Crowd Guidance in Building Emergencies: Using Virtual Reality Experiments to Confirm Macroscopic Mathematical Modeling of Psychological Variables

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Abstract A general challenge during a building emergency evacuation is guiding crowd to the best exits, given potential hazards and blockages due to high density use. Although computer simulation programs such as FDS+Evac allow researchers to evaluate various guidance policies under different circumstances, computational complexity limits their use during an actual emergency. A second limitation of such programs currently available is that they can only model certain psychological variables that affect evacuation. We suggest two innovations to address these difficulties. First, using macroscopic models, mathematical techniques can allow for rapid optimization of guidance that could eventually be used to provide real-time use during emergencies. Second, we conduct virtual reality experiments using human participants to provide confirmation of our models, and offer insights into

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how psychological factors not yet available in FDS+Evac will affect evacuation outcomes. Results of an initial VR experiment are presented.

Keywords Building emergency egress • Evacuation stress • Virtual reality experiments • Crowd guidance • Macroscopic modeling • Mathematical optimization • Social force model

1 Introduction

Crowd evacuation behaviors including disorder and blocking have been observed in tragedies such as the 2003 Rhode Island and 2009 Bangkok nightclub fires [1, 2]. Behavioral studies of evacuees have shown that psychological stress plays an important part in the emergence of disorder and blocking [3, 4]. However, there is a gap between theories that explain the behavior of evacuees and the methods of providing effective guidance to evacuees in building emergencies. With recent advances in fire detection methods and crowd communication, there is potential to alleviate these kinds of injuries and deaths in the future. Some advanced building designs incorporate sophisticated systems that monitor a wide range of building conditions, and sense locations and possibly densities of people. Such systems could be integrated with dynamic emergency guidance systems (signs that could be made more salient or less prominent, audio/signage/text messages that could be updated dynamically given the changing circumstances) to provide better guidance during an emergency evacuation. However, the lynchpin in such an approach is that a computerized modeling, optimization and simulation system need also be in place that would allow emergency personnel to, in rapid time, run optimization and simulation that determines the best way evacuees should be guided through buildings given relevant physical and psychological factors. In sum, two critical issues for determining optimal guidance is elucidating important psychological factors that influence egress and reducing the computational challenge such that these factors can be optimized and simulated rapidly.

2 Current Model

As a starting point for our model, Helbing's social force model [5] is used as the psychological basis for understanding the motivational/arousal state that propels people to move slowly or fast during an evacuation, and leads people to reduce or increase their desired velocity when the condition has been worsened (or when that initial velocity is being impeded). However, these dynamically changing variables or parameters are modeled macroscopically in our approach to reduce computational burdens.

Second, selected factors currently known about informational, psychological and cognitive factors that affect egress are included in our model. The challenge with using simulation programs available (e.g., FDS+Evac) to test our model is that not all of these factors are currently incorporated in the programs. In the table below, the crucial features of our model, as presented recently [6] are highlighted. In the final column of the table we suggest how these features already included in the simulations would be tested and validated using immersive virtual reality experiments. We also suggest ways in which VR could be used to extend the simulations by exploring features not yet included in FDS+Evac to account for them. One additional feature of our model not in the table is the social bond or cooperativeness factor [6, 7]. We postulate that social bonds among people (e.g., evacuating with familiar others) can reduce the impatience that can lead to competitive-appearing behavior postulated by Helbing (continued pressure on people at blockages, because of the nervousness due to failure to achieve desired speed). This is supported by substantial evidence provided by considerable accounts of evacuation that prosocial behavior during evacuations is more commonly experienced than competitive, self-interested behavior [8]. Although it is not yet clear how to incorporate this feature into FDS+Evac, there are well-established ways in psychological experiments of experimentally manipulating degree of cooperative vs. competitive behavior.

3 Using Optimization to Determine How to Guide Crowds

To address the problem of providing effective guidance to crowds, an optimization problem was formulated in our previous work [6, 7]. The underlying equations were chosen to follow a macroscopic model, where crowds are treated as a fluid [11, 12] to reduce the computational complexity for optimization. Our model improves upon existing fluid-type models by capturing psychological phenomena that previously have been examined only within computation-intensive microscopic models. In particular, one novel parameter, the desired flow rate (evacuees' feeling of urgency to move), was developed as a macroscopic counterpoint to Helbing's desired velocity [5]. This can help explain the emergence of disorder and blocking during an emergency event. It is an important factor since it can be affected by perceptions of imminent danger, or lack of information about narrowed passageways or obstacles that cannot be seen by pedestrians far from the source of the disorder or blocking. It can also be affected by introducing front-to-back communication in such situations [13] either by providing visual information to reduce impatience, or by social sources of guidance (a leader who requests people to slow down). Thus the first focus of our optimization and validation studies was on this psychological variable. The eventual goal is to use validated models and methods to solve the guidance problem in real-time, allowing effective guidance of evacuees during an actual emergency event. Although the current state of crowd guidance falls far short of such an objective, confirming our ideas to validate optimized procedures is a major step towards realizing this goal (Table 1).

Table 1 Comparison between simulation models and virtual reality procedures

Feature	FDS+Evac 2.3.1 [9]	Our model [6, 7]	Beta FDS+Evac [10]	Procedures for virtual reality experimentation
Social force	Helbing's desired velocity implemented via the so called unimpeded walking speed which remains constant except when vision is reduced by smoke	Translates Helbing's microscopic desired velocity into a macroscopic version: the desired flow rate	FDS+Evac 2.3.1 features but with unimpeded walking speed changing dynamically based on nervousness due to waiting times	*Basic validation:* Have participants experience a trajectory from a simulation and assess satisfaction with movement; also, experimentally heighten desired velocity via physical information (visible, auditory, and/or odor) or social information
Effects of failure to achieve desired velocity	Effects of a discrepancy between desired and actual velocity does not recursively impact desired velocity	Consistent with Helbing's nervousness parameter: failure to achieve desired velocity can dynamically increase desired velocity	FDS+Evac 2.3.1 features but with Helbing's nervousness equation dynamically determining desired velocity	See *Basic validation* procedure above; also, experimentally manipulate Helbing's nervousness by reducing uncertainty via visual or auditory information or via leadership
"Faster is slower" effect	Implemented by incorporating Helbing's equations for forces between evacuees	Translates this blocking effect into a macroscopic feature, using a probability distribution to determine flow rate	Same as FDS+Evac 2.3.1	*Basic validation technique,* but implemented as a massive multiple player online simulation
Exit selection	Exits ranked based on disturbing conditions at the exit, familiarity, visibility, and estimated queuing time	Use models to optimize guidance based on blocking, impatience due to hazards, and trust in guidance	Same as FDS + Evac 2.3.1.	Use experimental inductions of trust, source of information (expert leader versus peer versus standard audio message) along with *Basic validation technique*

4 Using Virtual Reality in Evacuation Research

One important advance in the area of emergency egress from buildings is the use of virtual reality (VR) to examine how individuals would evacuate a building under given circumstances [14, 15]. For instance, researchers have examined the impact of different kinds of emergency signs and different features of the escape route on virtual evacuations [16, 17], and have used VR to examine the impact of social bonds on evacuation behavior [18]. One novel way to use virtual reality is introduced in this paper – namely, tightly integrating its use with the output of simulation models such as FDS+Evac, and, in our next step, integrating with optimized guidance found using our model and methods. The position outputs for every agent throughout the course of simulated evacuation can be used to model the behavior of avatars in a virtual environment. One of these agents can then be replaced by a human participant (or multiple participants, in a massive multiplayer online version) with his/her actual behavior compared to the output of the program as a means of validating the FDS+Evac output, or developing additional insights into the adequacy of the simulation or optimization. We provide a first step toward doing this in the study detailed below.

5 Methods and Results

5.1 Optimization and FDS+Evac Simulations

In this paper we analyze the effects of one key psychological factor from Helbing's model, desired speed, which is the microscopic counterpart to the macroscopic desired flow rate used in our model. To examine this factor, a virtual reality testing platform was created. This allowed us to run many trials with participants and to better recreate the psychological effects of an emergency event by making the evacuation an embodied, immersive experience. The participant experienced the evacuation from a first-person perspective and provided us continual feedback about their reactions to that evacuation. For the virtual reality environment, a university library was chosen due to the potential benefits of guidance at this location. In particular, this library is often crowded with college students who are unfamiliar with the locations of emergency exits. Although peripheral exits are usable by patrons for inter-floor movements and they lead to stairwells which then lead to emergency exits out of the library, almost no students ever use these exits and they are not familiar with them. A 3D model of one floor was constructed and used in the evacuation simulator Fire Dynamics Simulator with Evacuation (FDS+Evac) [9] to determine the evacuation routes and speeds of agents. Graphical avatars were created in VR with their routes calculated using position data imported from FDS+Evac and displayed during the experiment. The participant, one for each trial, was immersed in the virtual environment through the use of a head mounted display and tracking equipment which updated the display based on the actual head movements of the participant. The camera position and orientation that generated the image being displayed to the participant was a combination of real-time tracking data and the pre-computed FDS+Evac agent position and orientation data. The participant's experience was thus as if he/she was being passively moved through the evacuation (as if he/she was walking at some computer-determined speed and direction).

5.2 Virtual Reality Experiment

Virtual reality experiments are valuable in the following aspects: (a) It provides a way to partially validate the output of FDS+Evac. For instance, we can confirm whether VR participants would want to move in the direction and speed that FDS+Evac is simulating they would do. (b) It also provides a way to develop or adjust parameters that are difficult to determine a priori in FDS+Evac. For instance, it may be difficult to determine how strong of a tendency there would be in a given situation to use the main, familiar exit, over nearby, unfamiliar exits. We can attempt different parameter settings in FDS+Evac and then confirm the adequacy of them by getting feedback from people who are immersed in first-person virtual simulations of that environment. (c) It also allows us to examine the underlying psychological mechanisms that are assumed to explain the behavior of simulated evacuees. For instance, during a virtual evacuation, joystick direction could be used to assess various psychological states such as how anxious they feel. Other states might also be assessed immediately after the evacuation, for instance, by using a questionnaire to assess how much trust an evacuee had in the guidance information provided during the evacuation.

The initial pilot experiment was designed to provide a test of whether (a) presented above was possible. One of the most basic assumptions in Helbing's social force model about psychological factors during evacuation is that perception of hazards will elicit the desire to move faster. To test whether VR experiments will provide a good platform for validating this psychological assumption, we examined the effects of hazard on desire to move rapidly. Specifically, we wanted to determine whether participants would show greater dissatisfaction with their evacuation speed when there was a mismatch between hazard conditions and evacuation speed. For a given trial, the participant was moved at a speed and direction based on what was specified by an FDS+Evac simulation. The participant was not able to control his/her movements during the virtual evacuation; instead a joystick was used to indicate whether the speed that he/she was being moved was satisfactory. Although the focus of the experiment was on the microscopic level (desired speed), the simultaneous movement of avatars around the participant during the evacuation would provide a visual flow of information that should correspond to the macroscopic flow rate.

Fig. 1 In this screenshot of an FDS+Evac simulation, a fire has broken out in a room on one end of the library that contains the writing center for the library. Smoke has begun to spread

5.2.1 Procedure

FDS+Evac Simulation

Evacuation simulations were created based on three different walking speeds in which 150 adults were evacuating a large upper floor of a university library with floor dimensions of 175 × 250 ft (53.34 × 76.2 m), where a fire was modeled to break out at one end of the floor. A screenshot of the simulation is illustrated in Fig. 1. For the medium speed condition, the unimpeded natural walking speed for adults of U(0.95, 1.55 m/s) [9] was used, with speeds for the 150 agents uniformly distributed across this range. In slow and fast walking speed simulations, the agents' speeds were uniformly distributed from U(0.325, 0.925 m/s) and U(1.3, 3.7 m/s), respectively. These distributions of speeds used in the slow and fast simulations were centered around unusually slow walking speeds (from about half normal walking speed to two-thirds of normal walking speed), and very fast walking speeds (from a fast-normal speed, to jogging and running speeds). The parameters in the FDS+Evac program for exit strategy were set to give these agents 100 % probability of being familiar with the two doorways of the central staircase that library patrons use almost exclusively. In addition, familiarity with peripheral exits leading to emergency exits was set to 20 % probability. The positions for agents throughout the simulations were used as the basis for determining the trajectories of all avatars used in the virtual experiment. Not all trajectories were entirely usable in virtual reality. For instance, approximately 15 agents were typically trapped in an FDS+Evac simulation in unrealistic ways because of the geometric limitations of FDS+Evac modeling and the cluttered library. Similar numbers of valid agent trajectories produced by FDS+Evac could not be fully implemented in VR because the avatar's movements in a cluttered environment led them to have difficulties escaping (e.g., an avatar trapped in-between what is modeled as an unmovable chair and a bookcase). After eliminating the trajectories of these agents/avatars, a total of 120 FDS+Evac trajectories were used to model the movements of 120 virtual persons (avatars) evacuating the library in virtual reality. Up to 30 % of these trajectories, each with a corresponding starting position, were available as options for the VR participant's trajectory during a virtual reality trial. The actual number, however, could be considerably less in some conditions. For instance, if the participant was to see a fire, then certain options had to be eliminated. With those constraints, the participant's starting position was chosen at random from these possible starting positions for each trial in the experiment. Figure 1 is a screen shot of a simulation from FDS+Evac.

Virtual Reality Experiment

Twenty-five undergraduate students participated in this experiment for experimental credit in their introductory psychology course. They participated in the experiment alone, in a cubicle room equipped with a computer, a Polehmus motion tracker, and a head mounted display (HMD). After the experimenter fitted a head-mounted display (HMD) with head tracker attached (see Fig. 2) to the participant's head, participants were told that they would be moving through some environment during each trial of the experiment. To familiarize the participant with being in a first-person perspective virtual environment, participants first experienced an introductory scene in which they were in what appeared to be a foyer of an apartment building. In this room, a virtual person (avatar Victor) explained that the experiment would involve the participant being moved through a virtual environment. Although they would not be able to control their movement, they would use the joystick to convey how they would normally have wanted to move in this situation.

Specifically, Victor said: "In this virtual world we have created situations in which you will be moved in the virtual world along with other people at a fixed speed: What we want to know is how well we are moving you in that virtual world. Are you moving about right? Or too fast? Or too slow? To tell us how satisfied you are with the movement, you will move this joystick." The participant then explored pushing the joystick forward and back, while seeing the display on the screen changing accordingly. Victor said "The visual display on the screen will let you tell us that you wish you were being moved faster or slower. The display will show you how much you are moving the joystick" As Fig. 2 indicates, up and down arrows conveyed whether the participant wished to be moving faster or slower to a slight, moderate, or considerable degree. Keeping the joystick at the middle, neutral point, indicated comfort with the speed of movement. Joystick position

Fig. 2 Participants viewed the virtual library evacuation through a HMD with position tracker attached. When the participant moved the joystick forward, *up arrow(s)* were displayed, representing a desire to move faster; *down positions* indicated a desire to slow down. When the participant was moving at a comfortable speed, only the bar in the neutral position was lit

was recorded as a value between 1 and 7, with values below 4 indicating desire to move slower and values above 4 indicating desire to move faster. Participants gave real-time continuous feedback on their relative desired speed during each trial by moving a joystick forward or backward. The position was recorded 20–30 times a second, with less updating in conditions that required more computation (e.g., smoke conditions). Thus, joystick position was updated every 2.4 ms on average during a trial.

After the introductory scene, the participant went through a series of library evacuation trials in which participant's speed was varied as slow, medium (natural speed), or fast as presented before. Moreover, hazard conditions were varied: no smoke or fire was visible, or only smoke was visible, or both smoke and fire were visible. When fire was visible, the sound of a crackling fire could be heard faintly. In sum, the design of the experiment was a 3 (Hazard) × 3 (Walking speed) within-subjects design, with the dependent measure being the desired speed scores (of 1–7) assessed continuously during the trial. All participants completed one block of nine trials, and for exploratory purposes participants completed as many as nine additional trials. In the second block, trials could be taken from any of the conditions (chosen at random, but with replacement), thus few participants had complete data for all nine conditions that would allow for analysis of the second block. Therefore only the results of the first block are analyzed. The order of the nine trials was counterbalanced across participants, with the restriction that the first three conditions (presented in random order) were the natural speed conditions. As each trial opens, the participant is already in motion (along with other avatars) during an evacuation of the university library, thus avoiding the complications caused by "evacuation initiation delay." As Fig. 3 illustrates, library details were reproduced

Fig. 3 An overhead view of the virtual floor of the library used in the experiment. The ceiling has been moved for illustration; the beams indicate whether the ceiling would normally begin

with a high degree of fidelity, including locations of all exit signs, the appearance of doors and images on the walls, and the organization of furniture (e.g., the location, size and shape of tables, movable boards, chairs (in fixed positions), lounge chairs, and bookcases) in different areas of the library. This floor is a high use, familiar floor to the student participants, and a wide range of studying activities (including centers for quantitative and writing tutoring) are conducted in areas that are differently structured. There are no traditional "stacks." Instead, there are about a dozen low-height book cases. The open floor plan and wide range of diverse areas can make it feel confusing to a visitor. The section of the floor accessible to only library staff was not modeled in detail. Participants saw fire alarms flashing and heard fire alarm and automated evacuation messages (recorded from actual library messages) throughout the trial. In any given trial, a participant could be near or far from a number of different exits in the library. When smoke was present, it spread horizontally as well as downward as a trial progressed. Screen shots during various hazard and speed trials are illustrated in Fig. 4. Each trial ended (faded to black) when the participant was propelled by the program into a stairwell.

5.2.2 Hypotheses

It is hypothesized that greater hazard conditions would lead participants to indicate greater feelings of discomfort with their speed than less hazardous conditions. It is also hypothesized that unnaturally slow speeds would lead to less satisfaction with one's speed than would natural speed conditions.

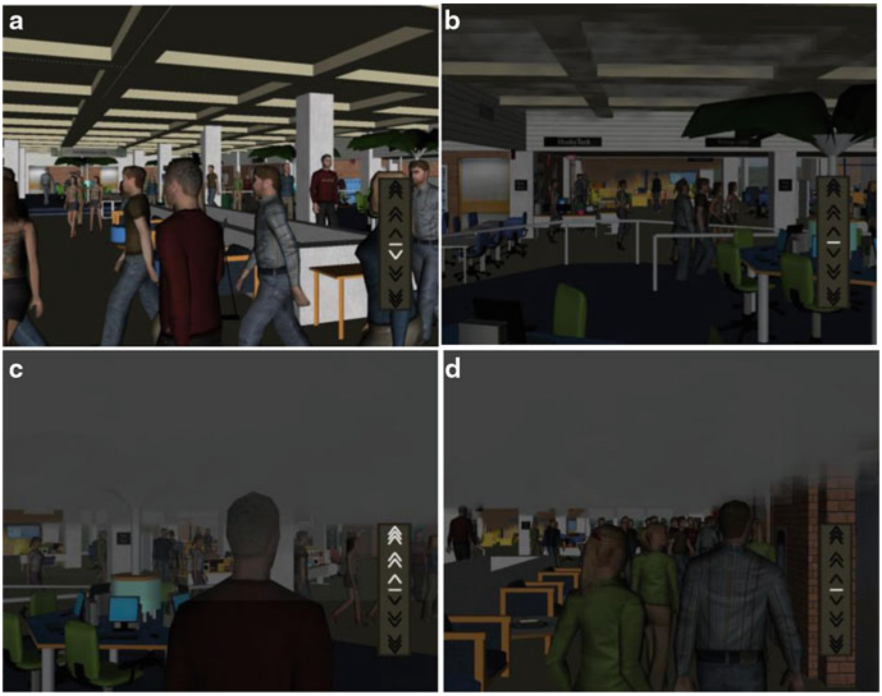


Fig. 4 Screen shots of situations (from *upper left*, clockwise) where (**a**) there was no visible hazard; (**b**) it is early in a trial, a fire was visible, but smoke was just beginning; (**c**) it was late in a smoke & fire trial where participant is reaching the crowded exit; and (**d**) smoke has progressed and participant desires to move fast

6 Results

A participant's desired speed scores throughout a given trial were used to produce a mean score for that participant, and a maximum value as well. Mean and maximum desired speed scores were analyzed in separate 3 × 3 within-subjects Analyses of Variance (ANOVAs). For exploratory purposes, epoch analyses were also conducted of the early, middle, and last segment of a given trial. Trials varied in length from 12 to 94 s (mean = 41.57, standard deviation = 23.05, median = 34.34). Responses in the first, middle, and last three seconds of a trial were used for these analyses.

For the maximum desired speed, there were significant main effects of both Hazard, F(2, 48) = 31.56, $p < .001$, and Walking Speed, F (2, 48) = 6.53, p = .003. As expected, when participants were walking through the environment slowly, they had the strongest desire to move faster, with an average value of 6.48 out of 7. When they were walking at medium and fast speed, averages for maximum desired speed approached 6 (means of 5.95 and 5.89, respectively). Moreover, hazard heightened participants discomfort with the speed as anticipated. On average, participants'

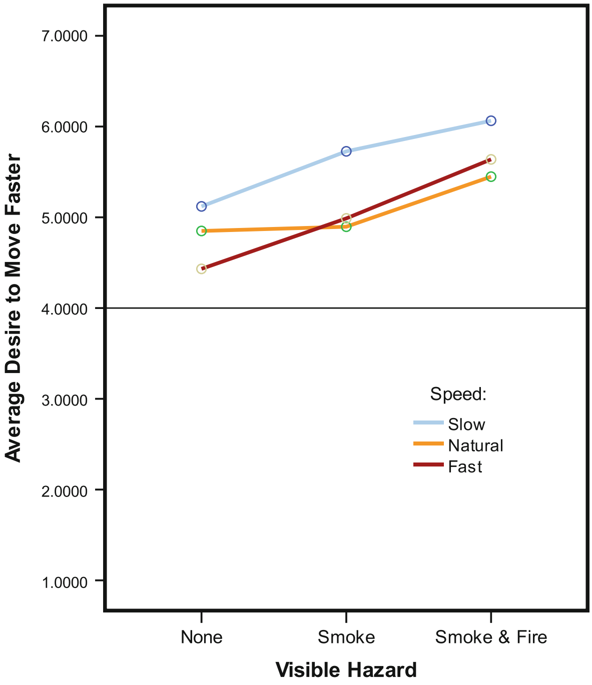


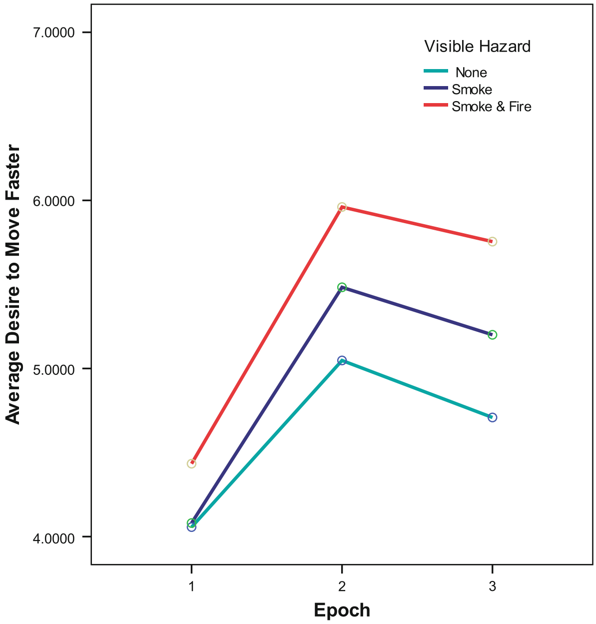
Fig. 5 A Hazard × Speed interaction moderated the main effects of Hazard and Speed on desired speed

maximum score when no hazard was present was 5.57. In contrast, participants' maximum value was typically over 6 when hazards were present (means were 6.11 for smoke visible, and 6.64 for smoke and fire visible).

The ANOVA on average desired speed similarly revealed main effects of Hazard F(2, 48) = 15.81, p < .001, and Walking Speed, F (2, 48) = 10.53, p < .001 as expected. Average desired speed was lowest when evacuating with no visible hazard (mean = 4.80) relative to evacuating when smoke (mean = 5.20) or smoke and fire (mean = 5.72) were visible. When individuals were moved slowly the average desired speed was higher (mean = 5.64) than when they were moved at a natural or fast walking speed (means = 5.06 and 5.02, respectively). As Fig. 5 illustrates, there was also an unanticipated Hazard × Walking Speed interaction that moderated these main effects, F(2, 48) = 2.52, p = .046. Only when no hazards were visible were fast speeds associated with the lowest levels of desired speed; with hazards present participants' desired speed showed no distinction between natural and fast speeds. Somewhat surprisingly, no means were below the midpoint – that is, even during the fast trials, participants did not indicate, on average, that the speed was uncomfortably fast.

Finally, a 3 (Epoch) × 3 (Hazard) × 3 (Walking Speed) within-subjects ANOVA replicated the main effects of Hazard and Walking Speed found on the other measures, each F(2, 48) ≥ 4.84, with each p < .013. A main effect of Epoch, F(2, 38) = 48.36, p < .001, revealed, as anticipated, that participants were more

Fig. 6 Effects of Hazard by Epoch interaction on desired speed. At the beginning of trials, participants' joystick position indicated they were comfortable with the speed (i.e., at the midpoint of 4) except when fire was visible. Effects of Hazard on desire to move faster intensified during the trial. In the last third of the trial, there was typically a decreased urgency to go faster



comfortable with the speed at the beginning of a trial (mean = 4.19) relative to the middle (mean = 5.50) and end of a trial (mean = 5.22). Interestingly, a Hazard × Epoch interaction, F(4, 96) = 5.43, p = .001 was unexpectedly also significant. As Fig. 6 reveals, Hazard's impact on their desire to move faster increased as the trial progressed.

7 Discussion

Our hypotheses regarding the effects of hazard and speed were mostly supported by the results of the virtual reality experiment. Desired speed increased when hazards were visible, indicating the effectiveness of the virtual environment to induce appropriate psychological responses. Being moved at an unusually slow speed also led participants to desire to move faster, but contrary to predictions, the distinctions between natural and high speed were minimal. Participants' responses were also responsive to the dynamic changing circumstances of the environment – as a trial progressed, desire to move faster was heightened, particularly as smoke was spreading. At the end of trials, desire to move was unexpectedly reduced, a phenomena which should be examined in further research.

7.1 Limitations of this Experiment

There are several limitations of this virtual reality experiment, some are specific to the details of this particular procedure, while others suggest broader limitations of virtual reality. One localized limitation concerns the way the joystick was used. Using a joystick to convey "this is faster than I'd like to go" or "this is slower than I'd like to go" is a rather unfamiliar use of the joystick for the participants. Despite the artificiality of this, the joystick measure was sensitive to dynamically changing aspects of the experience such as the slowdown at the exits. In subsequent experiments, participants will be able to use the joystick more actively, to deviate from the FDS+Evac plotted trajectory and directly choose a different speed or even different exit. Another limitation of the current experiment is that it may only generalize to situations of relatively high density in the library. Having over 100 people around already in motion toward exits is a different experience than evacuating with fewer avatars present. At high density phenomena such as "herding" (conforming to others' behavior regarding choice of exits, presumably because others' behavior is informative) are likely to be stronger, as social psychological theorizing would predict [20]. Moreover, others in motion decrease the attentional and cognitive resources available to search for and consider other exits. Having more people moving in the environment also increases occlusion of signage (such as signs directing one to unfamiliar exits). This limit on generalizability, however, is easily remedied by replicating such procedures with different numbers of avatars. It is also useful to note that even though the experience of evacuating with 120 other people on the floor in motion can feel moderately crowded, during final exams the actual number of students on the floor could be double this number, as observed by library staff.

7.2 Limitations of this Virtual Reality Paradigm

A more pervasive limitation of this method is that even though it is an immersive, first-person evacuation experience preserving a tight integration between perception and action, there still are some limitations on perception that make it more difficult to ideally examine variables such as evacuation speed. First, if the avatar's vertical displacement (i.e., with each step they take) is fully modeled veridically, it is physically uncomfortable to a participant (nauseating) because the display seems to jitter up and down as if watching a poorly shot hand-held camera scene. Humans do not experience this when actually moving up and down with each step, because the continuous haptic information about our motion is tightly integrated with the visual flow field. Thus, it was essential to remove the jitter for participants to be comfortable moving through the environment. On the other hand, removing this seemingly artificial jitter does remove a source of information that the participant is "walking." Because a participant has no other haptic information about how fast they are moving (subtle changes in sound as they move, feeling of air on one's face moving fast, and the feel of the ground beneath one's feet), an unnaturally fast movement was not necessarily experienced as running. This was likely exacerbated by the fact that participants did not need to worry about running into a table or stumbling because the program was moving their body: they did not have to navigate themselves. To have a sufficiently strong manipulation of movement speed, the upper range on fast walking was set unnaturally high (i.e., a running pace). Even so, in Fast Walking Speed conditions, the average desired speeds were not below the comfort midpoint of 4. One way to overcome this limitation would be to use a 360° treadmill that participants could walk on during their evacuation, rather than using a joystick. This would not provide perfectly integrated haptic information, but would be quite close.

7.3 Conclusion

Given the promising results of the above findings, we plan to test other psychological factors. For instance, we will attempt to understand when there will be excessive urgency to move due to blocking. A slowing that can seem unreasonable when no information is available may heighten anxiety or increase "nervousness" as Helbing's model suggests. We will examine whether providing visual information can change the psychological experience of slowing that can occur when obstacles at the front of a crowd are unseen by participants at the back of a crowd. Therefore we hypothesize that reducing uncertainty by providing visual information about the causes of the slowing, or social information about what is occurring, may lead to predictions that deviate from Helbing's model. Participants may be able to tolerate greater discrepancy between actual and desired speed, provided information is available and the participant is not under immediate danger. We will also examine other key factors of our model including trust in social over nonsocial information, and the effects of leadership and social bonds. Optimized guidance will be incorporated and tested. We are also planning to conduct a fire drill in the same library our virtual environment is created from. This could provide an opportunity to estimate parameters that are difficult to infer without realistic data from a large group of individuals. Such data could provide the basis for setting the initial value of parameters that are otherwise challenging to determine for running a FDS+Evac simulation, in addition to tuning the parameters in our macroscopic model.

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