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The effects of information and hazard on evacuee behavior in virtual reality

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ABSTRACT

Many contextual factors can influence evacuees' choice of egress route during an emergency. Anxiety caused by the emergency situation may lead to suboptimal choices, resulting in slower evacuation and greater risk of injury or death. The present pilot study tests the influence of hazard level (presence of visible fire and smoke) and information about an obstacle (delivered verbally or through signage) on evacuees' anxiety levels and choice of egress route in a virtual reality (VR) simulation of a fire evacuation with multiple possible exits. Physiological measures were recorded and used to validate the efficacy of VR in inducing anxiety germane to the situation of interest. Consistent with our expectations, providing information about the obstacle was shown to decrease total evacuation time. Contrary to our predictions, it did not significantly impact evacuees' choice of exit. Information also had a marginally significant effect on participants' self-reported anxiety. Providing more targeted information may further reduce anxiety and evacuation time. More generally, VR appears well-suited to assessing individual and psychological factors in evacuations.

1. Introduction

1.1. Issues in evacuation

Various considerations may impinge on an evacuee's choice of exit and egress route: familiarity with the available exits of the building, the choices made by other evacuees, the information provided by emergency officials or by building signage, and more. These factors frequently converge in ways which produce sub-optimal exit choices and egress routes, thereby increasing the time required to exit the building and the likelihood of not escaping safely [1]. Our aim in this pilot study is to use physiological and self-report measures to extend past research establishing the utility of Virtual Reality (VR) as a testbed to study issues in evacuation, and further to identify particular environmental and social factors which influence evacuees' choices and develop methods of improving efficiency in evacuations.

Detailed case studies provide a starting point for addressing common problems preventing safe and efficient evacuation during emergencies [3,8,10,25,41,42]. In one tragic case, evacuees fleeing a fire at the Station Night Club in West Warwick, Rhode Island headed towards the main doors of the building while ignoring available peripheral exits [1]. Overcrowding at the main doors significantly slowed movement, contributing to several dozen fatalities. [1] note that, in this case, evacuee density and death rate were highly correlated. Evacuee behavior of this kind during fire emergencies has historically been explained with reference to panic; untested "truisms" paint evacuees as an unthinking herd [41]. However, such assumptions about evacuee behavior have largely been discredited [18,32,33,35,41]. As such, modern evacuation research tends to forgo the panic explanation and approach crowd dynamics with greater nuance, addressing evacuee decision-making and associated social, physical, and situational factors [9].

Overcrowding at exits is theorized to result from the confluence of several problems. For individual evacuees, anxiety caused by the emergency situation may result in adverse effects, given the conditions faced. While anxiety due to a perceived emergency can motivate action [39], excessive physiological arousal will reduce performance [47]. This effect has been demonstrated in emergency evacuations, where evacuees tend to take longer in making decisions and make sub-optimal choices while under stress [4]. Furthermore, prior research indicates that the breadth of attention is reduced during high-anxiety situations, resulting in decreased salience of potentially important information – a phenomena known as attentional narrowing [6,48]. In the case of a fire emergency, high levels of anxiety may cause such attentional narrowing. Attentional narrowing could in turn cause evacuees to ignore signage or other

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information indicating alternative, less crowded exits and head for the main exit, with which they are likely to be most familiar and therefore have a propensity to use, even in non-emergency situations [42]. As a result of individual evacuees' anxiety-influenced actions, the main or familiar exits would become more crowded, and that crowding may, in turn, further increase anxiety. A combination of anxiety and crowding at main exits may increase competitive behavior, such as pushing, resulting in blocking of exits or narrow passageways and producing a faster-is-slower effect [7,26,43]. These phenomena are highly interrelated [19]; explain that impatience leading to faster movement can increase time to exit due to the associated increase in crowding – hence faster-is-slower.

Additionally, building occupants may take the exit choices of their fellow evacuees as informative of which exits are safe for use. [23,24] found that the social influence of one person evacuating with the participant affected participant route choice, but not destination choice. Theoretically, a larger group of individuals should exert greater social influence [27] and thus might affect destination or exit choice. [13] contends that the perception of affordances, or opportunities for action, in a given environment is contingent in part on a person's social identity and the social, intentional, and institutional aspects of the environment. When all building occupants have a shared intention to evacuate and a large number of those occupants head for one exit, it indicates to the members of the group that particular exit affords egress and safety, to the exclusion of other exits. Applying the affordance-based approach explicated by Ref. [13] and others in the Gibsonian tradition [16,38] enables the explanation or reconceptualization of this kind of behavior as the rational use of relevant, albeit incomplete or inaccurate, information, rather than the product of group-think or a "herd mentality". An affordance-based interpretation fits neatly with other modern approaches to understanding evacuee behavior which eschew a panic-based framework [1]. From a more practical standpoint, understanding and altering affordances of various types may improve evacuation efficiency. Indeed [37], were able to increase emergency exit utilization in a virtual evacuation by manipulating the affordances of the environment. Conversely, and more similar to the current study [30], applied the theory of affordances to evaluate signage which dissuaded participants from utilizing a particular exit in a virtual evacuation.

We suggest that evacuees' anxiety could be reduced by judicious deployment of well-tested, task-relevant information. Anxiety is theorized to result, in part, from evacuees' inability to exit at their desired rate or the expectation that they will not be able to do so. In the current pilot study, an obstacle (a low table) was placed near the main exit of a building during a virtual fire evacuation (see section 1.2), creating a bottleneck with reduced capacity and increased crowding. However, the obstacle was not initially visible to the participant due to its being occluded by the presence of several dozen computer-controlled avatars evacuating alongside the participant. Information provided to the participant was intended to reduce anxiety or irritation by resolving the ambiguity created by this occlusion regarding the cause of this otherwise unreasonable slowing of crowd movement. Information was provided by either a hanging sign indicating the table's presence, or a pre-recorded spoken message directed at the participant from one of the avatars, and will offer an explanation for slowing and crowding at the main exit – namely, that an obstacle is present and inhibiting egress. Reduced anxiety should, in turn, result in less attentional narrowing and competitive behavior, potentially attenuating the faster-is-slower effect and decreasing overall time to exit for the evacuee. Additionally, utilization of peripheral exits could be increased, influencing the loading of the available exit capacity. If this is found to be the case, it implies important real-world consequences. Namely, groups of evacuees with reduced anxiety will engage in less competitive behavior, attenuating the faster-is-slower effect. If their use of peripheral exits is increased, resulting in better utilization of the available exit capacity, it would further attenuate anxiety caused by crowding and reduce the total time required to evacuate a building. This would be especially true when peripheral exits are closer than main exits to many evacuees, as is often the case in large buildings. Decreasing the time required to evacuate a building should ultimately decrease the number of injuries and fatalities.

1.2. Virtual reality and methodological issues

Attempting to study the factors influencing evacuation behavior poses several methodological and ethical issues. Much of the existing literature on emergency evacuations comes from case studies of attention-grabbing events such as the Station Night Club fire, or the World Trade Center evacuations on September 11, 2001 [1,3,11, 50]. Case studies provide valuable insights into matters such as exit preference and evacuation initiation delay, but do not allow for the manipulation of key variables, and therefore offer little help in developing conceptual models or methods to increase evacuation efficiency. Computer models, capable of approximating evacuee movements during evacuations, are useful in understanding the influence of building layout, especially as it pertains to crowding and competitive behavior [21,31,49]. However, they do not faithfully incorporate psychological factors such as anxiety and attention which are key to understanding evacuee behavior. The limitations of case studies and computer modeling might be overcome through large-scale experiments approximating actual evacuations [20]. However, validating the ability of such experiments to replicate a real emergency with sufficient veracity to induce anxiety in the participants is difficult, limiting their ability to provide actionable information. In spite of these challenges, researchers have noted a critical need for social psychological experiments that "conduct tests under controlled circumstances … quantifying by formulating verifiable theories" [25].

As such, many have turned to VR to simulate emergency evacuations under controlled conditions. VR has proven useful in safely replicating high-anxiety situations for a variety of purposes, included Post-Traumatic Stress Disorder therapy [34], treatment of phobias [28,29], and firefighter training [44]. [23,24] have outlined several strengths and weaknesses of using VR in fire evacuation research. Namely, VR enables a unique combination of realism and control in emergency evacuation scenarios. In VR we can manipulate the circumstances of evacuation and collect fine-grained data on evacuee behavior. However, VR is only as useful as its ability to model the situation of interest and engender an appropriate response in participants. [23,24] state that "high – but not absolute – ecological validity of VR studies can be assumed if the visualization, observed behavior, and task difficulty of a simulated fire emergency is realistic …" VR simulations vary in their ability to capture many physical (sensation of heat, smell of smoke) and social (presence of friends and family, communication among evacuees) aspects of a fire evacuation. Additionally, the unfamiliar nature of VR interaction may result in behaviors unlike those exhibited in real evacuations. Despite this [15], note that participants respond adaptively to fire emergencies in virtual environments, seeking exits and hurrying in response to a sudden and unexpected fire emergency. The current pilot study expands on this and similar work to examine the efficacy of VR in convincingly replicating the circumstances of a real fire evacuation.

As previously indicated, anxiety and its resultant behavioral effects are hypothesized to produce or contribute to many problems in emergency evacuations. VR scenarios capable of inducing anxiety provide an avenue to assess methods of reducing that anxiety, and ultimately improving real life evacuation efficiency. Several prior studies have employed survey measures in order to assess anxiety caused by VR scenarios [23,24,29], indicating that self-reported anxiety can indeed be manipulated by VR. The current study includes survey measures, but adds physiological measures similar to those of [28]; who found that the heart rates of tunnel-phobic participants increased significantly when moving through a tunnel simulated in VR. The application of such measures in a VR fire evacuation context is, to the best of our knowledge, unique. Here, unlike [28]; physiological measures will be used to assess the responses of non-phobic participants to a universally stressful and hazardous scenario. Although the stakes involved in an evacuation are