The Human Brain in Fireground decision-making: trustworthy firefighting equipment?

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Background: How the limits of the human brain might affect fireground decision-making

In July 1994, fourteen firefighters lost their lives when overcome by a wildfire that had suddenly shifted direction in the South Canyon of Storm King Mountain in Colorado. Reviews of the incident have suggested organizational lapses, but also that the incident commander made some “suboptimal” decisions (Useem, Cook and Sutton, 2005) consistent with having incomplete “Situation Awareness” or SA (perception, knowledge and prediction about the situation: Endsley, 1995; Patrick & Morgan, 2010). For example, he had apparently not requested an updated weather report that would have warned of the shift in wind conditions that ultimately led to the deaths of the firefighters. Nevertheless, analysis of the command decisions in these terms does not really explain *why* SA may have been incomplete or errors and oversights were made. The commander clearly attempted to manage the situation–for example, he had earlier requested a complete overview of the fireground and he heroically died trying to warn the firefighters trapped by the advancing firefront. Why then were fatal errors and omissions apparently made?

Aside from wider organizational issues, the answer may be found in considering the natural limits of the human brain. Even the brains of highly trained and efficient professionals have restricted capacity to deal with information, especially under such extreme demands as those in the Storm King Mountain incident. Professionals improve performance within these natural limits by using prior experience to rapidly see and act on familiar patterns in situations (“Recognition Primed Decision- making”: Klein, Calderwood, & Clinton-Sirocco, 2010) but even in skilled professionals, the basic instrument for decision-making is still the human brain which can be stretched to its limits in changeable and dangerous conditions such as those in the Storm King wildfire. Under such conditions, there may be log-jams in key brain channels for taking in information from the outside world, focusing on that information and keeping relevant information in mind while making decisions. Psychologists refer to these abilities respectively as perception (seeing, etc.), attention and working memory and the brain processes for these abilities have known limits on how much information they can transmit or handle at any one time. To make matters worse, anxiety or fear in dangerous and stressful situations can overload these systems to further reduce their capacities. Excessive demands on these processing channels can tax the processing abilities of even the most experienced and conscientious professionals who may then show natural tendencies to overlook key information or focus on irrelevant aspects. It would seem highly likely that the conditions on Storm King Mountain could have fostered such mental overload with tragic results. These limitations and tendencies of the human brain may be natural but can obviously have potentially serious consequences for fireground decision-making. To further understand these natural limits and tendencies, we have been conducting a programme of research with the ultimate aim of supporting safe decision-making for fire professionals.

The research programme to date has involved a series of studies of the response of Fire and Rescue (FRS) crew and commanders in fireground training situations and simulations (tabletop, BA and incident command exercises) (Sallis, Catherwood, Edgar, Medley, & Brookes, 2013; Catherwood, Sallis, Edgar, Medley, & Brookes, 2012; Catherwood, Sallis, Edgar, & Medley, 2011). Obviously these contexts cannot fully replicate actual fireground conditions, but the research has revealed patterns and tendencies with potentially serious consequences for real FRS situations. The main conclusion from these studies is that the fire personnel involved were well-trained professionals with good "Situation Awareness" (SA) or knowledge of the incident under study, but two issues were of concern. These may be linked to the limits of the human brain as described above and could explain tragic errors of decision-making such as may have occurred on Storm King Mountain.

The first issue concerns a person's SA. There are in fact *two* key aspects to SA: (i.) "*actual SA"*, the actual accuracy of the achieved SA compared to the 'ground truth' and (ii.) "*perceived SA*" , the person's awareness or impression of their SA. If these are not in unison, critical errors of judgment may arise. It may be especially risky if individuals have poor SA but are unaware of this, believing that they fully understand the situation and so do not make efforts to update or improve their faulty SA. Why might such oversights occur? One explanation is that overload on the brain's processing power may not allow an individual to register that there are gaps between actual and perceived SA with potentially risky consequences. Our research has highlighted a second aspect of decision-making that further shows how such oversights can arise.

This second issue concerns the way that people sample or select from the information available about an incident. This can be described as their "bias" and concerns how they mentally filter or scope the information on offer: whether they apply a narrow scope/fine filter or instead a broad scope/coarse filter. This is revealed in our research by the type of errors people made. The personnel in our studies made few errors but when errors *were* made, some people were more likely to make “miss” errors (overlooking key information) and others “false alarm” errors (treating information as true or useful even when not).

These bias and error tendencies are undoubtedly linked to the natural limits of the human brain for handling information. Our finite brain capacity can either be (a.) concentrated on a part of the available information but at cost of missing other key aspects (conservative bias) or (b.) spread over a wider breadth of information but more thinly or shallowly, so it is difficult to decide what is “good” information, with “false alarm” errors likely (liberal bias). The omission of the Storm King commander to obtain the crucial weather report may be understandable in these terms. The situation is likely to have imposed a heavy load on brain resources, possibly causing a focus for selected aspects of the situation (e.g., cutting a fire-break on the mountain side) but at cost of making the “miss” error about the weather report.

Neither a conservative or liberal bias is necessarily “right” or “wrong”: a narrow focus may be best for some phases of an incident and a wider focus for others and people may move between these at different times in an incident. Nevertheless an inappropriate bias may increase the risk of error and it seems important to further understand bias tendencies. Our research shows that for any incident, individuals show a *general tendency* towards one type of bias *or* the other. The next question of interest is whether a person’s bias remains the same type across different incidents or situations. It may be that there is a “resting bias” perhaps due to inborn personality traits or life experiences - or otherwise individual bias patterns might vary with the circumstances: for example, a FRS commander may show a cautious pattern if there is high risk of injury to self or others but be more liberal when low-value property is at risk. Our research study described here explored these issues of actual versus perceived SA and the associated Bias patterns of operational FRS crew and commanders in two tabletop exercises.

Method

The Participants in both exercises were 20 operational UK firefighters and commanders (including both full-time and retained/part-time personnel) aged from 19 to 53 years (mean age 38 years). All participants gave informed consent for their participation.

Two different fireground scenarios (one in a house, one in a factory) were shown as powerpoint presentations projected onto a large screen. Each scenario involved slides displaying turn-out sheets, maps, plans of the building, photos of the local area, videos of the "drive to" and conversations with "neighbours" (for the house fire) or the "foreman" (for the factory fire) and finally a series of views of the fireground. All participants did both the House or Factory fire exercise at different sessions. At intervals the presentation was stopped and a series of true/false statements about the scenario were presented (overall, half were false and half were true with this being in random order). For each statement, participants were asked to indicate whether they believed the statement to be true or false, and to rate (on a scale of 1 (guess) to 4 (certain)) how confident they were that their answer was correct.

For the house exercise, 26 questions were asked, for example:

- *The front window was open on your arrival* T/F
- *There is a possible Explosion hazard upstairs* T/F

For the factory fire, there were 30 questions, for example:

- *Sandwich panels are a risk in these premises* T/F
- *There were cylinders outside the factory* T/F.

Each participant viewed the scenarios in a group session, but responded to the questions individually by recording answers on a response sheet. Participants were not given feedback during the exercise as to whether their responses were correct or not, but were informed of this during the de-briefing. The answers to the questions were used to calculate SA and Bias using QASA (Quantitative Analysis of Situation Awareness) based on a "signal detection" approach (Green & Swets, 1966). QASA has been used by the investigators in previous studies of fireground decision-making (for further details see Catherwood et al., 2011, 2012; Sallis et al., 2013; Edgar & Edgar, 2007). It uses the proportion of correct and incorrect responses to provide a measure of the person's actual SA (whether they could tell true from false information) and the proportion of true and false responses to provide a measure of the person's Bias (conservative or liberal). A measure of how participants perceived their own SA ("perceived SA") was also provided by calculating the average (mean score) of the "confidence ratings" the participants gave for their responses.

Results

The SA (actual SA), Bias and Confidence (perceived SA) for the House and Factory exercises were calculated for each person. QASA provides a score for SA (corrected for guessing) from +100 (perfect SA) to -100 (totally misguided and wrong SA). Bias is also scaled from +100 (very conservative bias) to -100 (very liberal bias), with zero meaning no bias either way. Confidence is also scaled from +100 (the person believes that all their answers are correct) to -100 (the person believes that all their answers are wrong).

Actual SA was high in both exercises: with a mean (average) of 69.4 for the House exercise and 66.5 for the Factory exercise. Also people perceived their SA ("perceived SA") to be at a similar level over the two exercises, meaning that if they had high confidence in their SA in one exercise they also had high confidence in the other exercise – or low confidence in one and low confidence in the other (statistical correlation across the exercises is significant: $r = .629$, $p = .003$). Of concern however is that there is no statistically significant correlation between actual SA scores and "perceived SA" scores. In other words, people may have had poor SA but perceived their SA as good or vice versa, had good SA but judged it to be poor.

The other important finding is that people showed Bias tendencies (no-one had a Bias score of zero or "no bias"). In the House exercise, 7 people had a conservative Bias and the other 13 a liberal bias, while in the Factory exercise, 8 had a conservative bias and the other 12 a liberal bias. People with a conservative bias accepted a narrower amount of information as being true but made more "miss" errors (eg., in the factory fire exercise, they may have said "False" to the true statement: *There was a cylinder next to a body,* making a "miss" error). On the other hand, people with a liberal bias accepted a broader scope of information as true, but made more "false alarm" errors (eg., they may have said "True" to the false statement: *The roller-shutter access was clear*, making a "false alarm" error). Of interest is that there was no significant correlation between the Bias scores across the two exercises, so people had a conservative bias in the house exercise and liberal in the factory exercise, or vice versa.

Conclusion: is the human brain a trustworthy firefighting tool?

The firefighters in our study had good SA overall and a level of confidence in their own SA that was consistent across situations. This perceived SA was not however strongly related to actual SA. Some of the firefighters in these exercises considered their SA to be good when in fact it was poor (and the converse). This lack of alignment between actual and perceived SA could conceivably lead to decision errors if it occurred on the fireground.

The results for the Bias scores also indicate a basis for decision error. Some people had a cautious approach to accepting information as true and others a more liberal approach. The former represents a conservative bias with a narrow focus on the incident that also produces “miss” errors, while the latter is a liberal bias with a broader but shallower processing of the information, leading to “false alarms”. People could be conservative in one exercise and liberal in the other, so bias may vary over situation or possibly over time, but any bias tendency could produce error in fireground decision-making.

The gap between actual and perceived SA along with the bias patterns allows for the *possibility* of error in decision-making that could have serious consequences in a real fireground situation. These tendencies are most likely due to processing constraints in the channels of the human brain. The brain systems of these personnel clearly provided generally good SA, but also displayed limits so that the personnel did not register the gaps between their actual and perceived SA and also showed bias and error tendencies. Of course these exercises cannot reproduce the conditions of the actual fireground. Nonetheless, if such patterns are apparent in the relatively calm environment for these simulations, they may be even more apparent under highly stressful and dangerous conditions such as those that assailed the Storm King commander in 1994. The further direction for our research is to develop guidelines that could support FRS personnel in monitoring their own SA and Bias patterns under such conditions. The human brain can be a highly effective firefighting tool, but its limitations are ignored at considerable peril.

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