical signs of trouble.

Aims and hypotheses

The purpose of this study is to build on the research findings produced by pre-HITL methodologies that have demonstrated variations in behavior as a consequence of (1) the presence or absence of high-risk environmental cues, and (2) individual respondent characteristics (such as age and sex). The data in this case resulted from a HITL simulation prototype developed as part of a PhD dissertation in Interactive Art and Technology (Park 2008), designed to explore the potential for examining criminological theories through the use of virtual environments. The present paper takes aspects of the data generated by this doctoral research and analyses them in a novel way, with a focus on age- and sex-specific differences in risk-aware decision-making displayed when individuals encounter a range of combinations of high-risk environmental contexts within a virtual environment. This is a highly-relevant initiative given the potential utility this simulation technology has for: (1) examining the impact of high-risk environmental contexts on decision-making in an ethical, safe manner while, (2) controlling for the impacts of individual differences in the interpretation of high-risk environmental cues, and (3) exploring the possible interactions/hierarchy of influence different types of high-risk environmental cues have for risk-aware decision-making.

To briefly outline the methodology involved in this case, participants' risk-aware decision-making was examined across a series of binary, forced-choice decisions while journeying through a virtual environment. Based on the trends from previous research into high-risk environments and decision-making, and utilizing the available participant demographic information, it was hypothesized that differences in risk-aware decision-making for the high-risk environmental contexts would occur as a function of participant sex but not participant age. It was also expected that females would be more risk-aware than males.

Methodology

Participants

Sixty participants were involved in this study: 23 male and 37 female. Participants were recruited through the networks of the authors' and all volunteers were accepted for involvement in this process. Age was captured in the dataset as a categorical variable with five levels: 1=19–29 years (49% of sample), 2=30–39 years (25%), 3=40–49 years (14%), 4=50–59 years (8%), and 5=60 years and older (3%). In order to complete the experimental procedure required for this study, participants had to attend the university laboratory. In addition to the efforts made to recruit participants from a wide range of age groups, there was also a desire to move beyond simply recruiting undergraduate university students to involve participants from outside of the university. This resulted in participants drawn from a range of backgrounds: self-classified as undergraduate and postgraduate students (44% of the sample), employed people (36%), home-makers (9%), self-employed (2%), retired (2%), and 'other' (8%). The majority of the participants had no criminological background.

Materials

Creating a virtual environment The design of the experimental setting was developed to maximize the likelihood that the participants would suspend disbelief during the experiment. The textures for the virtual environment HITL simulation model were created from photographs of buildings, streets, and other objects that were taken in an inner-city of Vancouver, Canada. Multiple photographs were taken at each location to enable editing to be done to ensure an image was available for each place that did not include unnecessary objects (such as pedestrians and cars) and also to control for shadows that resulted from different times of day and quality of light. The corresponding three dimensional (3D) models were developed using a 3D modeling software with the aid of *Google Maps* to provide additional information about relative positions and sizes. After applying the textures onto the 3D models, interactive features were added to the simulation so that participants would be able to change their views and navigate the virtual environment.

Experimental equipment Pilot studies were conducted to explore the utility of a range of experimental equipment. First, the VisionStation by Elumens was tested and, although it generated a good immersive experience, most of the subjects complained about dizziness during the navigation. Next, a regular screen with a projector was tested. Subjects sat down in front of the screen and navigated the simulation using a keyboard and a mouse. This alleviated the concerns about participant dizziness but was not considered to be immersive enough for participants to feel presence (an experience of "being there"). To counter this issue, the virtual environment scene was projected on to a 5 m×4 m screen. A Nintendo Wii hand-held controller was used by the participants to intuitively interact with the environment, enabling them to navigate through the simulation and to change the view displayed on the screen. A powerful workstation computer was utilized for the smooth and fast rendering of the scene.[3] Multiple pilot studies were undertaken to ensure that the rendering the scenes with the powerful computer was fast and smooth enough for the participants to engage in experiments without any flickering or lagging. To enhance the participant's feeling of presence, the experimental space was surrounded with thick black curtains and ambient background sounds of traffic were played.

Experiment

The participants were tasked with navigating a simulated virtual environment that was based on inner-city Vancouver. The participants were presented with a summary map that outlined the broad environment that they would have to navigate through, indicating at all times where they were in respect to their origin and destination. Participants were advised that the purpose of the simulation was to move as quickly as they could from the point of origin to the destination. Participants were free to navigate the environment as they saw fit, with the only condition that every time they encountered one of the five decision points they only selected one of the two options. Although the participants were able to control their directional choices when walking up and down the streets, in order to complete the task and reach their

[3] This simulation used the most powerful workstation computer available at that time. The computer model was a Dell Precision M90 with a NVidia Quadro FX 1500 graphics card. Technically, the benchmark score for the Dell Precision M90 was 3,926 points for 3DMark 06 with the capacity to calculate Super Pi to 2 million in 1 minute and 12 seconds.

destination, the map they were provided made it clear that they were need to move through alleyways that ran perpendicular to the main streets. The five alleyways were where the decision-points (and high-risk contexts) were located. In addition to collecting information about the decision made at each decision point, the overall time taken to navigate the virtual environment was recorded.

Participants knew that they had encountered a decision point because they could see a point where there was a break in the wall of the street they were walking along. Using the controller to turn towards the wall, the screen oriented to display a forked alleyway, with two possible paths that could be chosen. The varying environmental design of each of these decision points are as follows:

Decision Point 1 (DP1)	Alley width was the key in this case, with the two-alternative forced-choice decision between a narrow alley and a wide alley. In both directions, there were signs of physical incivility in the form of graffiti. The risk-aware decision in this case was the wide alley.
Decision Point 2 (DP2)	The presence of hidden-spaces, with zones beyond visibility and possible lurk lines/hiding places, was the distinction in this case. One alternative was a straight, clear alley. This was compared with a wider alley that had an alcove which could not be completely seen into from the decision point, resulting in lurk lines that impacted on the participant's knowledge of what to expect if entering the alley. The risk-aware decision in this case was the alley without the alcove.
Decision Point 3 (DP3)	As with DP2, the purpose of this decision point was to explore the impact of hidden-spaces on journey decision-making. Instead of a hidden-alcove (as in DP2), participants were encountered with a clear, open alley on the one-hand, and an alley with two large dumpsters on the other. There were also some signs of physical incivility in this alley, in the form of rubbish littered on the ground around the dumpsters. The dumpsters again obscured the visibility of the whole alley resulting in lurk lines that provided potential hiding places. The risk-aware decision in this case was the alley without the dumpsters.
Decision Point 4 (DP4)	This decision point presented the first sign of social incivility in the form of a single person who was doubled-over, coughing/vomiting, and giving the impression of being under the influence of alcohol or drugs. Aside from this person, the two options were identical, without any signs of physical incivility or any hidden-space concerns. The risk-aware decision in this case was the alley without the intoxicated person.
Decision Point 5 (DP5)	This decision point also involved the presence of people, with a single person present in one alley and a group of 3 people present in the other alley. The single person gave

the impression that they were walking towards the participant, while the group were more stationary around the middle of the alley. There were no other signs of physical incivility or any hidden spaces in either alley. Based on an assumption about increased risk associated with interacting with a larger group, the alley with the single person was determined to be the risk-aware decision in this case. However, the expectation as to how these decisions would be interpreted was slightly confounded relative to DP4.[4]

Results

One male participant was removed from this analysis because he failed to follow the researcher's instructions to (1) move from the origin to the destination as quickly as possible, and (2) select only one option at each decision point. This resulted in a sample of 59 participants that were examined in the final analysis. This section examines the overall risk-aware decision-making behavior across participants, and explores variations across decision points.

Overall individual differences in risk-aware behavior

A summed risk-aware decision score was produced for each participant that ranged from 0 (no aversion-conscious decisions made) to 5 (all aversion-conscious decisions made). Across participants, the mean number of risk-aware decisions made was 2.97 (sd=1.60). In addition to this, the total amount of time taken to complete the simulation (task duration) was recorded for each participant: mean= 415.00 s, sd=100.94 s, min=293 s, max=796 s (with positive skew displayed in Fig. 1). Both these variables were subsequently examined for variations as a function of participant Sex and Age. As discussed previously, age was recorded as a categorical variable. In order to make Age into a dichotomous variable with approximately equal numbers in each group, a median split separated participants into either 'young' or 'old' categories (based on a median age category of 30–39 years). The descriptive statistics for risk-aware decisions and task duration across Age and Sex are displayed in Table 1.

Given the uneven numbers of respondents within each cell of the Sex×Age design, general linear models were used to analyze the risk-aware decisions and task duration variables. The mean results for males (solid black lines with black triangles) and females (broken black lines with black squares) are displayed in Figure 2. There was a significant main effect of Sex on the risk-aware decisions as depicted by Fig. 2a, $F(1,55)=6.35$, $p<.02$, which constituted a moderate effect size (Cohen's d=.71). with females displaying a greater risk awareness than males. There was no main effect of

[4] It is unclear based on current literature that has examined alternative types of data which of these alternatives would produce the greatest sense of risk. Subsequent experiments will examine these issues in a systematic manner.

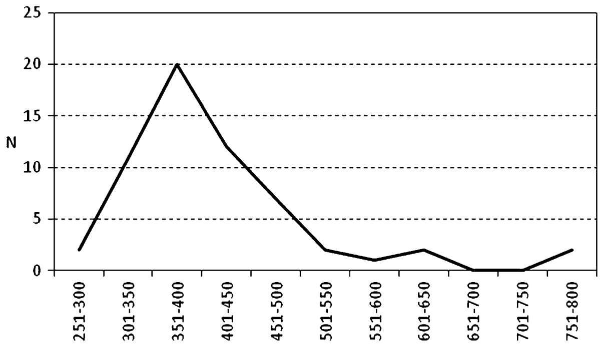

Fig. 1 Distribution of task duration (in seconds) across respondents

Age and no Sex×Age interaction for the risk-aware measure.[5] An equivalent pattern was found for task duration, with a main effect for Sex, $F(1,55)=9.53$, $p<.01$, Cohen's $d=.83$, that demonstrated females took longer to navigate the simulation. Non-significant results for Age and the Sex×Age interaction were produced for the task duration measure, as displayed in Figure 2(b). There was a significant correlation between risk-aware decisions and task duration, $r=.52$, $p<.001$.

Interactions between high-risk environmental contexts and individual participant characteristics

To examine the impact of the range of high-risk environmental contexts that were encountered across decision points, the patterns of male and female risk-aware decisions at each specific decision point were explored. The overall proportions of males and females who selected the risk-aware decision at each decision point are displayed in Fig. 3. As before, the male proportions are represented by the solid black line with black triangles and the female proportions are represented by a broken black line with black squares. In Fig. 3, chance performance is marked with the horizontal, broken black line (probability=0.5). The largest differences between male and female risk-aware decisions were observed for DP1 and DP2. In addition to this, the DP3 and DP4 preferences were very similar across sex and tended towards the risk-aware decision in both cases (above chance). Finally, the patterns of responses for risk-aware decisions at DP5 were functionally at chance regardless of participant sex.

The five panels of Fig. 4 display the proportions of risk-aware decisions made across all decision points as a function of Sex and Age. The line styles are consistent with the previous figures. A series of Sex/Age×Risk-Aware Decision non-parametric analyses were conducted across the five decision points.[6] Significant effects were produced by the 4×2 models for DP1 [$\chi^2(3,n=59)=7.93$, $p<.05$, displayed in Fig. 4a]

[5] No violation of the assumption of homogeneity of variance occurred here: Levene's test, $F(3,55)=1.09$, $p<.37$.

[6] For this analysis, the risk-aware decision each participant made was not an experimentally-defined independent variable. This resulted from the choice that they made when they encountered each decision-point. However, there is a precedent for undertaking this type of analysis based on cognitive psychology literature (e.g., the eyewitness identification literature from cognitive psychology dealing with lineup decision making such as Clare and Lewandowsky 2004, Meissner et al. 2001, Meissner and Memon 2002), which has been followed here.

Table 1 Descriptive statistics for risk-aware decisions and task duration (mean and *sd*) by *Age* and *Sex*

			Risk-aware decisions		Task duration (sec)	
Sex	Age	*n*	Mean	SD	Mean	SD
Female	Young	15	3.00	1.77	407.13	118.11
	Old	22	3.59	1.22	468.77	104.18
	All males	37	3.39	1.48	443.78	112.68
Male	Young	14	2.57	1.55	369.79	44.67
	Old	8	1.88	1.73	361.00	60.15
	All females	22	2.32	1.62	366.59	49.60
All respondents		59	2.96	1.60	415.00	100.94

and DP2 [$\chi^2(3,n=59)=9.63$, $p<.05$, Fig. 4b]. In both cases, post-hoc *Z* tests suggested that the difference could be attributed to the older males compared to the older females, with a significantly larger proportion of older females making risk-aware decisions (DP1: $Z=2.62$, $p<.01$, and DP2: $Z=5.14$, $p<.01$). As the 4×2 chi-square models for other decision points were non-significant [e.g., DP3: $\chi^2(3,n=59)=6.15$, ns; DP4: $\chi^2(3,n=59)=2.98$, ns; and, DP5: $\chi^2(3,n=59)=1.24$, ns], no post-hoc *Z* tests were performed in these cases.

Discussion

Overview of results

Given the findings from previous research into the relationship between participant characteristics and high-risk environmental contexts, it was expected that (1) females would demonstrate a greater awareness of victimization risk compared to males, and (2) that there would be no clear effect of age. Overall, there was support for these expectations, with a main effect of participant sex (with female participants more risk-aware overall), but no main effect of age, nor an interaction between these two variables.

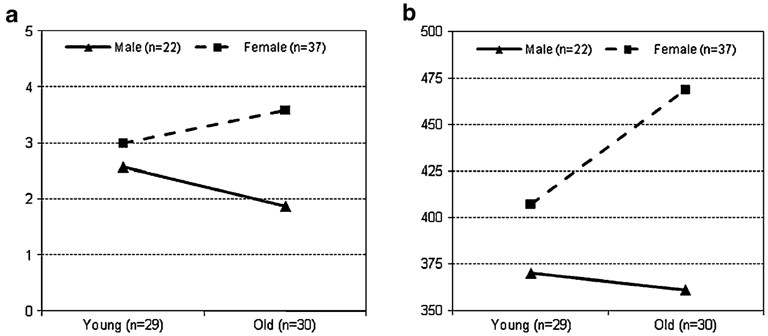

Fig. 2 **a** Mean risk-aware decisions by Sex and Age, and **b** mean task duration (s) by Sex and Age

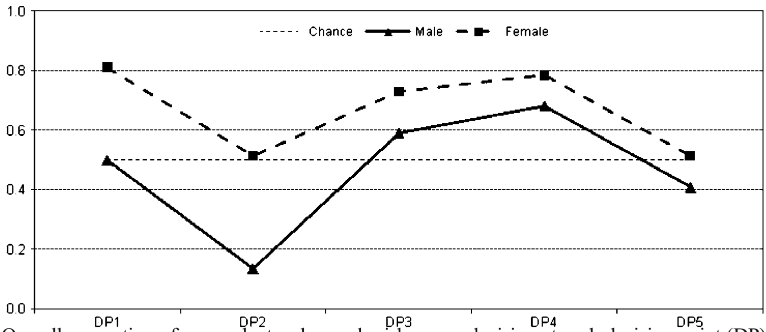

Fig. 3 Overall proportion of respondents who made risk-aware decision at each decision point (DP) by Sex

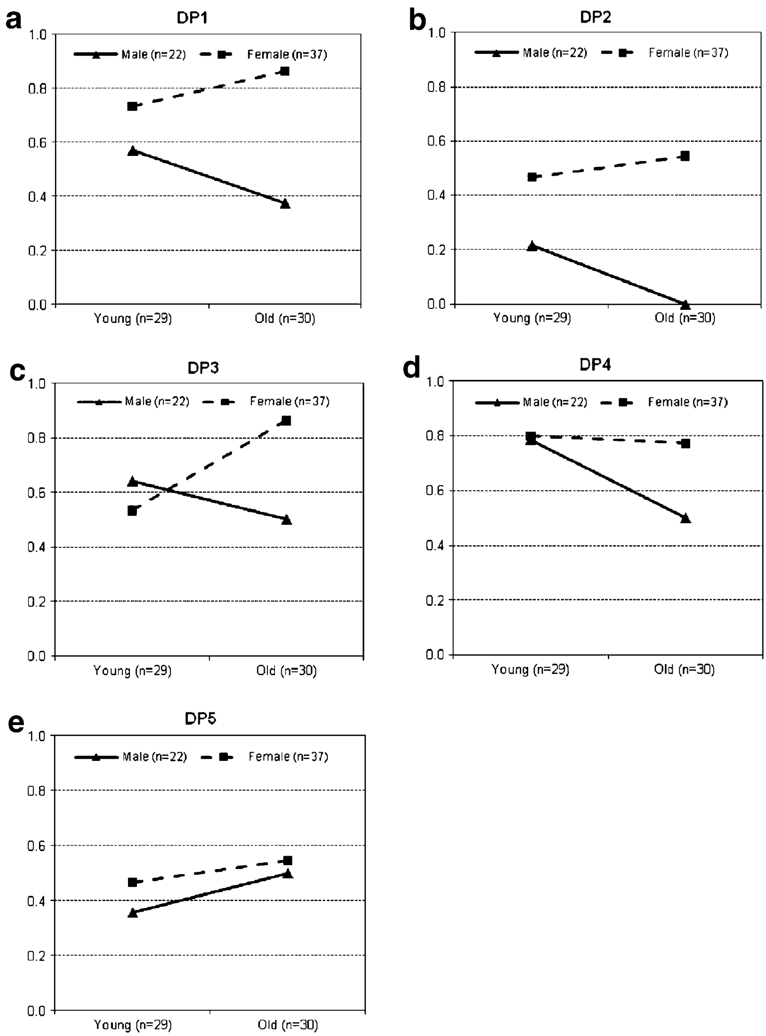

Fig. 4 Proportion of respondents who made risk-aware decisions by Sex and Age at **a** *DP1*, **b** **DP2**, **c** *DP3*, **d** *DP4*, and **e** *DP5*

This HITL simulation enabled direct analysis of the varied impacts of a range of high-risk environmental contexts on risk-aware decision-making. The five decision points produced consensus, divergence, and confusion with respect to the risk-aware decisions that were made (and by extension, it can be assumed there was a corresponding variation in the victimization risk these environmental contexts generated). In addition to these variations between high-risk environmental contexts, on two occasions, differences in risk-aware decisions emerged as a function of respondent age and sex within decision-points. All of these factors require subsequent follow-up research; however, with respect to looking at the capacity for HITL simulations to contribute to criminological theory development, the overall findings of this research are positive and the researchers feel this represents a solid start.

Twenty years ago, Warr (1990) undertook a factorial survey that attempted to examine the interactive effects of a range of contextual factors that were expected to influence perceptions of safety. One conclusion that emerged from this study was that, "there is almost certainly no way to fully capture the variety and subtlety of [contextual factors, such as lighting, crowds, etc.] without the use of photographic reproductions of scenes or, better yet, actual field measurements" (Warr 1990, p. 905). Across the studies examining the environmental cues associated with perceptions of risk discussed in the introduction to this paper, the common underlying methodological theme was the need to balance concerns about the research participant's safety with attempts to maintain a degree of ecological validity. Prior to the development of HITL simulation capabilities, Warr's conclusions were understandable. However, with technological advancements, the authors believe that HITL simulation provides a novel methodology for assessing the impact of high-risk environmental contexts on decision-making without requiring participants to experience any actual physical risk.

In addition to the benefits already broadly discussed for HITL simulations, another specific positive of this methodology for the examination of high-risk environments on perceptions of risk is the capacity to addresses concerns raised in other contexts about the questionable validity of behavioral indicators collected retrospectively via surveys. The HITL results presented here emerged as a consequence of what individuals actually did when they were placed within a fear generating environmental context, as opposed to what they may have said they would do in an abstract context should they have simply responded to surveys (see Fattah 1993, for a discussion of this issue).

Limitations and caveats

As discussed from the outset, this analysis was undertaken on data collected for a separate purpose (Park 2008). As such, there are a number of associated limitations that would need to be addressed by subsequent, future work. First, for a more powerful experimental design, it would be important to ensure that there were equal cell sizes across all levels of the experimental design. Although a moderate effect size was observed for the main effect of Sex when examining risk-aware decision-making overall, it is possible that additional effects may be observed with a larger, balanced sampling strategy in future studies.

Next, from a methodological perspective, there are a number of issues that should be addressed by future studies. For example: (1) the relationship between actual distance and perceived risk needs to be controlled, and (2) the interactions between high-risk environmental cues need to be examined systematically. With respect to this second point, an example from the current study involves DP1, which involved a mixture of graffiti and alley width rather than testing these factors independently. Benefit would also be gained from following the lead of Wang and Taylor (2006) with respect to monitoring perceptions of risk in a more continuous manner while navigating the simulation (for example, through use of galvanic skin responses to measure arousal). With respect to the way that HITL simulation is implemented, there is also scope for exploring alternative, developing technologies for executing these types of scenarios (i.e., the process by which the simulation is achieved, as opposed to the purpose of the simulation). Such alternatives could include incorporating different equipment for navigating the simulation, such as head-mounted displays (as in Blascovich et al. 2002; Hoyt et al. 2003). The quality of the images could also be varied to determine the impact that the realistic qualities of the simulation have on participants' decision-making. It would also be possible to trial the utility of additional mechanisms for measuring decision-making (e.g., eye-movements) and fear (e.g., galvanic skin responses, EEGs, and blood pressure measurements).

The third major issue concerns determining how the generalizable these findings are from the laboratory conditions they have been produced in to the real world. This is obviously an issue that plagues all examples of HITL simulation and is not specific to this particular example. However, it is a genuine concern should these types of research findings begin to be used for planning and crime prevention purposes (the potential for which is discussed below). To resolve this issue moves beyond the scope of this paper; however, it is important that future research acknowledges this divide and makes efforts to bridge this gap to ensure that the findings produced by these types of simulations are of relevance to crime prevention and community safety practitioners. Given the dependence that other fields place on these types of simulations, there is every reasonable expectation that this is achievable and that these findings are relevant.

Before discussing the potential implications of HITL simulation for criminological research, it is important to echo the concerns raised by Eck and Lui (2008) with respect to enthusiasm for and use of simulation models. As with Eck and Lui (2008, p. 211), the authors believe that while HITL simulations likely will constitute an additional tool for criminological research, they should not be adopted with "wild enthusiasm" nor "used in ways that are not justified." Instead, this type of simulation should be integrated within the full set of established techniques used for investigating crime, representing "another tool for researchers that can compliment older methods" (Eck and Liu 2008, p. 211).

Implications and future research directions

One potential avenue to explore with subsequent HITL simulation models focused on the relationship between high-risk environmental contexts and risk-aware decision-making would be to systematically manipulate the interactions between the five categories of high-risk environmental context cues classified by Brantingham and Brantingham (1997). Future work should also build on the approach of Wang and Taylor (2006), which continued examination of Fisher and Nasar's (e.g., 1992; 1995) refuge, prospect, and escape theoretical model. In undertaking exploration of these frameworks, it would also be possible to consider the significance of factors such as lighting (e.g., Hanyu 1997, 2000) and restricted cognitive awareness space (which could be explored through examination of factors such as alley curvature; e.g., Herzog and Flynn-Smith 2001). It is the aim of the research team to methodically examine the interactive effects of these contextual cues over a series of studies. Such a process would, for example, enable the risk posed by graffiti to be compared with that imparted by the presence of threatening people. In this way, it will be possible to identify the hierarchy of high-risk cues, and to examine how these interact with contextual cues such as time-of-day, lighting, and isolation, and also individual participant factors such as age and prior victimization experience.

Moving beyond risk-aware decision-making and the high-risk environmental cues, it would be possible to manipulate this simulation methodology to examine a huge range of criminological issues. For example, it would be possible to extend understanding of offender decision-making behavior, typically examined through offender-based interviews and field studies (e.g., Clare 2011; Nee and Meenaghan 2006) to test exactly what offenders do when presented with criminal opportunities. From a crime prevention perspective, this approach could work hand-in-hand with designing out crime and target hardening initiatives: a real-world test of the "think thief" approach (e.g., Design Council 2003) that would enable the effectiveness of new strategies to be evaluated preemptively (at least in virtual terms). To these ends, the researchers are aware that Nee (2011) and colleagues are already working on utilizing a type of laptop-based simulated virtual environments to assess offender decision-making from within targets.

Conclusion

Eck and Liu (2008, p. 196) identified three major ways that criminology has benefited from the application of simulation models. First, models enable researchers to circumvent the experimental logistical limitations stemming from a range of ethical, physical, practical, and financial factors. Second, simulations provide an ethically-safe context within which to explore offender cognition and adaptability. Third, large-scale, macro-level changes, impossible in real-world settings for experimental interests' sake, can be implemented within simulated environments. Eck and Liu also discuss the potential benefits that simulations have for empirical experiments, namely: (1) by enhancing the extent to which theories are formalized, (2) through requiring a clearly defined causal mechanism to be specified, and (3), as a consequence of these first two combined with the simulation outcomes, they provide the potential to eliminate insufficient theories. These benefits operate in an iterative manner to drive theory improvements, with ripple effects for crime prevention practice.

In brief, the findings from this paper can be concluded on two levels. Locally, this paper demonstrates an interesting set of results for theories about the impact of high-risk environmental contexts on risk-aware decision-making. More broadly, this methodology displays the potential the HITL simulation techniques have for extending criminological theory. Through expansion of the range of simulation techniques employed within this domain, the authors think it is possible that HITL has the capacity to make a significant contribution to experimental criminology, and encourage others to explore this technique to its full potential.

References

Andrews, M., & Gatersleben, B. (2010). Variations in perceptions of danger, fear and preference in a simulated natural environment. *Journal of Environmental Psychology*. doi:10.1016/j.jenvp.2010.1004.1001.

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.

Brantingham, P. J., & Brantingham, P. L. (1997). Understanding and controlling crime and fear of crime: conflicts and trade-offs in crime prevention planning. In S. P. Lab (Ed.), *Crime Prevention at a Crossroads* (pp. 43–60). Cincinatti: Andreson.

Bronaugh, W. F. J. (2007). 'Human-in-the-loop' simulation: the right tool for port design. *Port Technology International, 32*, 1–2.

Chen, B.-C., & Peng, H. (2000). *Rollover prevention for sports utility vehicles with human-in-the-loop evaluations.* Paper presented at the 5th International Symposium on Advanced Vehicle Control, Abb Arbor, Michigan.

Clare, J. (2011). Examination of systematic variations in burglars' domain-specific perceptual and procedural skills. *Psychology, Crime & Law, 17*(3), 199–214.

Clare, J., & Lewandowsky, S. (2004). Verbalizing facial memory: Criterion effects in verbal over-shadowing. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 30*(4), 739–755.

Cozens, P., Neale, R., & Whitaker, J. (2003). Managing crime and the fear of crime at railway stations: a case study in South Wales. *International Journal of Transport Management, 1*(3), 121–132.

Cubukcu, E., & Nasar, J. L. (2005). Relation of physical form to spatial knowledge in large-scale virtual environments. *Environment and Behavior, 37*(3), 397–417.

Cummings, M. L. (2004). The need for command and control instant message adaptive interfaces: lessons learned from Tactical Tomahawk human-in-the-loop simulations. *Cyberpsychology & Behavior, 7*(6), 653–661.

Design Council. (2003). *Think Thief: A Designer's Guide to Designing Out Crime*: Design Council.

Dudfield, H., & Butt, J. (2003). *Review of non-ATM human-in-the-loop simulations*: European Organisation for the Safety of Air Navigation: European Air Traffic Management Programme.

Eck, J. E., & Liu, L. (2008). Contrasting simulated and empirical experiments in crime prevention. *Journal of Experimental Criminology, 4*(3), 195–213.

Fattah, E. A. (1993). Research on fear of crime: some common conceptual and measurement problems. In W. Bilsky, C. Pfeiffer, & P. Wetzels (Eds.), *Fear of Crime and Criminal Victimization* (pp. 45–70). Stuttgart: Ferdinand Enke Verlag.

Fisher, B. S., & Nasar, J. L. (1992). Fear of crime in relation to three exterior site features: prospect, refuge, and escape. *Environment and Behavior, 24*(1), 35–65.

Fisher, B. S., & Nasar, J. L. (1995). Fear spots in relation to microlevel physical cues: exploring the overlooked. *Journal of Research in Crime and Delinquency, 32*(2), 214–239.

Gabriel, U., & Greve, W. (2003). The psychology of fear of crime: conceptual and methodological perspectives. *British Journal of Criminology, 43*(3), 600–614.

Goffman, E. (1971). *Relations in Public: Microstudies of the Public Order*. New York: Basic Books Inc.

Groff, E., & Mazerolle, L. (2008). Simulated experiments and their potential role in criminology and criminal justice. *Journal of Experimental Criminology, 4*(3), 187–193.

Hanyu, K. (1997). Visual properties and affective appraisals in residential areas after dark. *Journal of Environmental Psychology, 17*(4), 301–315.

Hanyu, K. (2000). Visual properties and affective appraisals in residential areas in daylight. *Journal of Environmental Psychology, 20*(3), 273–284.

Herzog, T. R., & Flynn-Smith, J. A. (2001). Preference and perceived danger as a function of the perceived curvature, length, and width or urban alleys. *Environment and Behavior, 33*(5), 653–666.

Herzog, T. R., & Kirk, K. M. (2005). Pathway curvature and border visibility as predictors of preference and danger in forest settings. *Environment and Behavior, 37*(5), 620–639.

Hoyt, C. L., Blascovich, J., & Swinth, K. R. (2003). Social inhibition in immersive virtual environments. *Prescence, 12*(2), 183–195.

LaGrange, R. L., Ferraro, K. F., & Supancic, M. (1992). Perceived risk and fear of crime: role of social and physical incivilities. *Journal of Research in Crime and Delinquency, 29*(3), 311–334.

Meissner, C. A., & Memon, A. (2002). Verbal overshadowing: A special issue exploring theoretical and applied issues. *Applied Cognitive Psychology, 16*(8), 869–872.

Meissner, C. A., Brigham, J. C., & Kelley, C. M. (2001). The influence of retrieval processes in verbal overshadowing. *Memory and Cognition, 29*(1), 176–186.

Nee, C. (2011). Research on residential burglary: ways of improving validity and participants' recall when gathering data. In W. Bernasco (Ed.), *Offenders on offening: learning about crime from criminals*. Devon: Willan Press (in press)

Nee, C., & Meenaghan, A. (2006). Expert decision making in burglars. *British Journal of Criminology, 46* (5), 935–949.

Park, A. J. (2008). *Modeling the role of fear of crime in pedestrian navigation.* PhD thesis, Simon Fraser University, Burnaby.

Smith, N. M., Lee, P. U., Prevôt, T., Mercer, J., Palmer, E. A., III, Battiste, V., et al. (2004). *A human-in-the-loop evaluation of air-ground trajectory negotiation*. Reston: American Institute of Aeronautics and Astronautics.

Sollenberger, R. L., Willems, B., Della Rocco, P. S., Koros, A., & Truitt, T. (2005). *Human-in-the-loop simulation evaluating the collection of the user request evaluation tool, traffic management advisor, and controller-pilot data link communications: experiment I - tool combinations*. US Department of Transportation, Federal Aviation Administration.

Wang, K., & Taylor, R. B. (2006). Simulated walks through dangerous alleys: impacts of features and progress on fear. *Journal of Environmental Psychology, 26*, 269–283.

Warr, M. (1990). Dangerous situations: social context and fear of victimization. *Social Forces, 68*(3), 891–907.

Andrew Park has a PhD in interactive arts and technology, and is an Assistant Professor in the department of computing science, Thompson Rivers University. He is also a senior research fellow at the Institute for Canadian Urban Research Studies. He has research interests in computational criminology, virtual environments for criminology research, agent-based modeling and simulation, and information visualization.

Joseph Clare has a PhD in forensic memory, and is an Assistant Professor in the Crime Research Centre, University of Western Australia. This research was completed while undertaking a Fay Gale Fellowship at Simon Fraser University. His research interests include the overlap between cognition and criminology, with an emphasis on crime prevention and environmental criminology.

Valerie Spicer is currently PhD Candidate at the School of Criminology, Simon Fraser University (SFU). She is also a graduate student in the Modelling of Complex Social Systems (MoCSSy) program at SFU and employed by the Institute for Canadian Urban Research Studies (ICURS). Her research interests include fear of crime, policing, spatial crime analysis, complex systems modelling, environmental criminology, and computational criminology.

Patricia L. Brantingham is Professor and RCMP University Research Chair in Computational Criminology in Simon Fraser University's School of Criminology and Director of the Canadian Institute for Urban Research Studies. Patricia's research focuses on environmental criminology with particular interest in pattern theory, criminal justice planning, and crime prevention through environmental design.

Tom Calvert is Emeritus Professor in the School of Interactive Arts and Technology at Simon Fraser University. His research interests focus on computer animation of human figures, e-learning systems, and computer based tools for user interaction with multimedia systems; his work on computer animation has resulted in the Life Forms system for dance choreography.

Greg Jenion has a PhD in Criminology from Simon Fraser University. Since 2005, he has taught at Kwantlen Polytechnic University in Surrey, British Columbia. Greg's publications include articles in the Canadian Journal of Criminology and Criminal Justice; Western Criminological Review; Criminal Justice Policy Review; and the Security Journal. His research focuses on community safety and crime prevention.