

INFLUENCE OF DISPOSITIONAL AND SITUATIONAL FACTORS ON HUMAN PERCEPTIONS OF FIRE RISK

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ABSTRACT

At what point does an individual perceive a growing fire as dangerous and decide it is necessary to take action? Studies of human behavior during emergencies have observed that when presented with situational cues that a hazard may be present, humans can fail to act on this information in a timely manner. Models of human behavior in response to fire-related emergencies explicitly account for potential delays in identifying and acting on the presented risk of a fire. For example, the protective action decision model incorporates the tendency of individuals to notice an aberrant signal, but fail to recognize the cue as indicative of the need to evacuate, until it has become more salient. Past research has indicated that variations in the disposition of individuals, such as psychological traits, can also influence responses to emergencies. The present study examines the extent to which responses to images of growing room fires were influenced by situational and disposition factors. Participants judged whether words reflecting normalcy, risk, or protective action applied to images of room fires that varied in intensity. Psychophysical models of responses revealed, as the visual extent of the fires increased, deviation from normalcy words were first reliably judged to apply, then risk, and finally protective action, in line with models of human evacuation behavior. Individual differences in a specific dispositional trait, self-reported discomfort when exposed to sensory stimuli, was significantly related to performance: those who reported greater negative affect with sensory stimulation took longer to identify a growing fire as indicative of risk. The presence of moderate correlations between performance and other dispositional measures suggests future studies with greater statistical power may observe additional relations. Results of the current study lend support to the presence of a normalcy bias: even though participants noticed small fires and identified the scene as abnormal, they did not reliably view them as a risk until they grew larger. Furthermore, in line with evacuation models, once participants judged the fire cues to be a risk, fire size further increased before participants judged a protective action was applicable. The corroborating evidence in the present study suggests that psychophysical and observational data align with models of human evacuation behavior.

INTRODUCTION

A growing number of fire and life safety codes used around the world provide performance-based design options ¹. To ensure adequate provisions for occupant life safety, egress calculations are

increasingly part of performance-based analyses ². The role of human behavior in egress calculations can vary from simple models that assume occupants will display identical responses with regard to pre-evacuation behavior (e.g., prescribed delay times in hydraulic based models ³) to more comprehensive models that account for individual differences in occupant decision making processes (e.g., perception of hazards, and identification and assessment of risk ⁴⁻⁶). Review papers of human behavior in fire stress the need to accurately assess pre-movement time (i.e., the time between first exposure to fire cues and movement towards a safe place) and have noted that it may be a more important element of required escape time than the time needed to move to a safe place ^{7,8}. Further, studies of real emergencies have shown that there is a connection between pre-evacuation time (delays in evacuation) and the number of fire deaths or injuries ⁸. Unfortunately, multiple studies have highlighted that pre-evacuation behavior receives comparatively less attention than the actual process of evacuation behavior ⁹⁻¹².

Pioneering efforts identified behaviors that are now recognized as key human responses to fire by surveying individuals after they had experienced a fire event and investigating the actions taken (as distinct from movement) when they encountered a fire in a building ^{13,14}. Later work would seek to better understand factors affecting human response (and related timing) in real fires including (but not limited to) occupancy ^{9,15}, cues received ¹⁰, and occupant action prior to fire cue ¹¹. However, the fidelity of human behavior in response to fire cues incorporated within computational models that simulate egress is still limited ¹⁶ and further research is still needed to identify the underlying processes that produce these observable human behaviors in fire ¹². Including behavioral theories of human decision making regarding the timing of pre-evacuation actions and research linking influential factors (e.g., individual characteristics and environmental cues) to occupant decision making (e.g., identifying threats, perceiving risk, and selecting appropriate protective actions ¹⁷) can improve these models. Greater understanding of how fire is identified as an imminent risk, a specific aspect of human decision making, could improve models and calculations of required safe egress time (RSET).

Models of occupant responses to fire emergencies suggest that specific factors can influence the perception of cues and assessment of the inherent risk of a situation. A specific model that has been applied to human behavior during emergencies, the Protective Action Decision Model (PADM), places an emphasis on the early processing of cues indicative of danger. According to this model, human responses to indicators of a present or imminent emergency depend on a series of processes where environmental cues can be perceived and considered when making decisions about how to respond ¹⁸. When applied to fire-related emergencies, earlier processes are composed of perceiving environmental cues related to the emergency, with subsequent processes involving identifying whether these cues are indicative of risk, and later processes focusing on the decision making regarding taking protective action ¹⁷. Studies of human behavior during emergency evacuations have observed that humans, at times, fail to perceive signs of a hazardous event as indicative of risk ¹⁹. When applied to fire-related emergencies, the PADM explicitly incorporates biases to account for the potential delays in identifying and acting on the presented indicators of risk. Specifically, applications of the PADM to fire-related emergencies incorporate the tendency of individuals to fail to recognize aberrant signals (e.g., smoke) as abnormal; this is known as the normalcy bias ¹⁷. This type of bias can shape initial perceptions as to whether changes in the environment are out of the ordinary and can lead to delays in responding to an emergency ¹⁷. Previous research suggests that perception of cues as indicative of risk can be influenced by dispositional (e.g., psychological traits of the individual) and situational (e.g., environmental) factors ²⁰. This likely also extends to decision making regarding whether such cues warrant taking protective action ²¹. When examining the impact of situational and dispositional factors on decision making, research that has applied the PADM to fire emergencies has predominantly used post hoc evaluations of human behavior during emergencies and interviews of individuals affected by emergencies as sources of data ^{19,20}. This leaves open questions regarding the extent to which perceptions and judgments

when viewing fire cues are influenced by dispositional traits and situational factors.

In the present research, psychophysical models were used to assess at what point individuals viewing images of a developing fire reliably perceived a risk was present and required protective action. Participants viewed images selected from four full-scale compartment fires conducted in realistic, fully-furnished settings (two kitchen and two bedroom fires) and subsequently made judgments about the state of the room. Situational factors were varied by manipulating the stage in fire development that the image was taken from (pre-ignition to flashover) and by varying the type of judgment. Specifically, participants indicated whether a word prompt from select categories did or did not apply to the displayed image. Words were selected to generally reflect earlier versus later processes of the PADM, namely assessment of threat credibility, cues as indicators of a threat, and assessing need for protective action²² – ‘normal’ or ‘ordinary’ (normalcy), ‘danger’ or ‘emergency’ (risk), ‘evacuate’ or ‘flee’ (protective action). The images ranged from rooms that did not contain flames or smoke, to rooms that had small fires that produced smoke, to rooms that had reached flashover. Psychometric functions were then fitted to collected responses to assess the point during fire growth at which participants reliably judged a word applied to the scene. To evaluate the extent to which variations in dispositional traits influenced judgments, participants also completed a series of questionnaires that assessed temperament (reactivity and self-regulation to changes in environment) and risk-taking tendencies. Individual differences in these factors have been observed to correlate with real-world behaviors such as risky driving²³ and pedestrian behavior²⁴, and recreational drug use²⁵. Variations in temperament reflect differences in the way individuals react and self-regulate to changes in the environment, rooted in biological processes²⁶. The focus of theories of temperament on the processes by which individuals respond to environmental factors suggests that individual differences in temperament may shape the ways in which individuals respond to fire cues. Furthermore, with risk taking involving actions that place an individual at an increased chance of experiencing harm²⁵, it was anticipated that risk-taking tendencies may also influence reactions to environmental indicators of an emergency. Correlational analyses examined whether individual differences in the psychometric curves were connected to variations in these psychological traits.

The anticipated impact of this research is two-fold. First, the novel application of psychophysical models to fire risk perception aimed to address concerns regarding past qualitative and rating-scale research when investigating the impact of situational factors²⁰. It was predicted that judgments of growing room fires would align with earlier and later processes associated with human responses to emergencies: participants would initially detect environmental cues indicative of a deviation from normalcy, then interpret more intense fire cues as indicative of risk, and finally judge that the growing fire would require protective action. If successful, the novel approach can be systematically used to study the influence of multiple factors on fire risk perception. Second, the results can be used to inform models of risk perception in emergency scenarios. The development and evaluation of such comprehensive models could enable competent model users to predict key evacuee behaviors, and account for individual differences in dispositional traits, rather than directly prescribing such behaviors, a priori, for a given scenario.

METHOD

Participants

The responses from a total of 40 participants (5 males; age: mean, $M = 20.55$, standard deviation, $SD = 2.34$) were included in the present study. The majority of participants identified as being black ($N = 37$ including 4 Hispanic) with others identifying as white ($N = 2$ including 0 Hispanic) and of mixed race

($N = 1$ including 0 Hispanic). Participants were recruited from undergraduate psychology courses at a mid-sized university in the Baltimore-Washington metropolitan area in the United States. Recruiting materials for the study emphasized that, as part of the study, participants would be viewing real images of room fires. For completing the study, participants received course credit. The research protocol was approved by an institutional review board and abided by the Declaration of Helsinki.

Hardware and Software

All study materials were presented on a laptop computer (39.6 cm diagonal screen) running the Windows 10 operating system. The judgment task was coded and presented via the Tobii Pro Lab (Tobii AB) software system. A custom Unity3D program was used to administer questionnaires.

Procedure

After providing written informed consent, participants were presented with the judgment task. Participants then completed three questionnaires and were provided with a debriefing form. Participants completed the study in about 35 to 45 minutes.

Judgment Task

Images presented during the judgment task were selected from four video clips of fires in realistically furnished rooms. Each video clip contained a room scene: specifically, two bedroom scenes and two kitchen scenes. A sequence of nine still images were extracted from each video clip such that the apparent size or intensity of the fire increased from no fire or smoke present, to low intensity (e.g., no flames, little smoke), and to high intensity (e.g., large flames, heavy smoke). Images were edited to occlude any labels that included timestamps or watermarks. The final set of images were 1024 x 768 pixels. Figure 1 plots each sequence of images (for each of the bedroom and kitchen scenes) viewed by participants in this study.

During the task, a set of words was presented with each still image (pseudorandom order). Words visually presented to participants during the judgment task were selected to reflect earlier versus later processes associated with human responses to emergencies. Specifically, two words reflecting normalcy ('ordinary', 'normal'), risk ('danger', 'emergency'), and protective action ('escape', 'flee') were identified during a literature search and pilot testing.

Images were presented full-sized on a black background followed by words presented on a black background in a white font. For the task, participants were presented with room fire images and were asked whether a presented word did or did not match the image. During each trial, participants were first presented with a fixation point (800 ms) that was replaced by an image of a room fire which remained on-screen for four seconds. Afterwards, a word was presented and remained on-screen until participants made a keypress response as to whether the word matched the previously presented image ('Y' key = does match, 'N' key = does not match) and the next trial began.

Blocks of trials that contained different words were presented in a pseudorandom order. At the beginning of each block, instructions were presented to the participants indicating the word that they were to use to judge each image (within-subject factor). Within each block, all room fire images were presented in a pseudorandom order (within-subject factor; 36 trials total per block; 216 total trials across blocks). Participants were randomly assigned to complete one of three different trial orders.

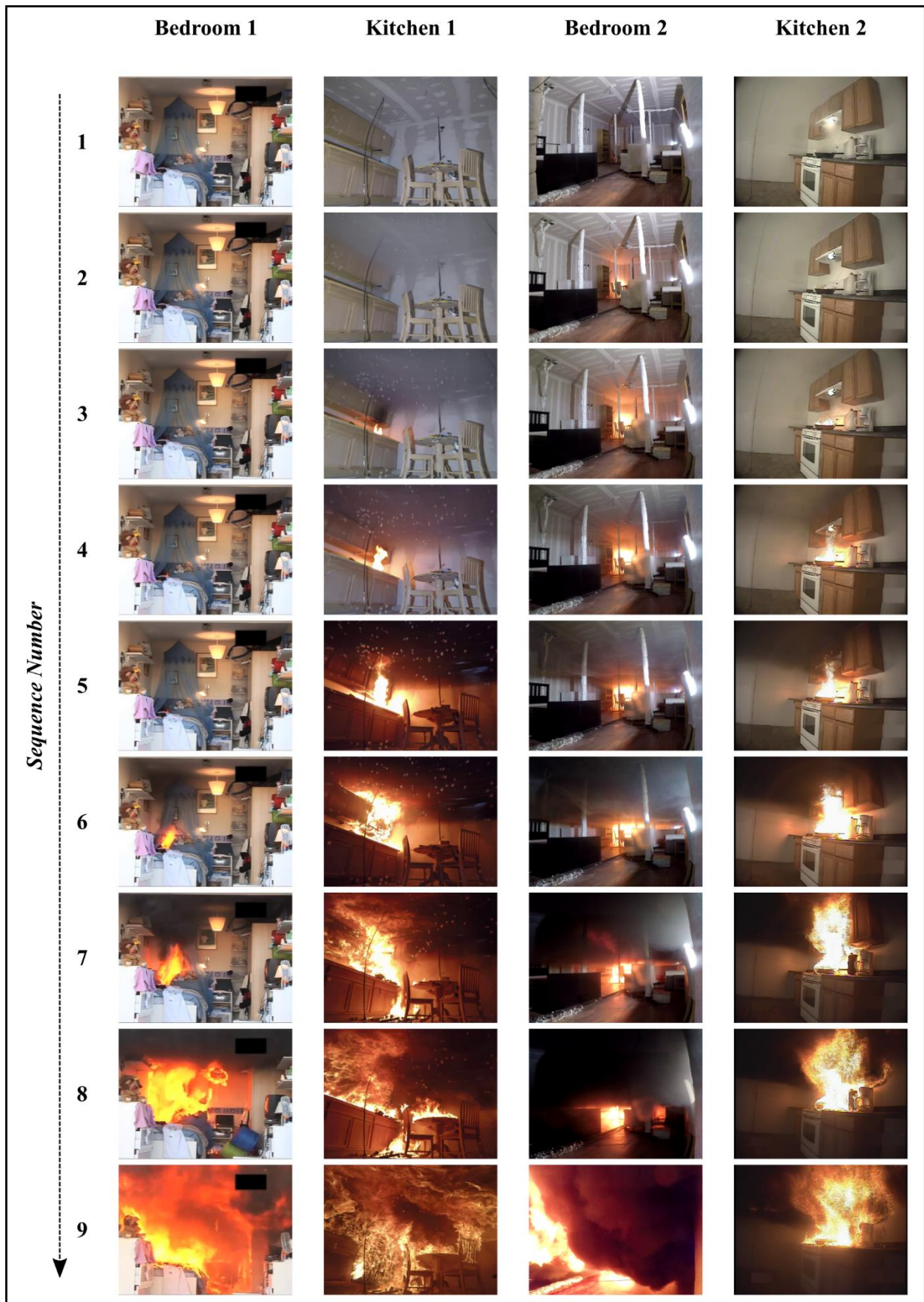


Figure 1. Room fire images presented during the judgment task. The images were selected to display no fire or smoke (#1), low intensity fire, up to high intensity fires (#9). Immediately after each image, a word was presented and participants judged whether the word applied to the image.

Demographic Questionnaire

A series of questions asked participants to provide select demographic information (e.g., age, sex, race). Participants were asked to select from the following options for each demographic factor: biological sex ('male', 'female'), race ('Asian', 'black', 'Native American', 'white'), and ethnicity ('Hispanic or Latino', 'Not Hispanic or Latino').

Adult Temperament Questionnaire – Short Form (ATQ-S)

This 77-item questionnaire has been used in previous research to reliably assess different aspects of adult temperament²⁶. For each item, individuals judged the extent to which a statement described themselves using a 7-point Likert-type scale (1 = extremely untrue of you; 7 = extremely true of you; e.g., "Sometimes minor events cause me to feel intense happiness."). If an individual judged a statement to be not relevant, they could respond "not applicable" (this was replaced by the sample mean for that item, following previous research²⁶). The responses to the adult temperament questionnaire (ATQ) were compiled into four factor scores, each with subfactors; higher scores indicated higher levels of the factor. Of interest to the present study were the following subfactors: fear (negative affect from anticipated negative event), discomfort (negative affect from sensory stimulation), attentional control (ability to focus and shift attention), and neutral perceptual sensitivity (ability to detect low intensity stimuli)²⁷.

Risk-Taking Questionnaire 18 Items (RT-18)

Composed of 18 items, the RT-18 has been observed to reliably assess the extent to which young adults engage in risky behaviors²⁵. For each item, participants indicated whether they agreed or disagreed that a statement applied to themselves. Scores were summed into two subscales, behavior (extent to which individuals engage in risk-taking behavior; e.g., "I sometimes do "crazy" things just for fun.") and assessment (extent to which individuals engage in behavior without consideration; e.g., "I often do things on impulse."), with higher scores indicating higher risk-taking tendencies (scores ranging from 0 to 9 for each subscale).

RESULTS

Task Responses

Prior to analysis, responses for normalcy words were reverse coded to reflect deviation from normalcy, in alignment with responses for risk and protective actions words (resulting responses: normalcy, no risk, no protective action = 0; deviation from normalcy, risk, protective action = 1; $\alpha = 0.05$, two-tailed for all analyses). To assess the extent to which responses to room fires changed as fire size increased and varied with the type of word being applied to an image, a logistic regression was used to model the transition of responses from 'does not match' (0) to 'does match' (1). Using the 'glmer' R package, a generalized linear mixed model ('logit' link; 'bobyqa' optimizer) with fixed effects of sequence number, word type, and an interaction between sequence number and word type was fitted to the response data with random intercept factors of participant, specific word, and scene, and a random slope and intercept for sequence number by scene.

Using an analysis of deviance, significant main effects of sequence number, $\chi^2(1) = 70.936$, $p < 0.001$, word type, $\chi^2(2) = 70.947$, $p < 0.001$, and interaction effect between sequence number and word category, $\chi^2(2) = 29.871$, $p < 0.001$, were observed. The significant main effects suggested that word prompts were more likely to be judged to apply with later sequence images (i.e., as the fire developed) and, overall, deviation from normalcy prompts were more likely to be judged to apply than 'risk' or protective action prompts. The significant interaction between the word type and the sequence

suggested that the rate of change of the applicability of that word with respect to sequence number varied by word type. Linear contrast codes used to examine the interaction between sequence number and word category were based on the PADM model, namely that the rate of change for deviation from normalcy (contrast code: 1) would be greater than identifying risk (contrast code: 0), followed by taking protective action (contrast code: -1; analysis used ‘glht’ R-package). Post-hoc tests revealed a significant effect for the planned contrasts, $z = 4.204$, $p < 0.001$: the largest rate of change was observed for deviation from normalcy, a smaller rate of change for risk, and the smallest rate of change for protective action (see Figure 2).

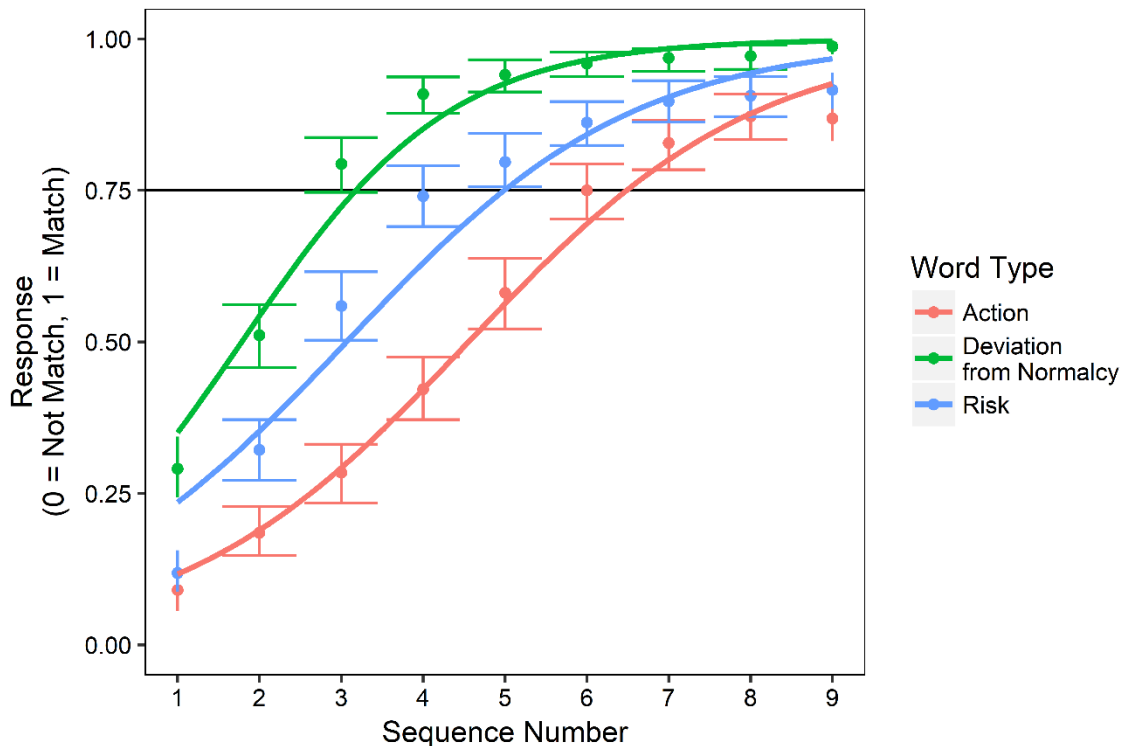


Figure 2. Response patterns on judgment task across word types. Data points reflect mean performance for each image sequence number (95% confidence interval error bars). Solid lines reflect logistic curves fitted to the data points for each word type. The horizontal line reflects 75% performance.

Threshold and Questionnaire Scores

To examine individual differences in performance on the judgment task, models were used to estimate psychophysical thresholds for each word type. Specifically, for each participant, the thresholds estimated the sequence number at which the participant reliably responded (75%) that a word matched subsequent images²⁸. To do so, for each participant a logistic regression with sequence number as the predictor and response as the dependent variable was fit for each word type. Due to a poor fit, six participants were dropped from further analysis. Similar to analyses of task responses, planned contrasts using a linear mixed model (random intercept for participant) revealed a linear increase in threshold for word types, $t(58.948) = 7.400$, $p < 0.001$, with participants waiting later in the sequence to reliably judge images as indicating requiring protective action compared to risk, while waiting less for deviations from normalcy compared to risk. Correlational analyses using the Pearson r statistic examined whether relations were present between individual variations in word type thresholds and scores on the ATQ and RT-18 (see **Error! Reference source not found.**). Significant positive correlations were observed between deviation from normalcy and risk thresholds and between risk and

protective action thresholds (trend for positive correlation between deviation from normalcy and protective action thresholds). A significant positive correlation was observed between the temperament factor ‘discomfort’ and risk threshold. Although not statistically significant, moderate correlation coefficients were observed between a subset of additional temperament factors and thresholds.

Table 1. Descriptive statistics and correlations between estimated thresholds and dispositional traits (N = 34).

| Factor | Mean | SD | Median | Min | Max | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------------------------------|-------|-------|--------|-------|-------|---------|----------|--------|---------|--------|----------|--------|-------|
| 1- Deviation from normalcy Threshold | 2.755 | 1.05 | 2.463 | 1.625 | 6.099 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2-Risk Threshold | 3.378 | 1.119 | 3.488 | 1.567 | 6.081 | 0.502** | --- | --- | --- | --- | --- | --- | --- |
| 3-Action Threshold | 4.530 | 1.512 | 4.623 | 1.87 | 6.699 | 0.289† | 0.545*** | --- | --- | --- | --- | --- | --- |
| 4-ATQ Fear | 4.005 | 0.911 | 4.143 | 2.143 | 5.571 | 0.075 | 0.199 | 0.05 | --- | --- | --- | --- | --- |
| 5- ATQ Discomfort | 4.181 | 1.045 | 4 | 2.5 | 6 | 0.248 | 0.381* | 0.178 | 0.446** | --- | --- | --- | --- |
| 6-ATQ Attentional Control | 4.253 | 1.026 | 4.2 | 1 | 7 | 0.236 | 0.095 | -0.055 | -0.347* | -0.158 | --- | --- | --- |
| 7-ATQ Neutral Perceptual Sensitivity | 5.247 | 0.896 | 5.3 | 3.2 | 6.8 | 0.238 | 0.036 | 0.042 | -0.093 | -0.021 | 0.643*** | --- | --- |
| 8-RT-18 Assessment | 6.029 | 2.249 | 7 | 1 | 9 | 0.036 | 0.112 | -0.001 | -0.108 | 0.288† | 0.309† | 0.342* | --- |
| 9-RT-18 Behavior | 3.412 | 2.439 | 3 | 0 | 9 | -0.048 | 0.012 | 0.075 | 0.145 | 0.188 | -0.04 | -0.14 | 0.064 |

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

DISCUSSION

In the present study, the extent to which judgments of developing room fires were influenced by situational and dispositional factors was assessed. Performance on the judgment task varied with situational factors, the apparent size of the room fire and word type (i.e., words indicating either, normalcy, risk, or protective action). This pattern of performance aligns with the PADM, suggesting that participants viewed the room fire scenes as indicative of emergencies. Across all word types, as the intensity of the fire cues increased, participants were more likely to judge that words applied to the image. However, the point during the developing room fire at which participants reliably judged that a word matched an image varied by word type. Both logistic model analyses and threshold estimates indicated that participants initially detected fire cues as indicative of a deviation from normalcy (between the second and third images in sequences), then indicative of risk (between the third and fourth images), and finally judged that fire cues indicated required protective action (between fourth and fifth images). This pattern of performance generally aligns with earlier and later stages of the PADM¹⁷ as well as previous observational and self-report evidence collected from fire-related emergencies²⁰.

Overall, the observed impact of situational factors on judgments of room fires suggests that judgments of presented visual fire cues can be used to examine how humans perceive a fire-related emergency.

When examining performance on the judgment task, participants varied in the point at which they viewed the developing room fires as indicative of risk and requiring protective action. Specifically, individual differences were present in the estimated thresholds for deviation from normalcy, risk, and action, which reflected the point across sequences that participants reliably viewed images as matching the presented words. This provides further evidence that individuals vary in their perceptions and judgments of fire-related cues. When examining connections between word type thresholds, the strongest correlations were between risk and protective action, and deviation from normalcy and risk. These connections align with previous applications of the PADM to fire-related emergencies in two ways. First, the strong positive correlation between risk and protective action thresholds indicates that participants who judged images with less intense fire cues as indicative of risk also judged images as indicative of protective action with less intense cues (and vice versa). This aligns with the stages of the PADM which suggest that when individuals decide a situation poses an imminent risk, they are more likely to take protective action¹⁷. The correlation between deviation from normalcy and risk thresholds supports previous research indicating that normalcy biases can influence the point at which individuals identify cues as indicative of an emergency²¹; individuals who were later to judge a deviation from normalcy required more intense fire cues before judging the cues as indicative of a risk. Although this aligns with the PADM, a key aspect of the model is the extent to which individuals perceive an emergency as posing a risk to themselves and others²². The extent to which participants in the present study simulated themselves, or others, within the images of the room fires may have influenced whether they perceived the fire as posing a risk to themselves or others. This could account for some of the individual differences in thresholds observed in the present study.

When examining individual variations in dispositional traits and judgments of room fires, weak connections were observed. In the present study, temperament and risk-taking measures were selected since previous research has observed that individual differences in these self-reported measures have been connected to real-world behaviors. Of the measures included, the temperament factor discomfort was significantly correlated with variations in risk threshold. Specifically, individuals who had higher discomfort scores took longer to identify images as indicative of risk. With higher levels of discomfort reflecting greater negativity towards sensory stimulation (e.g., greater negative reactions to more intense visual stimulation²⁷), this relation suggests that individual differences in dispositional traits may affect perceptions of risk cues in the environment. The lack of statistically significant effects between judgments of room fires and other dispositional traits included in the present study raises questions about the extent to which the present study was able to detect such relations. Specifically, the extent to which participants viewed the images of a fire as posing a risk to other persons may have moderated connections with dispositional traits. Future research that increases the perception that the room fires pose an imminent risk to humans may be better suited to determine whether temperament of individuals influences judgments of fire emergencies.

Future Considerations and Directions

The results of the present study provide initial evidence that judgments of still images of developing room fires align with past observations of human responses to emergencies. Although the words used during judgments for the present study were selected to reflect earlier versus later decision making processes present in the PADM, it remains to be determined which stages or phases of the model the words most directly align with. Earlier phases of the PADM focus on the perception of cues in the environment that are indicative of an emergency with later phases emphasizing the interpretation of the

cues²². Although the sequence in which words were judged to apply to developing fires generally aligned the order of PADM phases, questions remain regarding the extent to which participants interpreted the words selected to reflect risk and protective action as indicative of a threat to others. By design, the fire cues included in the present study were limited to visual forms and did not include human occupants. With evidence that decision making during emergencies can be influenced by the perceived risk of the hazard to the self and others, this may have influenced the judgments of participants. Future research that utilizes more realistic or immersive cues and/or information sources (e.g., virtual reality) and more descriptive emergency scenarios may be able to increase the perceived risk to the self and others. For example, with evidence that using virtual reality can increase perceived presence in an environment²⁹, presenting a three-dimensional virtual room fire, with the participant situated inside the room, may be able to increase perceived presence and sense of risk to the individual. Alternatively, providing participants with scenarios that emphasize the potential risk to others (e.g., describing a bedroom room fire as occurring adjacent to another bedroom where a child is currently sleeping), could lead to a different pattern of responses and relations to dispositional traits. Additionally, the stimuli in the present study were strictly within the visual modality. When conducting interviews with survivors of fire emergencies, many report that cues within other sensory modalities, such as smell, were noticed in addition to visual cues⁸. Open questions remain as to whether patterns in performance observed in the present study would be observed when using fire cues of different, or multiple, sensory modalities.

The stimuli selected for the present study focused on bedroom and kitchen fires that were video recorded as part of controlled burns. Although the videos were of real fires, some aspects of the videos may have led participants to view the rooms as atypical. For example, the angle of the video camera (e.g., near floor) and inclusion of measurement devices and recording instruments in a subset of the videos may have made it difficult for participants to visualize themselves as present in the room. Future research should include additional room fire scenes that are likely to be familiar with the targeted population of participants. Furthermore, there were differences across the room scenes with regard to the visual extent of the fires and sequence number. To account for differences in the rate at which visual cues of fire intensity changed across room fire scenes, mixed models that included a random effect of scene were utilized. Although this statistical procedure was used to minimize the effect of cross-scene differences, future research should more systematically match visual cues of fire intensity across different rooms and environments. Furthermore, the words included in the present study were selected to reflect different stages of the PADM, but future research could include a range of words, or phrases, to examine the impact on judgment performance.

Overall, the present study provides a decision-making task for examining how individuals judge fire cues in different situations. With evidence that judgment performance aligned with the PADM, future research can make use of the paradigm to continue to examine different facets of human perception and processing of cues present during fire, and non-fire, emergencies.

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