

Article

Deciding Whether to Use a Fire Extinguisher: The Impact of Fire Intensity, Smoke, and Growth Rate

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Abstract

The present study investigated how visual characteristics of a fire influence extinguisher use. Safety guidance indicates that occupants should consider situational aspects when deciding whether to use an extinguisher, such as fire characteristics. The visual fire cues of intensity, growth rate, and smoke thickness were systematically manipulated to examine the impact on judgments to intervene with an extinguisher. Participants ($N = 135$) viewed simulated fire scenes as part of an experiment and judged whether they could safely attempt to use an extinguisher. The results indicated that the participants were significantly less likely to attempt extinguisher use with greater fire intensity and thicker smoke. In contrast, variations in fire growth rate did not significantly affect participant decisions. These findings indicate that perceived fire intensity and smoke density are strong factors in extinguisher use decisions, while growth rate may not meaningfully influence occupant behavior. Understanding these perceptual factors can inform fire safety education and improve guidance on when extinguisher use is appropriate, potentially enhancing residential fire response outcomes.

Keywords: human behavior in fire; perception; fire simulation; protective action



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1. Introduction

During an at-home fire emergency, occupants with a readily accessible fire extinguisher have a critical decision to make: whether or not to attempt to suppress the fire. Prior research has investigated how different factors (such as fire characteristics) contribute to occupants taking protective action during fire incidents [1]. Both observational and experimental studies have investigated the impact of the intensity, size, and thickness of flames and smoke on protective actions taken by occupants [2–6]. However, questions remain regarding how these fire characteristics interact and influence the decision to attempt to use a fire extinguisher. Indeed, in a review of research in human behavior in fire research, the impact of cognitive process and greater insight into behaviors performed during fire incidents were highlighted as gaps in the literature [7]. Research investigating the fire extinguisher knowledge and perceptions of individuals has identified that the public varies in their preparedness to use an extinguisher [8] and judgements of how intense a fire an extinguisher can suppress [9]. With evidence of such ambiguity, the present study investigated how fire characteristics, the intensity, rate of fire growth, and the thickness of smoke, impacted judgments of whether to use an extinguisher.

1.1. Fire Incidents Involving Extinguishers

Fire extinguishers are portable devices used to suppress fires. According to a national survey, approximately 74% of USA households reported having at least one fire extinguisher [10]. The goal of having a portable fire extinguisher within a home is to reduce the harm posed by small fires to property and occupants [11,12]. Historically, occupants have used multiple methods to suppress fires (e.g., water, pot lid) [13], with modern fire extinguishers having the benefit of being effective with several types of combustibles (depending on the classification) from a distance [12]. Indeed, research indicates that, when used properly, fire extinguishers are available in homes as a means for suppressing incipient fires. Industry reports suggest that extinguishment was accomplished in approximately 95% of incidents where portable extinguishers were used [14]. However, several human-related factors contributed to failure to extinguish. This included using the incorrect extinguisher for the fire, user error operating the extinguisher, and attempting to suppress a fire too large for the extinguisher [14]. In the USA, residential fires account for a disproportionate number of casualties in fire incidents [15,16]. In addition, approximately 30% of casualties during residential fire incidents in the USA occurred when occupants were attempting to control the fire, which includes using a fire extinguisher [16]. Based on post-incident interviews, such engagement can include walking through smoke to reach the origin of the fire [4]. This evidence indicates that extinguishers are effective when used properly. However, attempts to engage fires that are not suitable for extinguishers are associated with casualties during incidents. Understanding why occupants judge a fire to be extinguishable is important for minimizing residential fire casualties, when extinguishers are present.

1.2. Occupant Decisions During the Fire Extinguisher Lifecycle

In homes where they are available and managed by the occupants, occupant interaction occurs at four main points during a fire extinguisher lifecycle: selection, installation, maintenance, and usage. In structures subject to building code requirements, standards, such as the NFPA 10 [17], provide guidance for each of these aspects of fire extinguishers. Although these standards are not required for all types of residential buildings in all local jurisdictions, the fire extinguisher lifecycle is applicable to occupants. Each of the preceding lifecycle events impact the decision on whether to use a fire extinguisher during an incident.

Fire extinguishers are labeled with a rating and classification which indicate the suppression performance and types of combustibles the device should be used with [18]. During selection, the occupant decides which type of fire extinguisher best fits the building, room, and typical activities. Multiple ratings and classifications are commercially available. The most common type of extinguisher involved in reported fire incidents are ABC dry chemical devices [19]. These are used with class A (solid combustibles including wood and cloth), B (liquid combustibles including grease and gasoline), or C (electrical combustibles including energized equipment and wires) fires [18]. The rating of the extinguisher indicates the suppression performance, with higher ratings indicating a device can suppress larger fires [20]. The installation location and the maintenance of the extinguisher are part of NFPA 10 standards. However, the focus of the present study is the usage of the extinguisher during a fire incident. Nonetheless, the selected class and rating determine what type and size of fire an extinguisher can suppress.

After deciding to engage the fire with an extinguisher, the occupant must perform a series of actions to effectively suppress the fire. Through a procedure known as PASS, the occupant first needs to pull ("P") the pin, aim ("A") the nozzle towards the base of the fire, then squeeze ("S") the trigger to release the agent, and move the discharging agent in a sweeping ("S") pattern across the base of the fire in order to effectively suppress the fire [18]. The judgment of the occupant of whether to engage the fire with the extinguisher

depends on several factors. This includes preceding decisions made during the extinguisher lifecycle (e.g., type of unit installed) as well as the situational factors encountered during the fire incident.

1.3. When Should a Fire Extinguisher Be Used?

Guidance available to the public on whether to use an extinguisher with a fire is available from several sources. These predominately are safety notices and guidelines from government organizations and instructional manuals provided by manufacturers. Guidelines emphasize the following factors when occupants decide whether to use an extinguisher: knowledge, egress path, smoke, and fire size [18,21,22]. Knowledge refers to the occupant's understanding of whether the class of the extinguisher matches the combustibles and how to use a fire extinguisher. If an occupant does not know how to use the extinguisher or if it is appropriate for the fire, they should not attempt to use it. In addition, egress path guidance suggests that occupants should only attempt to use a fire extinguisher if they have a safe exit. The following guidelines are specific to fire characteristics: whether the smoke and fumes are too thick or toxic to approach the fire and if the fire is in the incipient stage (i.e., small and contained enough to be suppressed by the extinguisher). In situations where these guidelines are met, it is still recommended that occupants only attempt to use the fire extinguisher when they feel confident in doing so [23–25]. However, industry reports state that the main reason for non-extinguishment is attempting to suppress too large of a fire [19]. With this in mind, it is apparent that guidelines regarding fire characteristics may be challenging for the public to put into practice.

Despite the critical importance to life safety, research has observed that the general public varies in awareness of how and when to use a fire extinguisher. Studies have investigated how fire extinguisher knowledge and estimates of fire size may contribute to ambiguity in fire extinguisher use. A study by Poole and colleagues examined whether individuals follow the PASS actions when using a fire extinguisher with a simulated fire [12]. Although the majority of participants were capable of doing so, others made mistakes. In addition, research has observed that individuals vary in their knowledge about the steps for using fire extinguishers [8]. Individual differences extend to judgments of how large a fire an extinguisher could suppress. In a study by Bonny and Russell, participants were asked to judge whether a fire extinguisher could be used to suppress a growing fire [9]. Using videos of simulated fires, the same extinguisher was judged to be able to extinguish only a small fire by some participants or a larger fire by others. This research suggests that the perceptions and actions of residential occupants during fire incidents may not align with publicly available fire extinguisher guidelines.

1.4. Impact of Fire Characteristics on Protective Action Decisions

Fire characteristics have been identified as playing a critical role in pre-movement decision-making in models of human behavior in fire. The protective action decision model (PADM) has been applied to fire events with sequential phases leading up to a decision of what protective action to take [1,26]. The initial phase of PADM includes occupant perceptions of situational cues, including the building environment, communications from others, as well as fire characteristics. In alignment with fire extinguisher guidelines, fire-related cues include the density of smoke and, if within line of sight, the size of flames. Subsequent phases of PADM rely on occupant perceptions of situational cues: interpreting that a fire event is occurring and assessing the level of posed risk (Phase 2), identifying and selecting what protective action to take (Phase 3), and ending the pre-movement stage by performing the selected protective action (Phase 4). In this manner, the perception and

interpretation of fire characteristics influence the timing and selection of protective actions during incidents.

Research has investigated how pre-movement factors impact the timing by which protective actions are taken. A key metric in fire safety engineering, required safe egress time (RSET) is used to estimate the necessary amount of time required for occupants of a building to take protective action during a fire incident from the initial ignition of a fire [27]. The pre-movement period of RSET is from ignition to before starting to take protective action, transitioning to the post-movement period, ending with the occupant completing the protective action. The timing of the pre-movement period is crucial to estimates of RSET: occupants that take longer in their decision-making require a longer RSET.

The PADM provides a framework for examining factors that influence the duration of the pre-movement period [28]. A scoping review of risk perception within PADM provided a framework for how situational factors may impact the perceived risk of occupants [29]. For example, having more intense and multi-modal sensory cues about a fire (e.g., thick smoke, strong smell, visible flames) can increase the occupant's perception of said cues (Phase 1) and interpretation that the situation poses a high risk of harm (Phase 2). This can potentially shorten the amount of time required to judge that a protective action is required. In response, performance-based models of RSET have proposed incorporating PADM to estimate pre-movement duration [30,31]. Indeed, several studies have incorporated situational factors when simulating occupant evacuation during fire incidents, including the location within a building as well as the number of other occupants [32] and fire-related cues such as smoke [33,34]. This research indicates that incorporating the perceptual and cognitive processes contributing to the decision to take a protective action can enhance predictions of pre-movement timing. Although these studies focus on evacuation as the protective action, PADM-based predictions should also apply to other protective actions, including using a fire extinguisher.

Prior research has observed that flame and smoke characteristics impact the perception and judgments of fires. A study by Bonny and Milke focusing on the visual perception of fires observed that individuals were able to detect differences in flame size and growth rate when presented as simulated fires [35]. In addition, simulated fires with thicker smoke, larger flames, and faster growth rates were rated as posing greater risk to a hypothetical occupant [36]. In parallel, a review of post fire incident reports and surveys observed that survivors who encountered more intense fire cues rated the fires as posing higher risk [29]. Research has further observed that certain fire characteristics can influence the selection of protective actions. For example, using hypothetical scenarios, Russell and colleagues observed that the smoke thickness of simulated fires, but not growth rate, significantly affected whether participants decided to select a protective action [37]. Overall, the PADM and related research indicate that occupants can incorporate the characteristics of fires when deciding whether, and what, protective action to take during a fire incident.

In line with fire extinguisher guidelines and PADM, research has identified fire intensity as a factor that influences judgments of fire extinguisher use. In the study by Bonny and Russell, participants were presented with videos of a simulated fire at increasing intensity, defined by heat release rate (HRR) [9]. Across the experiments, participants were significantly more likely to judge that the extinguisher could be used with fires with lower, compared to higher, HRR. This indicated that individuals did attend to fire intensity when deciding whether to use an extinguisher with a developing fire, despite variability in what intensity to stop attempting to do so. However, research has yet to provide empirical support as to whether individuals incorporate smoke thickness when judging whether to use a fire extinguisher. If so, this would be in alignment with extinguisher guidelines. Addressing this gap has important implications for communicating safe fire extinguisher

practices to the public as well as how to design fire safety training to both residential and commercial occupants.

1.5. Present Study

The objective of the present research was to understand how situational factors impact the decision to use a fire extinguisher. This is in line with recent calls to address the paucity of behavioral research investigating determinants of specific behaviors in fire incidents [38]. In focusing on fire extinguisher use, we aim to expand upon the specific types of protective actions studied in prior research, which has been noted as a limitation when developing theories of different behavioral responses [7]. Prior studies have focused on perceptions of extinguisher performance in relation to fire intensity, and the impact of smoke thickness and growth rate on other types of protective actions. However, the impact of smoke thickness and growth rate on the decision to use an extinguisher has yet to be empirically examined. We investigated whether individuals incorporated the smoke thickness and growth rate of fires when judging whether to suppress the fire with an extinguisher. We selected these fire cues for two reasons: fire extinguisher guidelines reference smoke when judging whether to use an extinguisher and prior evidence that growth rate may influence the perceived risk of a fire but not which protective action to take. In addition, we included fire intensity to both replicate the prior findings of Bonny and Russell [9] and examine how different fire characteristics may interact when influencing whether individuals decide to use a fire extinguisher. To systematically manipulate fire characteristics and control for environmental cues, fires were selected from the simulation library described in Bonny and colleagues [36]. Specifically, videos from the same type of room (living room) and the same viewpoint (entrance) were selected. The task procedure from Bonny and Russell [9] was adapted such that participants were presented with a single ABC fire extinguisher during a hypothetical scenario where they judged whether it was safe to attempt to use the extinguisher to suppress a growing fire.

Three hypotheses based on fire extinguisher guidelines and prior research were tested. We predicted that participants would be less likely to use the extinguisher with fires of greater intensity (H1), thicker smoke (H2), and faster growth rates (H3).

2. Materials and Methods

2.1. Participants

A total of 135 participants recruited from an online participant panel (Prolific.co) completed the study. A subset of participants ($N = 119$) provided demographic information (age: $M = 35.63$ years, $Min = 18$, $Max = 72$; N biological male = 62; race: N American Indian or Alaska Native = 1, N Asian = 2, N Black or African American = 25, N multiple = 5, N White = 86). A total of 92 participants reported some experience with fire extinguishers (Table 1). To be eligible to participate, participants were required to have normal or corrected-to-normal vision, United States residency, English fluency, and the use of a modern browser (Google Chrome or Mozilla Firefox) running on a laptop or desktop computer.

Table 1. Tabulation of participant responses to frequency of fire extinguisher experience questions.

Question	Never	Once	Several Times	Regularly
Have you ever been taught or trained in the use of a fire extinguisher?	30	40	42	7
Have you ever used fire extinguishers during training courses?	50	32	34	3
Have you ever used an extinguisher on a 'real' fire, outside of training?	78	25	14	2

2.2. Materials

Participants completed the experiment online. It was hosted via a JATOS server (version 3.8.0) [23] with tasks coded using jsPsych (version 7.3.1) [24]. Videos of simulated fires were selected from the library described by Bonny and colleagues (see [36] for additional details). The library contains fire simulations estimated using FDS (version 6.7.9) [25] and rendered as videos using PyroSim (version 2022.2.0803) [26]. The simulated room was a residential living room and an adjacent hallway. The fire was located in the center of the room on the floor. The viewpoint for the rendered videos was in the entrance to the room at approximately eye-level (1.6 m). A set of ten videos were selected (8 s duration) and displayed in the web browser with a 400-pixel (width) by 700-pixel (height) video player.

A common ABC fire extinguisher with a UL rating of 2A was selected and presented to participants. To describe the extinguisher and suppression performance, an image from commercial website was scaled in width and height in a diagram that contained a silhouette of an adult male (height = 1.77 m). Prior to making judgments, participants were provided with a description of extinguisher agent weight (~1.81 kg) and performance (based on manufacturer specifications, [39]) including discharge duration (12 to 15 s), distance (3.66–5.49 m), and UL water equivalent for class A fires (9.0 L, [20]).

2.3. Experiment Design

The experiment factors of smoke thickness, growth rate, and fire heat release rate (HRR, i.e., intensity) were presented by adjusting the parameters of the fire simulations in each video. Smoke thickness was manipulated by adjusting the opacity, or transparency, of the smoke rendered in PyroSim. To manipulate growth rate, FDS simulations were configured to use a t^2 curve to increase HRR during the simulation with different alpha parameters (up to HRR = 1 kW). Participants were randomly assigned to a slower growth rate (alpha = 0.003) or faster growth rate condition (alpha = 0.024; between-subjects); these growth rates were within the range of alpha coefficients observed with building furnishings [40] with differences in these rates previously observed to be discernable via videos of fires [35]. Participants were presented with all 10 levels of HRR in a fixed sequence from lower to higher (within-subjects; 10 levels). To account for differences in growth rate, the videos were selected such that the HRR at the end of each video was matched for both conditions (endpoint HRRs, in kW: 23.06, 57.62, 107.74, 173.40, 254.62, 351.38, 463.70, 591.58, 735.00, 893.98; Figure 1). Although this entailed that the HRR at the start of the videos was lower for the faster growth rate condition, this tradeoff meant that the last video frames presented to participants before making a judgment were consistent across conditions.

A challenge in experimentally manipulating smoke and growth characteristics is the strong association with HRR. For example, with all other aspects the same, a slower growing building fire will have accumulated more smoke in a room than a faster growing fire when measured at the same HRR. In addition, the soot production of a fire affects combustion [41]. The approach of the present study was to focus on the perceptual characteristics of a hypothetical fire while controlling the parameters of the fire across the experimental conditions. To do so, the thickness of smoke was manipulated using the opacity settings of the rendered fire within PyroSim rather than by changing the soot production parameters of the simulation. Although this approach artificially adjusted the visual characteristics of the fire, by doing so, the FDS results underlying the simulation were consistent across conditions with the transparency of the smoke being manipulated. Participants were randomly assigned to either thinner (5% opacity, more transparent) or thicker smoke (10% opacity, more opaque; between-subjects). These levels of opacity have been observed in prior research to influence judgments of fire risk and protective actions during hypothetical scenarios [36,37].

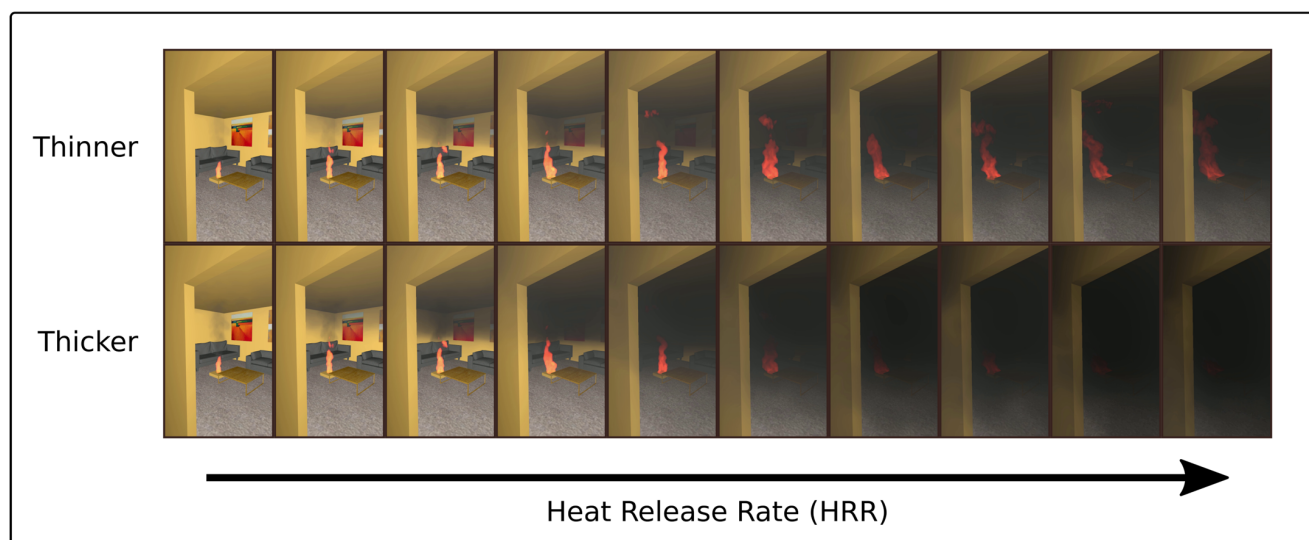


Figure 1. Frames from the end of each video that were used in faster growth rate conditions. The different smoke conditions are presented in the top and bottom rows with intensity (heat release rate, HRR) increasing from left to right.

2.4. Procedure

Eligible participants were presented with a consent form. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at Morgan State University (protocol number 22/12-0209). Informed consent was obtained from each participant. Those who provided consent were presented with the task.

At the beginning of the task, participants were presented with a hypothetical scenario. They were asked to assume the perspective of a person who was at the house of a neighbor to return a borrowed item. When they entered, the house was unoccupied and they smelled smoke when passing down the hallway. Upon looking into the living room, the participant noticed that a candle had started a fire. The scenario continued by stating that the person knew a common residential ABC class fire extinguisher was in the kitchen, down the hall. The description of the extinguisher was then presented. Participants then completed an information check which included questions about the scenario. They were then reminded of the scenario and of the performance information of the extinguisher.

After the scenario, participants were provided with instructions for the judgment task. They were informed that they would view videos of the fire as it grew in intensity. Their task was to judge whether they (assuming the role of the person in the scenario) could safely retrieve and use the extinguisher to put out the fire. The instructions emphasized that in order to use the extinguisher, the person would have to travel to the kitchen and return, which would take some time to complete.

For the task, at the beginning of the trial, participants were informed the fire had grown in intensity. After pressing the “start” button, the video of the corresponding HRR automatically played. Next, they were presented with the following prompt with response options of “yes” or “no”: “Can you safely retrieve and use the extinguisher to put out the fire?”. The task continued until either the participant responded “no” or the last fire video had been presented.

After the judgment task, as a manipulation check, participants were asked to rate the perceived risk posed to the occupant in the scenario after completing the judgment task. They subsequently provided demographic information and were provided with a debriefing regarding the purpose of the study as well as compensation (hourly rate of USD 15).

2.5. Measures

2.5.1. Perceived Risk

Participants responded to three perceived risk scale items from prior research [36]: “What was the severity of the fire?” (1 = “very low”, 9 = “very high”), “There was risk of serious harm from the fire.” (1 = “strongly disagree”, 9 = “strongly agree”), “The fire posed imminent danger.” (1 = “strongly disagree”, 9 = “strongly agree”; responses were scored as 0 to 8, respectively, for all scales). These ratings were treated as a manipulation check. It was predicted that participants would stop attempting to use the extinguisher when they judged the situation to pose too high a risk to the occupant. If supported, this would indicate that the responses made by participants were in reference to the perceived risk based on the fire cues presented in the videos.

2.5.2. Response Choice

For each fire video, participants were assigned a score of either 0 or 1. Participant “yes” responses were assigned a 1, indicating that the participant judged they could safely retrieve and use the fire extinguisher. A score of 0 was assigned in the following manner: when participants responded “no” they were assigned a 0 for that intensity and for any higher intensities remaining. The assignment of 0 to all unseen videos was in line with the task instructions that participants judged the fire had reached an intensity that was no longer safe to retrieve and use the extinguisher. Response choice was used to analyze the impact of intensity on whether a participant judged they could safely retrieve and use the fire extinguisher.

2.5.3. Extinguisher Threshold

Similar to Bonny and Russell [9], the extinguisher threshold was calculated for each participant using task responses. Specifically, the greatest HRR for which a participant responded “yes” was marked as the threshold. For participants who did not provide a “yes” response, the minimum HRR was set as the threshold. In this manner, the threshold indicated the greatest HRR that participants judged could safely be extinguished.

3. Results

All statistical analyses were conducted using R (version 4.4.1) with the following packages in addition to base functions: ‘emmeans’ (version 1.10.4), ‘car’ (version 3.1-2), ‘ggplot2’ (version 3.5.1), ‘psych’ (version 2.4.6.26) [42–45]. When entered into statistical equations, all predictor variables were scaled and centered. All hypothesis tests were two-tailed with $\alpha = 0.05$ and post hoc comparisons were adjusted for family-wise error using Holm corrections.

3.1. Analysis of Perceived Risk

A multivariate analysis of variance (MANOVA) was used to examine whether ratings for the three risk scales varied by smoke thickness, growth rate, and the HRR of the fire in the last video they viewed. No significant main or interaction effects were observed with Pillai’s Trace values ranging from 0.010 to 0.036, F -values from 0.41 to 1.56, and p -values ranging from 0.204 to 0.746 (Figure 2). This suggested that participants across all conditions perceived the last fire they viewed as similar in posed risk.

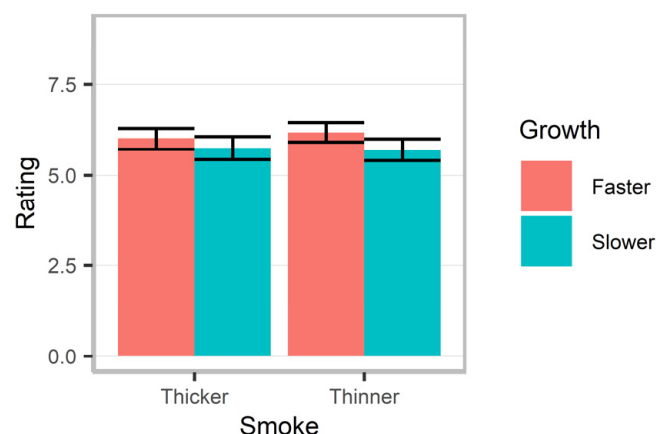


Figure 2. Mean risk ratings for each smoke and growth rate condition, collapsed across scales and heat release rates, of the fire in the last video viewed (error bars equal 95% confidence intervals).

3.2. Task Responses

An initial analysis investigated whether participant responses varied with fire HRR (Figure 3). Evidence of sparsity in responses was observed across participants. Specifically, few 0's ("no" responses) were observed with lower HRR. To provide a more robust analysis with more stable convergence behavior, the 'glmmTMB' package (version 1.1.12) [46] was used to run a logistic regression with a random intercept for participant and slope for HRR. A significant main effect of HRR was observed, $z = -12.39$, $p < 0.001$; participants were less likely to use the extinguisher as HRR increased.

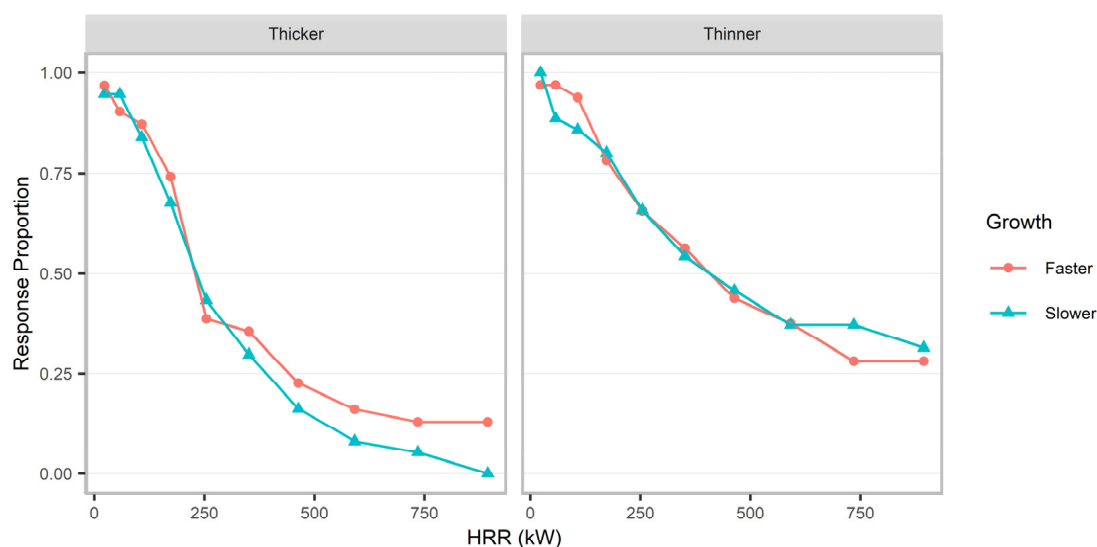


Figure 3. Mean response scores for whether to use the extinguisher (1 = "yes") for each smoke and growth rate condition across heat release rate (HRR).

With prior evidence of individual differences in extinguisher use judgments [9], we next examined whether variances in extinguisher threshold differed across smoke opacity and growth rate conditions. A Levene's test revealed significant heterogeneity across conditions, $F(3) = 5.93$, $p = 0.001$. Follow-up tests indicated that this was specific to smoke thickness, $F(1) = 16.62$, adj. $p = <0.001$ (growth rate, adj. $p = 0.480$). This indicated that extinguisher thresholds were more variable in the thinner ($SD = 328.42$) compared to thicker ($SD = 221.66$) smoke conditions.

Extinguisher threshold was next compared across smoke thickness and growth rate conditions (scaled and centered). Due to evidence of heterogeneity across conditions,

a robust linear model was run using the ‘MASS’ (version 7.3-60.2) ‘sandwich’ (version 3.1-1), and ‘lmtest’ (version 0.9-40) R-packages [47–49]. A significant main effect of smoke thickness was observed, $z = -2.80$, $p = 0.005$; no significant effects of growth rate nor interaction were observed ($ps > 0.8$) This indicated that participants in the thinner smoke condition were more likely to attempt to use the extinguisher with more intense fires than those in the thicker smoke condition (Figure 4; see Supplementary Material for exploratory demographic analyses).

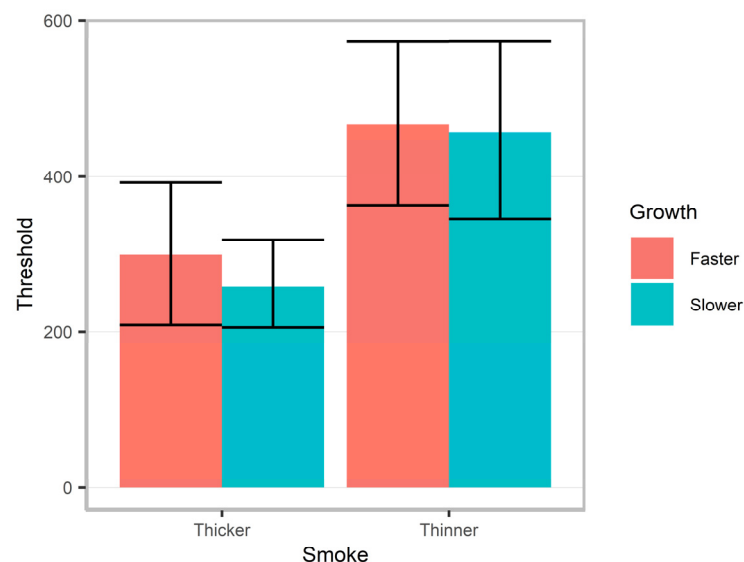


Figure 4. Mean extinguisher threshold (heat release rate, in kW) for each smoke and growth rate condition (error bars equal 95% confidence intervals).

We ran a post hoc analysis examining participants who responded “yes” to all fire intensities presented. Across smoke and growth rate conditions, 17.78% of participants ($N = 24$) had a maximum extinguisher threshold (thicker smoke + slower growth $N = 0$; thicker smoke + faster growth $N = 4$; thinner smoke + slower growth $N = 11$; thinner smoke + quicker growth $N = 9$). A Fisher exact test, evaluating whether participant counts varied by smoke and growth rate conditions, was not statistically significant, $p = 0.098$. This suggested that the number of participants with maximum threshold did not significantly vary by smoke and growth conditions.

4. Discussion

The goal of the present study was to investigate how visual fire characteristics were incorporated into decisions of whether to use a fire extinguisher. Based on safety guidance for when occupants should use a fire extinguisher, the size and thickness of the fire and smoke, respectively, were examined. In addition, fire growth rate was examined as a fire characteristic based on mixed evidence that it may affect protective actions. Using a judgment task, we observed that participants were less likely to attempt to use a fire extinguisher with greater fire intensity or thicker smoke. No significant impact of growth rate was found. This research provides evidence that fire intensity and smoke thickness are incorporated into judgments of when to use a fire extinguisher.

4.1. Fire Characteristics Impact Extinguisher Use

The present study replicates and extends prior research on fire extinguisher usage. In support of H1, participants were less likely to attempt to use the extinguisher with greater fire intensities. This effect was similar to Bonny and Russell [9], providing additional evidence that fire size is a cue that individuals attend to when judging the use of fire

extinguishers. In addition, participants had a lower extinguisher threshold with thicker smoke, in support of H2. This extends prior protective action research [37] by providing evidence that individuals incorporate the thickness of smoke when judging whether to engage with an extinguisher. In contrast, no significant effect of growth rate was observed. This did not provide support for H3: viewing a faster or slower growing fire did not affect when a participant judged an extinguisher could be used. Overall, the present study suggests that individuals attend more to certain fire cues, such as intensity and smoke, than other characteristics when judging whether to use an extinguisher.

The lack of a significant effect of growth rate aligns with prior lab observations. In past research, fire growth rate did not significantly affect the selection of protective actions [37]. Although fire growth rate can be detected by individuals [35] and can affect perceived risk of simulated fires [36], it does not appear to be incorporated into protective action decision-making during hypothetical scenarios. Differences in attention to flame and smoke characteristics could account for this disparity when compared to smoke thickness. Prior research suggests that, with larger fire sizes, individuals may be less able to perceive flames with greater smoke, impacting performance when recalling the size of these characteristics [50]. As applied to the present study, flames may have been less visible in the thicker smoke condition, limiting the impact of growth rate. However, an interaction effect, which would have indicated that growth rate impacted performance in the thinner smoke condition, was not significant. This suggests that individuals may attend more to fire intensity and smoke thickness, compared to growth rate, when judging whether to use a fire extinguisher.

4.2. Effects of Fire Intensity and Smoke Thickness Align with Extinguisher Guidance

The present research suggests that individuals are in alignment with safety guidance on using fire size and smoke thickness when deciding to use a fire extinguisher. A primary motivation for the present study was the emphasis of government and manufacturer guidance on the size of the fire and smoke toxicity. Prior research has identified that smoke and flame size, when visible, are key cues when occupants describe their actions in post-incident interviews [4,6] and when judging the risk of simulated fires [36]. Although the present study used hypothetical scenarios, the corroborating evidence from prior research [4,6] suggests that occupants incorporate fire and smoke characteristics when deciding whether to use a fire extinguisher.

Individuals displayed substantial variability when they judged whether an extinguisher should no longer be used. In addition, these individual differences varied by smoke condition. Specifically, participants were more variable when deciding to stop using the extinguisher with thinner compared to thicker smoke. This indicated that individuals were more consistent in not using the extinguisher with larger fires when the smoke appeared thick, in alignment with guidelines. However, when smoke appeared more transparent, some participants judged that the extinguisher could be used with a much greater intensity fire than other participants. Evidence suggests that smoke visibility may not be a reliable indicator of toxicity level (e.g., some less opaque smoke can be more toxic than visibly thicker smoke) [51]. Whether knowledge of this link affected the level of variability in threshold for the thinner smoke condition should be investigated in future research.

Similar to PASS actions, the present study indicates that attention to fire characteristics should be included in extinguisher training. The variability in extinguisher threshold with smoke opacity is in alignment with residential fire casualty rates. Existing guidance from the NFPA emphasizes that the primary goal of occupants during fire emergencies is to evacuate the home safely [52]. However, casualty statistics indicate that a common source of occupant injuries during a fire is from engaging with the fire [16]. To address

this, fire extinguisher training and safety materials could include additional emphasis on attending to situational factors, such as the toxicity of smoke. Doing so could lead to greater consistency in a lower threshold, with more individuals judging that a fire poses too high a risk to use an extinguisher. Including additional guidance to consider fire characteristics, along with PASS actions, could improve the effective use of fire extinguishers in homes and reduce casualty rates.

4.3. Future Directions and Limitations

Two limitations of the present research were the use of video-only cues and hypothetical scenarios. The method of presenting videos of simulated fires was selected to allow for a larger sample of participants to be studied and to address human subjects ethics concerns, as compared to real, multisensory fires. However, prior research has used in-person burners with a fire extinguisher to simulate a real fire [12]. Adapting such an approach to allow for fire cues to be manipulated could enable multisensory experiments to test the transfer of the effects observed in the present study to realistic environments.

During scenario-based studies, whether using videos or real fires with extinguishers, the hypothetical bias is present. The hypothetical bias refers to differences in behavior when an individual is faced with real versus imaginary outcomes [53]. In short, participants in ethics-board approved research believe that they will not be harmed beyond what is described in the consent form. As applied to human behavior in fire research, the behaviors observed when participants are aware they will not encounter a real risk of harm (whether using videos or in-person methods) may not align with the behaviors of occupants facing a real threat of harm. Based on risk taking research, individuals tend to take higher risk when they are presented with a hypothetical scenario (e.g., risk losing hypothetical money) compared to a real scenario (e.g., risk of losing real money) [54]. Beyond behavioral measures, cognitive neuroscience research has compared brain activity during decision-making that involves real and hypothetical outcomes. Studies tend to observe substantial overlap in the network of brain regions involved, with differences in the intensity of brain activity between real and hypothetical outcomes (e.g., imagined versus monetary reward) [53]. In the present study, this could have manifested as the fire extinguisher threshold being higher compared to a real situation with a real fire real risk of harm. To address this, corroborating evidence could be gathered from post incident interviews where fire extinguishers were present in the structure. In doing so, occupants could be asked to recall specific information about different fire characteristics and their decision of whether to use the extinguisher. This could allow for comparisons to be made with observations from hypothetical scenario research regarding what fire characteristics were attended to.

A challenge that emerged in the present study was that a subset of participants exceeded the available intensities when judging that the extinguisher could be used. Upon closer inspection, the number of participants doing so did not significantly vary by smoke and growth rate conditions. This suggests that future research should include a range of larger intensities, continuing up to flash over. The hypothetical bias may have also contributed to this pattern of performance: individuals displayed higher risk taking due to it being a hypothetical scenario. Future studies could use a financial incentive and penalty component to link a tangible, real risk to judgments made during the task. For example, participants could be awarded a bonus incentive for extinguisher decisions that align with safety guidelines and remove the bonus incentive for decisions that do not align with safety guidelines. Taking these approaches may address the hypothetical bias and improve the threshold measure in capturing extinguisher use judgments across a range of individuals.

Future research can examine how the timing of decision-making and actions involved in using a fire extinguisher are affected by fire characteristics. The approach of the present study was to have participants view a sequence of videos, responding until they judged they should no longer attempt to use a fire extinguisher. Although a strength of this approach was to be able to identify the extinguisher threshold, the procedure did not allow for capturing the timing of these decisions. In addition, the presentation of multiple video clips may have yielded carry-over effects, with prior judgments influencing subsequent judgments. Prior research investigating PASS actions with fire extinguishers have presented individuals with a single fire episode to examine action-sequence timing [55]. Similarly, studies have also used immersive virtual reality to examine the timing of protective actions during fire incidents by presenting a single fire incident to participants [3]. Subsequent studies can take a similar approach to examining the impact of fire characteristics on extinguisher usage: presenting participants with a single fire episode to record the timing of responses and manipulating characteristics across participants. Furthermore, similar to prior research that has used FDS simulations to reconstruct building fires (e.g., [56]), future studies could simulate real fire incidents, particularly those where occupants attempted to use an extinguisher, to provide a real-world analog for examining decision-making. The observed extinguisher thresholds in the present study can inform the selection of HRR values in future research. Values of HRR close to extinguisher thresholds would be most likely to yield different responses across individuals. By using a between-subjects design informed by the present study, the impact of fire characteristics on the timing of the decision to attempt to use an extinguisher can be investigated.

5. Conclusions

In the present study, individuals attended to certain fire cues when deciding whether to use a fire extinguisher during a scenario. The results indicated that flame size and smoke thickness influenced an individual's decision to engage with a fire using an extinguisher. However, contrary to our hypothesis, growth rate did not have a significant impact on this decision. Additionally, substantial individual differences were observed suggesting that the way in which fire cues impact the decision to use extinguishers varies across people. These findings fill a gap in human behavior in fire research by providing empirical evidence of a connection between fire cues and fire extinguisher use. The study highlights that fire extinguisher training should include fire characteristics (such as smoke thickness and flame size) when instructing when it is appropriate to engage with a fire.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/fire8100386/s1>, Figure S1: Scatterplots and lines of best fit for age (in years) and extinguisher thresholds (left) and risk ratings (right); Figure S2: Boxplots of extinguisher thresholds (left) and risk ratings (right) by fire extinguisher experience (horizontal line = median; diamond = mean); Figure S3: Boxplots of extinguisher thresholds (left) and risk ratings (right) by biological sex (horizontal line = median; diamond = mean). Refs. [4,6,29] are cited in Supplementary Materials.

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Abbreviations

The following abbreviations are used in this manuscript:

NFPA	National Fire Protection Association
UL	Underwriter Laboratories
HRR	Heat release rate
SD	Standard deviation
PADM	Protective action decision model

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