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Exit choice in an emergency evacuation scenario is influenced by exit familiarity and neighbor behavior

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ABSTRACT

'Movement to the familiar' has been reported during evacuation incidents but has not yet been studied in controlled experiments. We investigate effects of exit familiarity and egress behavior of other pedestrians on exit choice in an ambulatory virtual environment. Participants walked into a virtual museum through a 'familiar' door and were asked to evacuate when a fire alarm sounded as they normally would in the real world. They were significantly more likely to exit through the familiar door than through a second available exit. This effect was greater when virtual neighbors also left by the familiar door and was reduced when neighbors left by the unfamiliar door; this social influence was stronger with two neighbors than with one. The results show that exit familiarity and neighbor behavior influence evacuation behavior, and that social influence increases with the number of neighbors. The findings have implications for modeling pedestrian evacuation and improving evacuation procedures.

1. Introduction

In 1973, in the Summerland leisure center on the Isle of Man, a burning cigarette caused a catastrophic fire that led to the deaths of fifty vacationers and another eighty injuries. Post-incident analysis revealed that many occupants had attempted to evacuate through the same exit, ignoring less crowded points of egress. This tendency to evacuate buildings through a familiar exit or with familiar people in an emergency has been termed the *affiliative model* or *movement to the familiar* (Sime, 1983). Sime concluded that although several exit routes were available, affiliation with familiar places and people influenced evacuation behavior. Numerous other fire tragedies around the world are consistent with this observation (e.g., Darlington and Carter, 2013; Fridolf et al., 2013; Gillet, 2015; Kuligowski, 2011; Levy, 2009; Pearse and Weaver, 2009; Robinson, 2006; Spencer, 2008).

Familiarity with the environment has been reported to influence behavior during the evacuation of the World Trade Center during the September 11th attacks (Kuligowski, 2011). Proulx (2001) speculates that people tend to approach familiar exits, even if another exit is available and closer, because they are "very unlikely to be prepared to try a new unknown route during an emergency" (p.11, Proulx, 2001). Indeed, a survey study showed that as many as 60% of the occupants reported that they did not feel prepared by their personal fire safety training to properly evacuate the towers of the World Trade Center (Gershon et al., 2011). Given uncertainty about when, how and where to evacuate, occupants may rely on the people around them. Furthermore, in many public spaces, occupants "play the roles of visitors, and as such expect to be taken care of… [in an emergency], people will be looking at what others are doing. The role of visitors is usually to conform to the general behavior of others" (p. 223, Proulx, 2001).

Although the affiliative model may contribute to an understanding of emergency evacuation, the existing evidence for movement to familiar places comes largely from anecdotal observations and uncontrolled field studies. One field study documented place affiliation during evacuation from a large furniture store (Benthorn and Frantzich, 1999). Participants, who were under the impression that the study was intended to test the effectiveness of Public Address messages, were informed of a technical failure and were asked to evacuate the store. When participants had a choice of two exits, each located the same distance away, about 71% of them chose the door through which they had entered the building. Kobes et al. (2010) tested unannounced fire drills in a hotel, and found that most occupants who were unfamiliar with the general layout of the building evacuated through the main entrance.

In addition to familiar places, people can have an affiliation with familiar people (Sime, 1983), which we refer to as social influence. In

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another field study, patrons in a movie theatre experienced an unannounced fire drill (Nilsson and Johansson, 2009). The results showed that occupants tended to coordinate and evacuate with others in neighboring seats, consistent with affiliation with other people during evacuation (Lovreglio et al., 2015). The first experimental evidence for social influence on evacuation behavior was Darley and Latané's (1968) classic 'smoke-filled room' study, which showed that the passive behavior of neighbors reduced the probability that participants would evacuate a room after simulated smoke began seeping in through an A/C vent. Simulated *crowd* evacuation studies found that effects of social influence on spatial decision making are bounded by contextual information available to evacuees at the time of exit choice. For example, distance and visibility of exits, crowd size and flow patterns have been shown to influence evacuation decision making (Haghani and Sarvi, 2017a,b). In addition, several VR studies found that social influence in smaller groups affects exit choice (Bode and Codling, 2013; Kinateder et al., 2014a; Lovreglio et al., 2014, 2016b) and navigation (Kinateder et al., 2014c; Ronchi et al., 2015) in various simulated evacuation scenarios. Here, we distinguish the *exit familiarity* hypothesis (place affiliation) from the *social influence* hypothesis (affiliation with other people).

Balancing ecological validity and experimental control continuous to be a challenge in fire evacuation research. One approach to this problem is the use of immersive virtual reality (VR) techniques (see Kinateder et al., 2014b for a more detailed discussion of this topic). We recently extended the findings of Darley and Latané (1968) by investigating the social influence of active as well as passive bystanders on the decision to evacuate in matched real and virtual environments (Kinateder and Warren, 2016). In a one-trial experiment, participants were more likely to evacuate in response to a fire alarm when they saw a bystander do so, and less likely with a passive bystander, compared to a control condition in which they were alone. This pattern was observed in both the real and virtual versions of the experiment (with real and virtual bystanders), albeit with slightly weaker effects in VR, supporting the use of VR as a tool to study evacuation behavior.

In the present study, we perform the first experimental test of the exit familiarity hypothesis and investigate how it interacts with social influence to determine exit choice during evacuation. Participants walked into a virtual museum and, when a fire alarm sounded, evacuated through a familiar or an unfamiliar exit. To investigate the influence of bystanders, which we refer to as "neighbors", participants were accompanied by a virtual human who would either ignore the alarm (passive neighbor) or exit through one of the two doors (active neighbor); in a control condition, participants were alone in the museum. To determine whether social influence varies with the number of neighbors, half of the participants were accompanied by one virtual human and the other half by two virtual humans who walked to the same exit. We find that exit choice is significantly influenced by both the familiarity of the exit and the egress behavior of neighbors, and that the social influence increases with the number of neighbors.

2. Methods

2.1. Sample

Forty participants (19 female, 21 male; mean (age) 21.08 years, sd (age) 2.83 years, majority undergraduate students from North America) completed the experiment. An additional five participants were tested but did not complete the experiment due to technical difficulties. Informed consent was obtained from all volunteers, who were compensated for their participation. The study was approved by the Brown University Institutional Review Board and was carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki.

2.2. Design

To investigate the influence of neighbor egress behavior and exit familiarity on exit choice (the dependent variable), we manipulated three independent variables: neighbor behavior, number of neighbors, and door configuration. (1) Neighbor behavior (4 levels) determined whether the virtual neighbor walked out the familiar door (active familiar condition), the unfamiliar door (active unfamiliar condition), remained standing (passive condition), or whether no neighbors were present (control condition). (2) Number of neighbors (2 levels) presented one or two virtual neighbors, who always exhibited the same behavior. (3) Door configuration (3 levels) positioned the two doors in the same wall, opposite walls, or perpendicular walls. In addition, there were two control variables: Room decor (3 levels), which varied the flooring, wall color, and artwork, was crossed with door configuration, resulting in nine distinct virtual rooms. The entry door (2 levels) served to define the familiar exit (Door 1 or Door 2) in each trial; it was randomly varied and counterbalanced across subjects. These variables were completely crossed to determine the experimental scenarios; number of neighbors was a between-subject variable, while the rest were varied within-subject. This created a 3-way mixed design for statistical analysis: 4 neighbor behaviors (within-subject) x 3 door configurations (within-subject) × 2 numbers of virtual neighbors (between-subject), yielding 24 experimental conditions.

2.3. Virtual environment

2.3.1. Apparatus

Testing was conducted in the Virtual Environment Navigation Lab (VENLab), a 14 × 16 m room. Head position and orientation were recorded at a sampling rate of 60 Hz using a hybrid ultrasonic-inertial tracking system (IS-900, Intersense, Billerica MA), with a tracking area of 12 × 14 m. Participants viewed the virtual environment in a wireless head-mounted display (Rift DK1, Oculus, Irvine CA) with a 110° diagonal field of view (approx. 90° horizontal and 65° vertical), set at 6.4 cm IPD, and a resolution of 640 × 800 pixels per eye. Displays were generated on a Dell XPS workstation (Round Rock TX) at a frame rate of 60 fps, using the Vizard 4 software package (WorldViz, Santa Monica CA). Head coordinates from the tracker were used to update the display with a latency of 50–67 ms (3–4 frames).

2.3.2. Scenario

The virtual environment consisted of a square museum room (7.7 m on a side) surrounded by a ground plane and blue sky. There were nine distinct rooms, created by crossing the three door configurations by the three room decors; each contained two doors and three pieces of artwork (a statue located equidistant from the two doors; two photographs on walls without doors) with bronze nameplates beneath them; there was a fire alarm in the ceiling, and a red 'EXIT' sign above each door. Outside the room, a wall extended outward from each corner so only one door was visible at a time. A red car was located outside the entry door to help establish place familiarity for the participant (Fig. 1).

Eighteen (nine female) virtual humans were rendered using high-polygon (M = 8099, SD = 813) and texture-mapped (2048 × 2048 pixels) 3D models (Vizard Complete Characters HD, WorldViz, Santa Monica CA), and animated at 60 fps. The virtual human models were randomly assigned to each trial with the constraint that the two models on a given trial differed. The virtual fire alarm and flashing light were based on a standard fire alarm (SpectrAlert Advance P2R, System Sensor, St. Charles IL) and were simulated by a stereo directional sound source located in the center of the virtual ceiling. When the alarm sounded, there were four types of virtual neighbor behavior: (a) in the passive condition, the neighbor(s) ignored the alarm, (b) in the active familiar condition, the neighbor(s) walked out the familiar exit, (c) in the active unfamiliar condition, the neighbor(s) walked out the unfamiliar exit, and (d) in the control condition, no