Assessing Decision Making under Stress Using Virtual Reality Environments

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ABSTRACT

Making quality decisions under stress is a critical Warfighter attribute. Enhancing decision making skills requires two elements: (1) assessing decision making quality and (2) facilitating effective decision making training. Current methods for assessing decision making in real-life settings are based on retrospective process tracing; however, this method often yields unreliable data due to memory distortion, biased interpretation, and inability to recall facts that were not encoded in long-term memory (Reidi, Brandstatter & Roithmayr, 2008). Current training modes typically focus on covering gaps in states of knowledge rather than on the more appropriate cognitive skills (Klein & Baxter, 2009). Thus, developing effective training for decision making is hampered by a number of limitations.

Ideally, assessments of decision making quality would be made in real-time and *in situ*. Training would be done similarly but using computer automated After-Action Review programs that capture and then replay the decision process *in situ* for facilitating the desired cognitive changes.

The purpose of this investigation was to assess the effectiveness of a simulation engine created to test decision-making skills in naturalistic, virtual environments. For this experiment, novice (n=23) and veteran (n=39) firefighters were exposed to two stressful “real-world” virtual simulations (Difficult Tradeoffs, High Time Pressure) while decision-making strategies, physiological responses, and situation awareness via cue recognition were assessed. The results suggest that experience does not immunize from making suboptimal decisions. Analysis of the distribution of decision making strategies suggests that the Recognition-Primed Decision model (Klein, 1998) is employed often when Time Pressure is the stressor; it is not as prevalent when the stressor is Tradeoffs. Physiological responses suggest that veteran firefighters have greater autonomic arousal than novices under similar situations. Post-simulation feedback indicates a high level of immersion and training usefulness.

These results support the effectiveness of the developed simulation engine to assess decision making quality in real-time and *in situ* albeit using virtual reality. Therefore, this framework has promise for use in warfighting.

ABOUT THE AUTHORS

Nir Keren is an associate professor of occupational safety in the Department of Agricultural and Biosystems Engineering and a graduate faculty member in the Human Computer Interaction (HCI) program at Iowa State University. His research interest is in developing Naturalistic Decision Making models. For his research, he develops simulation engines that utilize virtual reality environments to test decision making under stress in extreme occupations such as Warfighters, law enforcement officers, and firefighters.

Warren Franke is a professor of exercise physiology in the Department of Kinesiology and a graduate faculty member in HCI. His research interests center around cardiovascular health in emergency responders. For the line of research reported here, he is responsible for assessing the physiological responses to the stressful situations.

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BACKGROUND

Schools of Thoughts in Decision Making Research

Classic theories of choice emphasize decision making as a rational choice process. The classic model for making decisions among sets of alternatives that vary on several dimensions is the Multiattribute Utility Theory (MAUT; Dillon, 1998). MAUT proposes that a decision maker identifies a set of alternatives and a set of decision dimensions, assigns a weight to each of the decision dimensions, calculates the utility of each alternative on each dimension, and eventually selects the alternative with the highest overall utility.

A Heuristic and Biases (HB) discipline of decision making later evolved and demonstrated that MAUT as well as other classical decision theories are not good descriptions of how decisions are actually made (e.g., Kahneman & Tversky, 1979). Rather, a distinction must be made between *normative* and *descriptive* theories; i.e., how decisions ideally should be made given unlimited resources versus how decisions actually *are* made (Dillon, 1998). Although extensive research has been performed assessing descriptive theories of choice, much of this research used abstract decisions that bear little resemblance to the naturalistic decisions actually encountered by decision makers. Unfortunately, a sacrifice of realism in research laboratories has often been necessary to gain the experimental control needed to test psychological theories adequately.

The tension between the need to control the research environment and the need to understand how decisions are made in ecologically valid environments led to the development of the Naturalistic Decision Making (NDM) (Klein, Orasanu, Calderwood, & Zsambok, 1993) community. While members of the NDM community agree that making quality decisions is an important attribute in everyday business operations, their main focus is with making quality decisions as a critical attribute in mission driven occupations. These types of operations, where recurring high-risk, time-critical functions, ill-defined goals and extreme environments are the nature of the operations, are typical of Warfighters, law enforcement officers, firefighters, and other emergency responders. For such operations, research in laboratory settings does not provide the appropriate ecological validity; thus, NDM research is conducted in real-life situations.

To conduct NDM research, methods such as cognitive task analyses and field observations are typically utilized in order to understand the complexity of making decisions in these extreme environments. Using cognitive task analysis techniques to trace decision making processes requires conducting retrospective decision interviews. While these field observation techniques have generated a wealth of knowledge, they are not ideal since retrospective interviews often yield unreliable data due to memory distortion, biased interpretation, and an inability to recall facts that were not encoded in long-term memory (Reidi et al., 2008). Furthermore, they are limited in the type of data that can be collected.

To maximize the utility of NDM research, what is needed is an NDM methodology that allows for real-time assessment of “real life” decision making. Ideally, this methodology would include an after-action review process that remains faithful to the “real life” scenario. A highly immersive virtual environment with a proper mechanism for collecting decision making data could bridge the gap between the need to have well-controlled experimental settings with ecological valid decision environment.

Simulated Immersive Environments for Decision Making Training and Research

The growing interest in identifying effective methods to research and train in decision making led to the development of several immersive simulators. The Decision Theater at Arizona State University was established for enhanced visualizations to enable policy makers to make informed decisions regarding to aspects of urban growth, public health, etc. (Edsall & Larson, 2006). The Jet Propulsion Laboratory at Caltech used immersive environments to assist space mission operators in making mission planning more intuitive (Wright, Hartman, & Cooper, 1998). Immersive environments were also used for examining effectiveness of feedback providing expert system to support decision making quality in ship damage control (Sniezek, Wilkins, & Wadlington, 2001).

In their review, Patterson, Pierce, Bell, Andrews, and Winterbottom (2009) shed light on the applicability of synthetic environments for training and research in decision making. Patterson et al. indicated that the potential of synthetic immersive environments for enhancing decision making skills will be more completely realized when designs of these synthetic environments address cognitive and mental limitations effectively. For example, Flame-Sim (www.flamesim.com, 2013) is a visually appealing 2-D simulator that provides virtual environments for training tactical responses in firefighting. At the conclusion of the simulation, the system presents a list of the actions required for the scenario against a list of the actions taken. Unfortunately, the system is not designed to identify the cognitive state of the decision makers and the psychophysiological aspects of the response. The resultant output from Flame-Sim has the form of 'you did X but you did not do Y' (prescriptive decision making). While this has merit, it is limited since the output does not provide indication as to why 'Y' was not pursued – a critical component in understanding the constraints of the decision maker in the decision environment.

In their concluding remarks, Patterson et al. (2009) wrote:

> *…immersive environments can be structured to promote robust decision making in situations involving data overload, time pressure, high risks and high stakes, and ill-defined or multiple goals, if (a) intuitive (pattern-based) reasoning is optimized by structuring the immersive environment so as to present the relevant perceptual and cognitive cues that simulate the actual scenarios found in real world, and (b) sufficient training is given.* (*p.* 354)

Klein and Baxter (2009) discussed the complexity of improving decision making skills further. They suggested that improving decision making skills is not a process that can be effectively gained through the traditional learning process where the bridge between the current and desired knowledge states is pursued with simple 'diagnosis-practice feedback' procedures. Cognitive skills depend highly on mental models which are established based on previous experiences, biases, and beliefs. Therefore, training to improve cognitive skills should include a process of unlearning so the decision maker-in-training can abandon a current, but inappropriate, mental model and replace it with a new, more suitable model. Klein and Baxter proposed the Cognitive Transformation Theory (CTT) to facilitate the transformation of states of mental models through shedding outmoded sets of beliefs, unlearning habits and behaviors, adopting new set of beliefs, and creating better mental models (2009).

Psychophysiology of Decision Making under Stress

Salas, Driskell, and Hughs (1996) adopted the following definition of stress:

> "*Stress is a process by which certain work demands evoke an appraisal process in which perceived demands exceed resources and result in undesirable physiological, emotional, cognitive and social changes*" (p. 6).

Seyle (1976) argues that there are two differentiating forms of stress: negative stress (distress) and positive stress (eustress), both resulting in significant physiological responses. Blascovich and Tomaka (1996) presented a similar framework that differentiates challenge-related stress from threat-related stress states: challenge-related stress is a state where the decision makers perceive they have the cognitive capacity to deal with the situation, whereas in a threat-related state, they do not (Frankenhaeuser, 1986; Henry, 1980). Mendes, Blascovich, Hunter, Lickel, and Jost (2007) suggested that these two stress states have different cardiovascular signatures. Challenge-related stress results in an increased cardiac output and a reduction in the total peripheral resistance to allow increased blood volume to the periphery and increased blood flow to the brain and muscles. In contrast, a threat state presents a cardiovascular profile with reduced efficiency and increased vasculature resistance. Kassam, Koslov, and Mendes (2009) assigned participants to social feedback conditions designed to engender challenge and threat states, and showed that participants in the challenge group adjusted cognitively better than those in the threat group, with this effect mediated by cardiovascular reactivity. Their work demonstrates the importance of considering profiles of cardiovascular reactivity when examining the influence of stress, emotion, and motivation on decision-making.

The importance of assessing the psychophysiology of decision making in real-life simulations is twofold. First, NDM falls under the *descriptive* decision-making school of thought. Thus, physiological responses may provide indications of cognitive states, mental workload, arousal, etc. Second, next generation simulators may include adaptive systems that can identify participant cognitive state and workload and adapt the level of challenge of the training scenario to the participant skills level (Feigh, Dorneich, & Hays, 2012). For example, Fiedler (1992) assessed captains and lieutenants among urban firefighters and found that the performance of seasoned officers actually improved under the stress of a fire while the performance of less-prepared officers declined. The adverse effects of under-preparation on decision-making become most pronounced under acute stress. Consequently, a training simulator with adaptive characteristics could potentially provide more efficient remedy for under-preparation since it would adapt the challenge of the simulation to the skill set of the trainee and, over time, become more like real-life situations.

Desired Attributes of an Immersive Simulator for Decision Making Training

Critical attributes of naturalistic decision making need to be heavily considered when designing synthetic simulated frameworks for effective training for mission driven occupations such as those mentioned earlier. Table 1 presents a translation of these attributes to technological features needed in synthetic frameworks to facilitate effective decision making training:

Table 1. Attributes vs. simulation framework feature

Attributes	Features of synthetic simulated frameworks
Ecologically valid environment	Immersive synthetic environment (preferably 3-D): • Real-life like experience • Naturalistic operational functions (e.g., use controls that are as true as possible to the decision environment by avoiding use of game pads)
Capture cognitive-rich process data	Implementation of decision process tracing – preferably mid-simulation (e.g., avoid memory distortion and memory loss due to information that was not encoded into long term memory)
Development of pattern recognition skills to enhance intuitive responses	Repeated exposure in naturalistic environment, yet maintaining a controlled setting
Identification of psychophysiological constraints	Assess psychophysiological responses in real-time: • Collect physiological responses • Implement post-experiment data analysis • Present decision portraits that can be contrasted with physiological constraints for psychophysiological mapping
Facilitate transformative cognitive learning	After Action Review protocol(s)

SIMULATOR FOR DECISION MAKING UNDER STRESS AT IOWA STATE UNIVERSITY

Infrastructure

A simulation engine, VirtuTrace, was created which utilizes the features described in Table 1 for training and experimental research using naturalistic decision-making. The engine utilizes the C6, a virtual reality environment consisting of a 10’x10’x10’ room where all six walls are projection screens, housed at the Virtual Reality Application Center at Iowa State University (ISU). The C6 has screen resolutions that approach the limits of human vision, a three-dimensional eight-channel surround sound system and a motion-based navigation system that allows people to “move” around in the created virtual worlds. Thus, extremely high levels of immersion can be created. Because of these technological capabilities, the C6 allows for the development of realistic occupationally-specific environments for emergency responders to interact with. VirtuTrace combines the human-computer interaction capabilities of the C6 with decision process tracing technology to create ecologically valid simulated environments that implement the features in Table 1.

Facilitating Decision Process Tracing

Decision process tracing is facilitated through projection of a decision matrix that the participants can recall and interact with during their “journey” in the virtual environment (Figure 1). The tracking system of the C6 determines the orientation of the participant’s head, and upon clicking a button on a hand-held wand, displays the decision matrix as a transparent floating window on top of the simulation. This matrix is projected in front of the participants and moves with them as they move in the virtual scene.

The decision matrix is an interactive table where the top row lists the decision choices, or alternatives, available and the left column presents relevant decision dimensions. Information “bins” are at the intersections between alternatives and dimensions, allowing for an evaluation of the implications of a specific alternative on a specific dimension. Process tracing is facilitated by collecting information on (a) the sequence in which participants acquire information, (b) the number of items that participants view for every alternative along each dimension, (c) the amount of time that elapses from the time participants begin the task until they make their choice, (d) when and how long information rubrics have been reviewed, and (e) their final choice. VirtuTrace includes a post- session analyzer with "decision portraits" of the subjects. The portrait includes calculated information search indices for the decision process dimensions described (Keren, Mills, Freeman, & Shelley, 2009), the amount of information reviewed, time data, and cognitive maps that are used to identify decision strategies.

For example, in one of the training scenarios used in the experiments described here, each study participant is in a virtual car dealership and is asked to choose a preferred car from four models available in the scene (i.e., the decision alternative). Decision dimensions include gas mileage, insurance costs, safety, and maintenance costs. Figure 1 shows a subject participating in this training scenario with the decision matrix visible. The red dot on the matrix is following the line of sight of the participant. To acquire information, the participant looks at the rubric that presents the intersection between the alternative and dimension of interest. Upon clicking on the button on the wand once again, the participant will hear a virtual salesman providing them with the information. In Figure 1, the subject is seeking information on the gas mileage (the dimension) of the green car (the alternative). Upon pushing the button, the participant will hear the salesperson state that "*This car gets 25 miles per gallon.*" The participants can move around the car showroom, interact with the environment and the matrix, and when ready to make a decision, indicate their choice by clicking on a circle at the bottom of the matrix below their preferred car model.

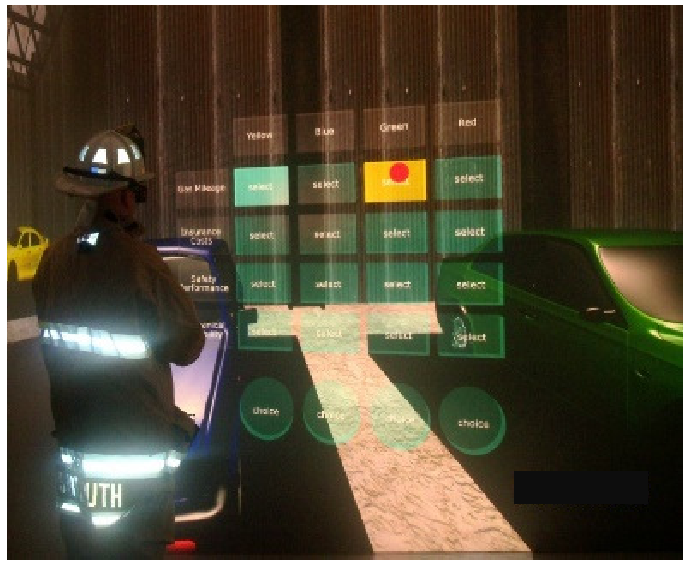

Figure 1. Participant in a training scenario

It is important to note that participants do not need to acquire information from the matrix to make a decision. Should the participants immediately decide what the best decision is, they only need to call up the matrix and make a decision choice.

Physiological Responses

VirtuTrace includes algorithms that collect data from a variety of physiological sensors. These sensors include non-invasive blood pressure, heart rate, ECG, cardiac output, respiration rate, and galvanic skin response. The data are integrated with a property map that includes all data generated in the simulation (scene, tracking data, user interaction with the environment, user interaction with the matrix, and physiological responses). This property map is then used to populate the After-Action Review program with the relevant data.

After-Action Review

The *Leader's Guide to After-Action Review* standard of the Headquarters Department of Army (1993) defines After-Action Review (AAR) as:

> *An after-action review (AAR) is a professional discussion of an event, focused on performance standards, that enables soldiers to discover for themselves what happened, why it happened, and how to sustain strengths and improve on weaknesses. It is a tool leaders and units can use to get maximum benefit from every mission or task…*
>
> *Of course, AARs are not cure-alls for unit-training problems. Leaders must still make on the-spot corrections and take responsibility for training their soldiers and units. (p. 1)*

The AAR is a process used to capture successes and failures during simulations, training, and operations. During AAR sessions, the participants have the opportunity to reflect on their actions – usually with an experienced team member – reassess their responses, and identify lessons learned that then can be used to enhance future performance.

To pursue the 'transformative cognitive learning' attribute described in Table 1, the research team developed VT-Review, or the AAR component of VirtuTrace. To maximize the learning experience, VT-Review allows for the participant's session (including all interactions) in the virtual scene to be played forward and backward in a user-selected variable speed. The facilitator can use bookmarks during the training/experiment session and, during AAR, 'teleport' to these bookmarks at any time. When running VT-Review, an avatar is used to indicate the participant's location and actions in the scenario. A virtual 'laser beam' is presented to indicate the direction of the participant's gaze. The AAR facilitator can experience the journey in several modes: (1) ride along with the avatar, (2) travel in the scene independent of the avatar's motion, or (3) review the scenario from a birds-eye view. Finally, the facilitator can recall graphs of the participant's real-time physiological responses, thereby gaining insight into the participant's stress level and potentially explain behavior anomalies. Figure 2 illustrates an AAR session with VT-Review.

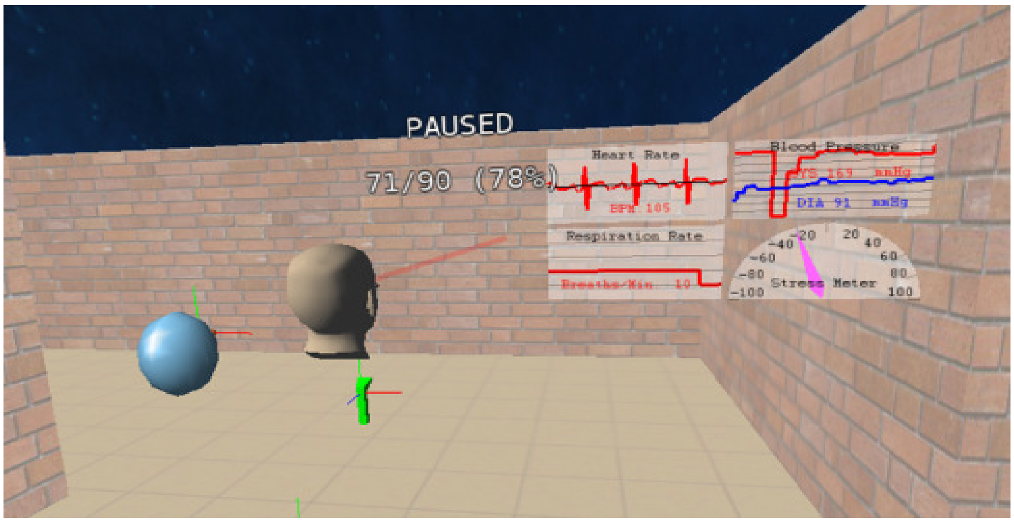

Figure 2. VT-Review

EXPERIMENTS ASSESSING THE UTILITY OF THE SIMULATION ENGINE

Overview

Because of ready access to a pool of firefighters and personal expertise of a member of the research team, the first assessment of the VirtuTrace simulation engine was with firefighters. This application, or Simulator for Enhancing Emergency Response (SEER), consisted of three scenarios to teach firefighters how to use the simulation engine and decision matrix followed by two fireground scenarios to assess decision making under stress. A video clip of SEER for firefighters is available at http://youtu.be/37ehMpyIKWY (2011). When on the fireground, firefighters are in frequent radio contact with their superiors, peers and subordinates in order to gather information that they cannot get themselves. Consequently, to further enhance realism in the firefighting scenarios, analogous to the car dealership scenario, information provided in the decision matrix came in the form of "radio communication."

Theoretical Background for Firefighters' Decision Making

Firefighting is a hazardous occupation. The magnitude of losses due to fires and responding to fire calls is significant. For example, about 100 firefighters are killed each year and 30,000 are injured while on duty; over 3,000 people die in fires and property losses due to fire exceed $11 billion (Cote, 2004; p 62). Even with significant safety improvements in equipment, clothing, and protocol—recognized and supported by fire personnel—firefighter death and injury statistics continue to remain largely unchanged (Paulson, 2008). Sub-optimal decision-making, exacerbated by job-related stress, is potentially a major contributor to the losses, as epitomized by the 2007 Charleston fire of a commercial showroom, in which nine firefighters died as a result of a series of poor decisions (NIOSH, 2009).

The most-cited descriptive model of choice for high-stress time-critical decisions, such as those made by fireground and military commanders, is the Recognition-Primed Decision (RPD) Model. RPD was introduced by Klein (1989) as a descriptive model of decision making in naturalistic settings. RPD proposes that experienced decision makers employ a *singular evaluation strategy*. In singular evaluation, the decision maker considers only a single possibility and then acts on it, rather than comparing two or more alternatives as proposed by classic decision theories. In the RPD model, the decision maker first examines the situation for identifying cues and immediately thinks of a possible action. The action is evaluated by running a *mental simulation*. The decision maker modifies the action based on the results of the simulation, and then implements the action if the results seem acceptable.

Klein (1998) suggested that experienced decision makers typically do not evaluate other alternatives, because their first impulse is usually an appropriate response to the situation. Klein argues further that explicitly comparing alternatives is done primarily in unfamiliar situations that cannot be assigned to a prototype, either because the situation is sufficiently novel or because the decision maker is inexperienced (1998). Klein also suggests that these decisions are often inferior to those made by experienced decision makers using a singular evaluation strategy.

Klein, Calderwood, and Zsambok (2010) interviewed 26 experienced fireground commanders where they reviewed 156 decision points and concluded that ". . . *In less than 12% of them was there any evidence of simultaneous comparisons and relative evaluation of two or more options"* (p. 186). RPD was established with retrospective interviews to facilitate process tracing. As mentioned earlier, retrospective methods are limited in the data that can be collected due to the nature of the protocol. Data reliability is a concern as well (Reidi, Brandstatter & Roithmayr, 2008).

To shed more light on the decision making processes of fireground commanders, the research team utilized the SEER application of VirtuTrace with 62 career firefighters of varying levels of experience.

Experimental Design

This project aimed at examining firefighters' decision-making under two types of stressors often seen on the fireground: Difficult Tradeoffs and High Time Pressure. Pre-backdraft was used as the scenario for facilitating the Difficult Tradeoffs stressor. In pre-backdraft, the entire contents of the house are consumed by the fire and the house is filled with hot-highly flammable gasses that are oxygen starved. Although a challenging situation, pre-backdraft is a static situation in which scenario conditions do not change until an action is taken or an explosion occurs. In this scenario, the firefighter approached a virtual house with varying cues of pre-backdraft conditions such as windows that are coated on the inside with a black film from smoke particles, a red glowing door knob, smoke pushing from windows and doors cracks, and the absence of flames (Figure 3). Firefighters are very well trained to identify pre-backdraft conditions based on these cues. To alter the stressfulness of the Difficult Tradeoffs scenario, cues associated with the presence of victims in the house were used to suggest that the likelihood of the house being occupied was either low (low Difficult Tradeoffs, Figure 3) or high (high Difficult Tradeoffs). Here, the Tradeoff centered around weighing the risk of exposing firefighters to the risk of injury vs. rescuing victims.

Figure 3. Difficult Tradeoff (Pre-backdraft)

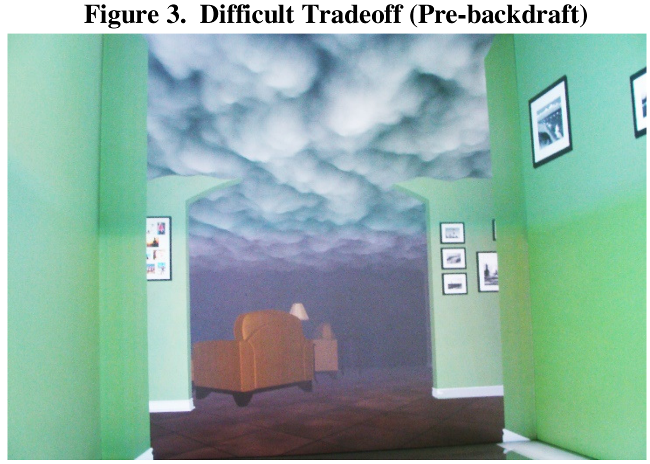

Figure 4. Time Pressure (Pre-flashover)

Pre-flashover is a situation where the gases accumulated due to the fire can instantaneously explode. Thus, pre-flashover is an often lethal situation for firefighters and because it is dynamic, the most appropriate decision choice changes as the situation evolves. Thus, a pre-flashover scene was used for the Time Pressure stressor. In this scene, the firefighters were located in the house and smoke was accumulating downward from the ceiling (Figure 4). Cues, such as changes in the smoke patterns provided indications as to how imminent the flashover was likely to occur (i.e., low Time Pressure vs. high Time Pressure). The Time Pressure stress centered around gauging how much time was available to make a decision before the potentially lethal flashover occurred.

Prior to participation in the experiments, the firefighters provided written informed consent and were subsequently instrumented for the assessment of heart rate (HR, ECG) and beat-by-beat noninvasive blood pressure. After approximately 15 minutes of quiet seated rest, each firefighter underwent three training scenarios.

The first scenario incorporated a maze where the firefighters practiced moving, or navigating, in the virtual environment. Then, the firefighters went through a car dealership scene to learn how to the use the decision matrix in a naturalistic scene (Figure 1). The final training scenario was similar but used bicycle models instead of cars. The firefighters were accompanied by one of the research team during these scenes. At the end of the bicycle scenario, the member of the research team verified that the firefighters did not suffer from simulation sickness and that they completely understood how to operate and interact with the decision matrix and the virtual environment. The research team member then exited the C6. The firefighters (one at a time) were left alone in the virtual world, the door of the C6 closed, and the fireground simulations began. At the end of the simulations, each firefighter was asked to complete a demographic and post-experiment data collection. Informal assessments of the immersiveness and appropriateness of the scenarios were also performed.

RESULTS AND IMPLICATIONS

The Effects of Stress on Decision-Making in Similarly Experienced Firefighters

Analyses of individual psychophysiological responses for the firefighters suggested that occupational experience did not necessarily immunize firefighters from the effects of stress. To illustrate this finding, Figures 5 and 6 present the physiological responses [i.e., heart rate, blood pressure, and heart rate variability (LF/HF ratio)] of two veteran fire department chiefs. Both chiefs had more than 25 years of experience in very active fire departments and both routinely had fireground command responsibilities with the associated decision-making responsibilities.

Their similar professional profiles suggested that they would respond similarly to the Tradeoff and Time Pressure scenarios. Their physiological responses to the fireground stressors and their decision-making portraits were on opposite ends of the response spectra. One fire chief was found to be a "high reactor" to stress while the other was a "low reactor."

Figure 5 shows the physiological responses of the high reactor chief. At the end of the Tradeoff scenario, this chief's physiological response was the typical response to a threat-related stress (Kassam et al., 2009). In contrast, the blood pressure, heart rate, and heart rate variability responses of the low reactor chief hardly fluctuated as he experienced the training, Tradeoff and Time Pressure scenarios (Figure 6).

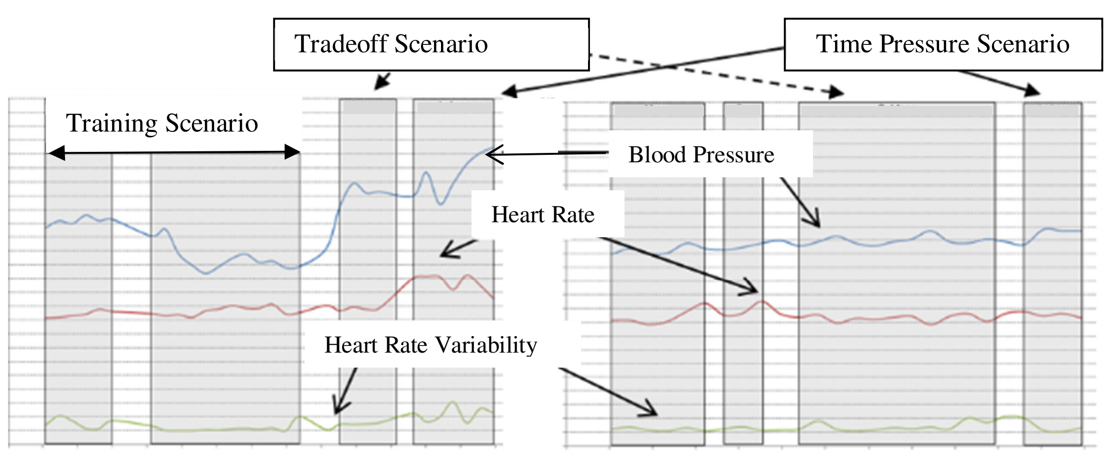

Figure 5: Cardiovascular profile of a high reactor **Figure 6: Cardiovascular profile of a low reactor**

The post-session analyzer created a *decision portrait* for each fire chief (Figures 7 and 8). The portraits present information processing sequences, the information reviewed, the order in which this information was reviewed, and the final decision made by the subject. Figure 7 is the decision portrait of the high reactor. He repeatedly reviewed information and had a difficult time deciding how to make a decision. Finally, he made a decision that, if acted on at a real fireground, would have resulted in a major explosion and almost certainly injuries. In contrast, the decision making portrait of the low reacting chief suggests a decision strategy that is consistent with the *singular evaluation* strategy of RPD (Klein, 1998). After reviewing the cues in the environment, the chief identified the scenario as a pre-backdraft situation, reviewed one information bin, and selected a line of action that was appropriate for the scenario.

	Attack through main door	*Horizont. ventilate through a window*	*Ventilate through the roof*	*Ventilate from ladder truck*
Risk/ Benefits	1 (565.9)	2 (595.7)	3 (607.8)	4 (615.3)
Size-up factors	5 (621.6)	6 (632.1)	7 (641.2)	8 (650.0)
Type of structure	9 (658.2)	10 (671.0)	11 (690.7)	12 (688.3)
Avail. resources	13 17 (701.1)(743.3)	14 (709.2)	15 (717.9)	16 (725.4)

Fig. 7: Decision making process of the high reactor

	Attack through main door	*Horizont. ventilate through a window*	*Ventilate through the roof*	*Ventilate from ladder truck*
Risk/ Benefits				
Size-up factors				
Type of structure	1 (500.7)			
Avail. resources				

Fig. 8: Decision making process of the low reactor

Comparison of Stress Responses between Novice and Veteran Firefighters

This study also compared group, or mean, responses between the 23 novice and 39 veteran firefighters to determine the extent to which experience affected the responses to the occupationally-specific stressors. Ten years was identified as the cutoff experience level to distinguish between novices and veterans (Bayouth, Keren, Franke, & Godby, 2013). For the cohort of 62 firefighters, robust increases in heart rate (46 ± 39 bpm above resting, mean ± SD), systolic blood pressure (26 ± 23 mmHg; $p<0.001$), and a marker of sympathetic arousal (16 ± 31 fold increase in LF/HF ratio; $p<0.002$) were seen. Moreover, the blood pressure and sympathetic arousal responses were higher in the Time Pressure than in the Tradeoff scenario ($p=0.000$ and $p=0.002$, respectively). Effect sizes were moderate-to-large for these responses (.75, .58, respectively, Cohen's *d*) but absent (.08) for heart rate suggesting that sympathetic arousal affects cardiovascular responses to stress differently based on the nature of the stress**.**

In comparing differences in responses between novice and veteran firefighters, the Time Pressure scenario yielded no significant differences in either systolic blood pressure (t=.64, $p=.2624$) or heart rate (t=.65, $p=.2603$), suggesting that all firefighters recognize the dangerousness of this situation. However, veterans demonstrated more threat-related stress responses than novices in the Tradeoff scenario; normalized blood pressure was significantly higher in the veterans (t=2.18, $p=.0334$), while changes in normalized heart rate was not significantly different (t=.59, $p=.5542$).

The non-significant difference in the cardiovascular responses between the two groups in the Time Pressure scenes may be due to firefighters of all experience levels being able to recognize the cues of a flashover situation. This potentially lethal situation is commonly recognized as such. This is in contrast to the Tradeoff scenario. The different response profiles suggest that, potentially, the novices did not fully grasp the gravity of the Tradeoff scenario while the veterans did. The veterans are also more likely to devote the mental resources needed to monitor changes in smoke color and behavior in order to identify any escalation to a full backdraft scenario – thus, the increase in threat-related stress.

Assessing Decisions Strategies – RPD as a Strategy of Choice

Analyses of the decision portraits of each firefighter enabled determining the decision strategies used in each of the scenarios. Figure 9 presents the frequency distribution of the "simple version of RPD" (see Klein, 1998, p. 34) as the strategy used en-route to making a decision.

The simple version of RPD was not used frequently in the Tradeoff scenario. It was used considerably more in the Time Pressure scenario and especially so when there was high Time Pressure. These results are consistent with Klein's assertion that this strategy will be more prevalent when time constraints are around one minute. On the other hand, our data do not support the finding that RPD was used in at least 88% of the decision cases that were examined (Klein, 2010). It is important to note here that differences in methodologies may underlie these disparate findings. Klein's findings are largely based on both retrospective and field interviews. Our results are based on mid-simulation assessments of decision strategies where four alternative lines of actions were presented to the subjects. The visibility of other lines of action may promote consideration of different strategies that otherwise would not have been consciously considered.

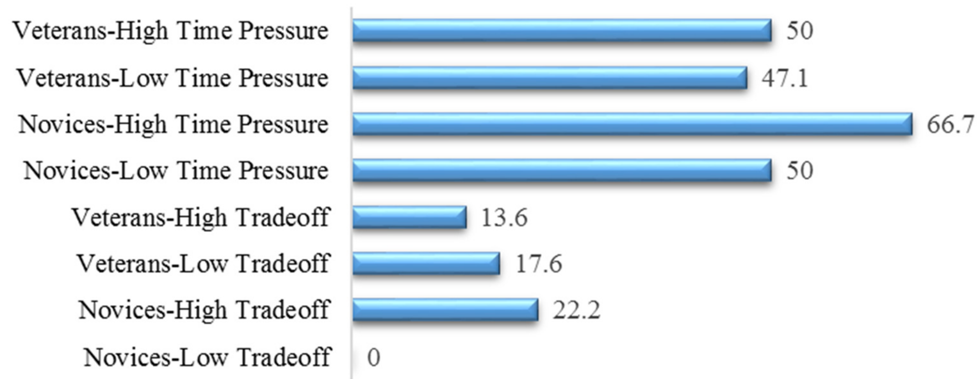

Figure 9. Distribution of RPD (%) as strategy of choice in the fireground scenarios

SUMMARY

The results of the present study support the utility of using virtual reality environments, within an NDM framework, to assess decision making in real-time. The experiments reported here demonstrated that differences in occupational experience levels were associated with differences in decision strategies and physiological responses; yet, even in veteran firefighters, there were marked differences in both strategies and responses. Future work should continue to improve the AAR utility of these environments as well as assess their usefulness in Warfighter environments.

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