

# Empathic design of tunnel rescue rooms

## Human behavior in emergency situations and design guidelines for stress relief in tunnel rescue rooms

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### ABSTRACT

Due to the critical nature of a tunnel fire, several administrative bodies connected to Norwegian tunnels have initiated a project aimed at exploring rescue rooms as an alternative self-rescuing opportunity. This literature review is based on the hypothesis that the likelihood of developing post-traumatic stress disorder (PTSD) is reduced if correct measures are taken in the design of the rescue room. Hence, this paper aims to create an understanding of aspects such as stress and coping during traumatic life events. This is further synthesized into a set of guidelines that seek to guide the designer while developing a tunnel rescue room. The goal is to help people feel safe and in control. The conclusion is five guidelines for the design of future rescue rooms: Architecture and interior architecture, information, communication, expectations, and facilitation for coping.

**KEYWORDS:** tunnel rescue room, design guidelines, emergency behavior, empathic design, stress, coping, underground spaces, fires, self-rescuing

## 1. INTRODUCTION

Between 2011 and 2017 Norway faced six tunnel fires with the potential for catastrophe (Amundsen, 2017; G. Jenssen, Roche-Cerasi, Hoem, & Grøv, 2017). In the wake of these accidents, The Accident Investigation Board of Norway, Road Inspectorate and Norwegian National Audit are asking for measures to increase safety in road tunnels through better self-rescuing opportunities (G. Jenssen et al., 2017). In collaboration with SINTEF, one of Europe's largest independent research organizations (SINTEF, n.d.), they are now exploring the design of rescue rooms for tunnels. These rescue rooms will be fire safe spaces inside the tunnel where people can evacuate and reside until rescue teams arrive. This can take up to three hours.

Victims of Norwegian tunnel fires report that they experienced major stress, discomfort, confusion, and uncertainty during the course of events (G. D. Jenssen, personal communication, 2018). Designing the rescue rooms to ensure a feeling of safety and control could be vital in order to decrease or eliminate the potential for post-traumatic stress disorder (PTSD). It is thus important to understand how factors such as stress affects the end user of a rescue room to ensure that their needs are taken care of. This kind of information will enable us to take measures that reduce or eliminate the negative and long-term consequences of experiencing tunnel fires.

Literature suggests that understanding factors such as the causes and effects of stress is key when achieving empathy with this user group (e.g. Carmody, Huet, & Sterling, 1994; LeBlanc, 2009; Ringstad, 1994; Roberts, Christopoulos,

Car, Soh, & Lu, 2016). Closely linked to stress is a person's perceived control and coping strategies during the course of events. Taking measures to reduce stress levels and enhance a feeling of control and coping is therefore an initiative for being able to design empathically for this vulnerable user group. Hence, this literature review aims to create a better understanding of how humans behave in the self-rescuing process of a tunnel fire and what they experience based on a selection of articles and reports addressing this theme.

## 2. METHODS

Today, rescue rooms for tunnels are either prohibited or uncommon. They are e.g. not permitted in Norway or in the European Union (G. Jenssen et al., 2017; Samferdselsdepartementet, 2007). Consequently, there is a lack of insight on human experiences with such rooms. Therefore, this literature review primarily includes papers from several related or familiar domains (e.g. urban underground development) in order to formulate some conclusions. In addition, there is a thorough body of papers from medical and psychological domains addressing stress responses and coping during emergencies. The aim of this paper is thus to synthesize the chosen literature and relate it to self-rescuing rooms for tunnels. By doing so, it is possible to postulate what kind of implications these findings should have. The findings will in turn serve as a base to create guidelines for a project conducted in parallel to this literature review. The project aims to design a rescue room for road tunnels with human-centered design as a framework.

Google Scholar and NTNU's digital library, Oria, were used to search for literature related to human behavior and experiences in acute emergencies. In addition, design suggestions and studies on the psychology of underground environments have been reviewed. SINTEF has recommended additional articles and reports, among these is an extensive study conducted by themselves on self-rescuing in tunnels during a fire (G. Jenssen et al., 2017). Secondary resources have also been found in the references used by the reviewed literature. These sources have been used to further expand on some topics.

The search was limited to papers written in Norwegian or English, and the vast majority is written during the last 18 years. The literature has been chosen based on several criteria, among these are the relevance to the topic and number of citations.

Working with victims of tunnel fires as the end user is challenging and gives rise to some ethical issues. The thoughts and reactions obtained through interviews with tunnel fire victims could serve as valuable insight and is hence desirable to read. Due to the sensitive and personal nature of this information, it is protected by personal protection laws and has been hard to find. The findings that were made available to read has been generalized to a large extent and is referred to as confidential in the resources list at the end of this paper. This is in order to uphold the protection of personal data.

This paper starts off with an introduction to empathic design to state the relevance of this literature review. Furthermore, stress and stressors are explored before coping is addressed. At the end, this information is summarized and presented as a set of design guidelines to consider when designing a rescue room for tunnels.

## 3. EMPATHY IN DESIGN

Future users of rescue rooms could be old or young, Norwegian or Chinese, delicate or brave, and so on. In other words, rescue rooms should be suited for a wide range of people. Consequently, it is difficult for the designer to solely rely on personal perceptions and thoughts when designing. Getting closer to the experiences of future rescue room users (Kouprie & Visser, 2009) is therefore a measure to increase the likelihood that the end result fits people's needs.

Empathy is the ability to step into the shoes of another person and share their feelings. This ability is stressed as an integral part of human-centered design. When designing with empathy, designers get a deeper understanding of the feelings and experiences of the persons whom they are designing for (Kouprie & Visser, 2009).

This allows the creative discipline to make conclusions, and furthermore create solutions, for persons unlike themselves.

According to Mattelmäki and Battarbee (2002), empathy supports the design process as considerations move towards personal experiences and private contexts (Kouprie & Visser, 2009). Hence, this literature review represents one take on how to gain an understanding of potential experiences, feelings and reactions induced during life-threatening and stressful events such a tunnel fire.

## 4. STRESS

### 4.1 What is stress?

“Stress” is a general term used frequently in everyday life as well as in scientific contexts. Formulating a clear definition of the term has been proven difficult due to the term’s versatility and many fields of application (Bourne Jr & Yaroush, 2003; Staal, 2004). According to Ursin and Eriksen (2004, p. 567), stress is a general alarm in the body inducing “neurophysiological activation from one level of arousal to more arousal”. However, in the context of this paper, it is fruitful to work with a definition that relates the term more specifically to human psychology and behavior in emergency situations. Therefore, defining stress as “a state of mental or emotional strain or tension resulting from adverse or demanding circumstances” (Oxford Dictionaries, 2018a) is adequate.

Experiencing or witnessing a threat of death to oneself or others can cause an acute stress disorder (Kivi, 2017). Those who initially meet the criteria for this disorder are more likely to develop subsequent PTSD (McFarlane, 2010) than those who do not. PTSD occurs among persons that have been exposed to traumatic life events. It is commonly characterized by flashbacks to the trauma, anxiety and physical symptoms such as a racing heart and sweating (NIMH, 2016).

It is likely that the time before entering the rescue room will be experienced as the most stressful and threatening experience of a tunnel fire event. Despite this, it is not desirable that the time inside

the rescue room should prolong this high-intensity stress period. Hence, it is important to take measures to reduce stress levels and make people feel safe and calm after entering the rescue room.

### 4.2 Causes of stress in rescue rooms

A stress response is triggered by any type of stimulus or “stressor” (Sanders, 1983). In relation to the definition quoted above, a stressor is the underlying cause of strain or tension (Oxford Dictionaries, 2018b). Stressors stem from either internal or external forces (Greene, n.d.). The former is related to the human mind and can be e.g. phobias or emotions such as fear or anger. The latter relates to external events such as a fire, or physical stimuli such as light or temperature. In the event of a self-rescuing operation during a tunnel fire there are numerous relevant stressors to uncover. This paper will, however, focus on those relevant inside the rescue room.

Stress is a subjective response (LeBlanc, 2009), meaning that what can cause stress for one person, might not affect another. Whether stimuli results in pleasant or threatening responses is dependent on the individual’s assessment of the situation (Ursin & Eriksen, 2004). Nevertheless, it is reasonable to believe that victims caught in a tunnel fire, in general, experience stress levels above normal. For this reason, it is important to establish an understanding of how residing in a rescue room triggers stress responses, and what this implicates for the human psyche. This allows us to design the rooms with caution, ensuring that what we create does not constitute for additional stress.

#### 4.2.1 *Negative attitudes toward underground spaces*

In order to get a better understanding of possible stressors in rooms such as a tunnel rescue room, research on underground spaces (UGS) (Ringstad, 1994; Roberts et al., 2016; Soh, Christopoulos, Roberts, & Lee, 2016; Tan et al., 2018) has been reviewed. The nature of a tunnel rescue room makes it classifiable as a type of UGS. This has implications for people’s perceptions of the space, and hence, it gives rise to some implications for the design.

The general population view UGS negatively due to negative associations and phobias (Carmody, 1997 and Ringstad, 1994 as cited in Roberts et al., 2016). These negative feelings can e.g. be induced by cultural connotations, evolutionary traits or past experiences (Soh et al., 2016). The uneasiness triggered by UGS tends to be related to the fear of isolation or being trapped (Wasa & Sakugawa, 1990 and Carmody and Sterling, 1993 as cited in Roberts et al., 2016). Consequently, some people might hesitate to lock themselves in a closed room during a tunnel fire, not being certain what happens after they enter the room.

Although many people will not experience the rescue room as claustrophobic, victims with claustrophobia or other anxiety disorders should be considered carefully. The experience of using the rescue room should not constitute for additional stress during the event (Roberts et al., 2016). It is also likely that people without claustrophobia will get a better experience of the rescue room if it is designed to prevent a feeling of entrapment. Moreover, Galen (1999) have pointed out that these negative attitudes could be the result of prejudices rather than concrete experiences (Durmisevic & Sariyildiz, 2001). This implies that the rescue room, if designed with thought to the prevention of such fears, might disprove prejudices and rather enhance a feeling of safety. This is backed up by Mohirta (2012), who states that UGS can provide a feeling of security and safety, as it provides shelter from possible threats. In the tunnel fire scenario, it is likely that this positive connotation will be evident, as the rescue room provides shelter from the heat, smoke, and flames inside the tunnel.

#### *4.2.2 Perceived control*

A factor that is emphasized by multiple researchers is how perceived control plays a key part in whether a situation increases stress. Ringstad (1994) states that negative attitudes to UGS are closely intertwined with the level of perceived control. The nature of UGS limits the number of possible escape routes and physical connection with the surroundings (e.g. Carmody et al., 1994; Roberts et al., 2016; Soh et al., 2016). In tunnel rescue rooms there is only one way in and out, namely the door leading to the burning tunnel. This could result in a feeling of little

control in the event of a self-rescue operation. However, these findings imply that being trapped inside the rescue room does not necessarily need to trigger a fear response if the users feel that they have control over the situation (Ringstad, 1994). Facilitating for communication with the outside world or providing real-time information about the rescue mission could therefore increase perceived control, and thus reduce stress levels (Ursin & Eriksen, 2004). This is also stated by Gandit, Kouabenan, and Caroly (2009), who found a significant link between tunnel users' level of anxiety and their perceived control in a tunnel fire: Those who have low anxiety levels are more optimistic when they feel they are able to handle the situation.

#### *4.2.3 Injury*

Injuries arising during self-rescuing in the tunnel can constitute for additional stress. People who have attempted to evacuate a tunnel fire report that they crashed into the tunnel walls both by car and by foot, fell to the ground and hit their heads (G. Jenssen et al., 2017). Furthermore, some got combustions (Christophersen, 2018) and smoke injuries to the respiratory system. As tunnel fires can develop to be fatal within just two to ten minutes (G. Jenssen et al., 2017), the likelihood that someone will arrive the rescue room injured is large. This is supported by insight from past tunnel fires (Gandit et al., 2009; G. Jenssen et al., 2017) that reveal passive behavior among the victims: People waste valuable time when they avoid taking actions to get themselves to safety. This behavior increases the possibility of getting injured.

Arriving the rescue room injured, or being inside the room when someone enters injured, is inevitably a factor resulting in increased stress levels. Providing temporary means to take care of the injured is thus important to enhance a feeling of control, and most importantly to ensure that people are able to take care of the most acute injuries.

### **4.3 The effects of acute stress**

Stress affects human performance and the cognitive system. The classical arousal model predicts that performance is at its maximum at a

mid-point between high and low levels of arousal (Hebb, 1955 and Yerkes and Dodson, 1908 as cited in Roberts et al., 2016) (see Figure 1). This theory states that stress can have both positive and negative consequences, depending on the intensity of one's arousal level. It is likely that the arousal level of people trying to escape a fire, when still inside the tunnel, are high. However, it is difficult to know how entering the rescue room affects the stress intensity. It might decrease, as it the victims finally have gotten themselves to temporary safety, or it might remain stable due to the nature of the event. Further studies on how arousal levels are affected when entering a rescue room should be conducted in order to conclude on this subject.

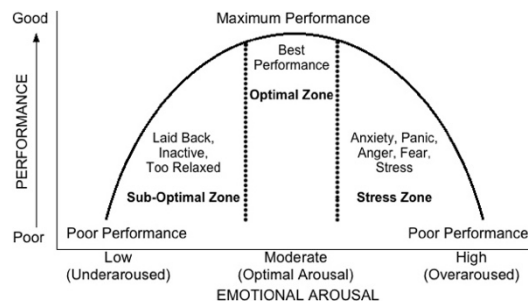


Figure 1: Visualization of the relationship between the level of arousal and performance (Sun, n.d. interpretation of; Yerkes & Dodson, 1908).

Another take on how high stress levels can lead to both positive and negative outcomes is given by LeBlanc (2009). She states that stress can either enhance or diminish performance depending on whether the source of stress is the task itself or something external. If the stress response is related to the task, such as getting yourself to safety, stress facilitates for task performance. This is a positive outcome of the response. On the other hand, if the stress is related to sources external to the task, such as noise or intense pain, the stress response becomes disruptive to performance. This implies that a stress response does not necessarily lead to negative consequences for performance, as long as peripheral stressors are eliminated. Some of these peripheral stressors, e.g. an injury, is difficult to eliminate. However, as discussed earlier, measures to limit stressors such as fear or claustrophobia can be taken. It is therefore, in theory, possible to make sure that the stress evident inside the rescue room are mostly related

to the tasks a person needs to conduct. This could e.g. be to call emergency services to inform about the situation.

The idea that stress can enhance performance is related to the theory of selective attention which states that attention becomes more selective as stress increases (Chajut & Algom, 2003, as cited in LeBlanc, 2009). The process of selective attention filters out factors that are irrelevant to a given task and prevents the cognitive system from becoming overloaded (LeBlanc, 2009). This mechanism is often referred to as cue utilization (Ozel, 2001). For this reason, stress can be viewed as beneficial when a task requires exclusive attention to specific information. However, criticism has been raised in regard to whether the reduction of attentional resources under stress rather results in a decreased ability to distinguish irrelevant information from relevant information (Braunstein-Bercovitz, 2003, as cited in LeBlanc, 2009). These findings suggest that the brain is more sensitive to large amounts for information during high levels of stress. Making sure that information is limited and displayed in an easy manner (Gandit et al., 2009) is thus important.

## 5. COPING

### 5.1 What is coping?

One of the most natural ways to reduce arousal levels is to eliminate or limit the threat itself by taking action (Ursin & Eriksen, 2004). The term "coping" refers to the actions we initiate to do so (Centre for Studies on Human Stress, n.d.). The act of coping is often taken without consideration to the impact or value of the deed (Beasley, Thompson, & Davidson, 2003). Consequently, coping is not necessarily equivalent to a positive outcome. Hence, it is interesting to investigate how different coping mechanisms might affect the mental health of persons using a rescue room, both considering short-term and long-term consequences. According to Ursin and Eriksen (2004), the level of stress can be dependent on the responses available for coping. If facilitation for one type of coping could serve as a means to reduce the likelihood of PTSD, this information is essential to have in mind when designing a rescue room.

## 5.2 Different coping strategies

The literature on coping strategies presents several takes on how people cope (e.g. (Carver, Scheier, & Weintraub, 1989; Suls & Fletcher, 1985). However, this paper presents three of the main coping strategies (as cited in LeBlanc, 2009): *Problem-focused coping* addresses the source of uneasiness in an active way. In a rescue room, this could e.g. be to plan out how to make sure that emergency services will get the necessary information to rescue you. In contrast to this is *emotion-focused coping* strategies, which aim to handle emotional distress, rather than the actual problem. Getting emotional support from emergency services or other residents inside the rescue room is examples of such strategies. Lastly, there is *avoidance coping*, where the goal is to avoid or distract oneself from the problem (LeBlanc, 2009); to engage in tasks that take attention away from either the source of stress or one's psychological reactions (Suls & Fletcher, 1985). Due to researches disagreement on how to classify different coping mechanisms, emotion-focused coping is sometimes classified as one type of avoidance-oriented coping or vice versa (Beasley et al., 2003). Hence, this paper will address these two concepts together, using both terms.

Folkman and Lazarus (1980) state that most stressors evoke several types of coping. However, they found that problem-focused coping seems to dominate in situations where people experience that something constructive can be initiated to deal with the threat. Contrary, avoidance- and emotion-focused coping predominate when the threat is perceived difficult to tackle, and thus must endure (Carver et al., 1989). Eliminating the overarching threat, namely the tunnel fire, is difficult while staying inside the rescue room. This implies that emotion-focused coping is likely to be the most evident coping strategy in this scenario. Despite this, it can be argued that getting yourself to the emergency shelter is an active and problem-focused way of coping with the fire, and hence the threat is already eliminated when entering the rescue room. Even so, there are several other stressors which could constitute a perceived threat after you enter the shelter. Stressors such as lack of control or injury can possibly be dealt

with. These kinds of threats could hence be targets for problem-focused coping. This suggests that all the three types of coping strategies could be evident inside a rescue room.

## 5.3 The efficacy of coping strategies

It is seemingly no clear conclusion on what kind of coping strategy is the most efficient. As stated by Suls and Fletcher (1985) an answer to this discussion could presumably be that one strategy works best under certain conditions, while another strategy is a better fit under other conditions. For such reasons, it has been difficult to draw a clear conclusion on this matter. Moreover, stress factors and perceived threats inside a tunnel rescue room has yet to be uncovered.

Weisenberg, Schwarzwald, Waysman, Solomon, and Klingman (1993) studied children who had stayed in a sealed room during a Scud missile bombardment in Israel. The researchers aimed to uncover the relationship between the children's coping strategies and their postwar stress reactions. This event has some similarities with the rescue room scenario: The victims need to evacuate to a closed room and stay inside it for an unspecified amount of time, and there is nothing they can do with the overarching threat (the bomb attack and tunnel fire respectively). Weisenberg et al. (1993) state that the children who were able to focus on emotion-oriented coping involving elements of denial also indicated less postwar stress reactions. Consequently, those who focused on more problem-focused coping were associated with a higher degree of PTSD. This implies that as long as the threat(s) inside the rescue room is perceived as uncontrollable, facilitating for emotion- and avoidance-focused coping is desirable (see Figure 2). Laboratory studies have also found avoidant coping strategies to reduce physical stress reactions such as cold or pain (Chaves & Barber, 1976 as cited in Suls & Fletcher, 1985). However, even though avoidant coping might be beneficial during an uncontrollable traumatic event, some researches state that it can impede coping later on (e.g. Carver et al., 1989; Roth & Cohen, 1986; Suls & Fletcher, 1985).

Some threats inside the rescue room could possibly be addressed actively. An example of such threats is the fear of not being rescued from the rescue room. Problem-focused coping is stated as the most effective strategy to deal with such threats (Weisenberg et al., 1993) (see Figure 2). This strategy has been found to positively correlate with optimism and the feeling of being generally able to take measures about the situation (Carver et al., 1989). Efforts that are active and future-oriented have also been found to reduce future stressors and furthermore (indirectly) prevent subsequent mental illness (Roth & Cohen, 1986). Giving people the opportunity to communicate with emergency services inside the rescue room is one measure to facilitate problem-oriented coping in this scenario.

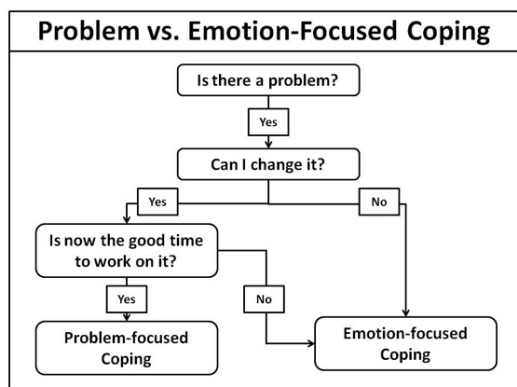


Figure 2: Illustration of how to determine which coping strategy is the most efficient in a given situation (Stress to strength, 2016).

## 6. DESIGN GUIDELINES

The following sections include suggestions for what to keep in mind when designing a rescue room for people evacuating a tunnel fire. The goal of formulating these guidelines is to indicate what measures a designer should keep in mind when designing to enhance a feeling of safety in this scenario.

### 6.1 Architecture and interior architecture

*The rescue room should be designed with consideration of the reduction of claustrophobia and a feeling of entrapment or isolation.*

Reducing claustrophobic reactions can be done by making sure that the construction of the room itself is perceived as light and open. A study conducted by G. D. Jenssen and Kummeneje (2011) on underground parking garages discovered that the two most common barriers against parking in such spaces are that they are perceived as dark and tight. Consequently, their research found that parking garages which were perceived as open, airy and bright are preferred.

In a scenario where e.g. 50 people from a bus are to evacuate to the rescue room, crowding of the room could also induce a claustrophobic reaction due to little personal space (Roberts et al., 2016). People’s perception of crowding in underground spaces are related to architectural factors such as the physical shape of the room, but also the room partitioning and seating arrangements (Bell, Fisher, Braun and Green, 1990, as cited in Ringstad, 1994). By considering such factors, it is possible to reduce the potential impact of phobias stemming from crowding and being underground. This could also enhance a feeling of control (Ringstad, 1994).

### 6.2 Information

*The rescue room should provide people with adequate information about the situation.*

Providing information to the users of underground facilities could be a measure to enhance people’s perception of control (Ringstad, 1994). It is highly unlikely that a tunnel fire victim has experienced escaping to a tunnel rescue room earlier in their life, thus they have little knowledge of how to behave and act after they enter. Furthermore, it is important to give people the opportunity to act upon this information (Ringstad, 1994), which is an active way of coping with the situation. Proulx (1993) found that additional information provided during an emergency can reduce stress levels, motivate for accurate behavior and thus reduce the negative consequences of the event. As stress has proven to affect how we process information, it is important to limit the amount of information given and display it in an understandable and easy manner (Gandit et al., 2009).

### 6.3 Communication

*The rescue room should provide means to communicate with the outside world.*

Due to the unfamiliar nature of a rescue room, making two-way communication with someone on the outside available is desirable (Ringstad, 1994). The procedure to follow while staying in the room should be clear. Establishing contact between the fire victims and e.g. the Road Inspectorate could be a means to inform about the situation and hence facilitate problem-oriented coping. Furthermore, communication channels do also facilitate emotional coping. Emotional support and comforting from an authority with an overview over the situation could relieve the victims by e.g. giving them answers to questions they might have.

### 6.4 Expectancies

*The rescue room should be designed to meet people's expectancies for safety.*

According to Ursin and Eriksen (2004), a stress response is triggered in all situations where our expectancies are not met. Consequently, it is interesting to investigate what people expect of a tunnel rescue room. This question would be interesting to explore in a more thorough study on rescue rooms. However, it is likely that the stress response will be reduced if the unexpected responses to a rescue room are mostly positive. This could be the case if the previous and following guidelines are taken into concern.

### 6.5 Facilitation for coping

*The rescue room should provide people with means to cope with their stress and fears.*

Giving people the opportunity to cope during the hours they spend inside the rescue room is essential. Further studies on people's behavior while staying inside the rescue room, and furthermore how they feel in the wake of the event, will contribute to an understanding of what people perceive as threatening during the event. If the threat is uncontrollable (e.g. the fire inside the tunnel or claustrophobia), there should be means to cope in an avoidant or emotion-

oriented way. However, if it is possible to reduce or eliminate the threat (e.g. being thirsty or bleeding), means to take action, and hence cope in a problem-focused way should be made available.

## 7. DISCUSSION

Studies on tunnel rescue rooms are scarce as this field remains undiscovered up until today's date. This lack of insight makes it hard to predict how people will behave, feel and cope in the event of self-rescuing during a tunnel fire. Whether people will be stressed after entering the rescue room or feel safe because they have escaped the fire is yet to be discovered. It is important to emphasize that the present study is based on a body of literature from several familiar or relevant domains (i.e. underground spaces, psychology, and medicine) and not research addressing the theme directly. Thus, this article can be viewed as a summary of hypotheses that seeks to relate concepts from mature fields to an immature one. Research and analyzes in the wake of future tunnel fires will give progression within this field.

This literature review does not take individual differences such as age, sex or cultural background into consideration. It is based on general hypotheses stemming from studies conducted around the world, but mostly western countries. There could be differences in how e.g. children versus adults or Norwegians versus Chinese will react, adapt and connote inside the rescue room. However, the theories presented in this paper constitute an early contribution to the field of tunnel rescue rooms. The risks we face by designing without consideration of human factors are that we could fail to let individuals have an opportunity to function during a traumatic life event (LeBlanc, 2009). This could result in negative long-term consequences both at an individual level and to society as a whole.

The prevention of PTSD or other negative health responses to the fire emergency should not solely rely on the design of a rescue room. As stated by McFarlane (2010, p. 3), "one of the greatest challenges to the field of traumatic stress has been the observation that many individuals who coped at the time of their traumatic exposure



became unwell at a later date". It is important to highlight how post-emergency support systems and debriefing could play a key part in the recovery from such a critical life event.

As stated by Ringstad (1994, p. 7), "it should be noted that attempts to influence people's experience of danger and control raise important ethical questions". The design should not give people a sense of safety at all costs. It is important to give people the opportunity to assess the situation in a realistic manner and hence act accordingly (Ringstad, 1994).

## 8. CONCLUSIONS

This paper suggests that coping and reduction of stress are key factors to consider when designing for a feeling of safety in a tunnel rescue room. Furthermore, the architecture of the room has been stressed to have an influence on people's arousal levels. With consideration to the reviewed literature, five design guidelines have been formulated. The guidelines highlight that architecture and interior architecture, information, communication, expectations and coping are essential factors to consider when designing a tunnel rescue room.

## REFERENCES

- Amundsen, F. H. (2017). *The 5 major tunnel fires in Norway*. Retrieved from Statens Vegvesen:
- Beasley, M., Thompson, T., & Davidson, J. (2003). Resilience in response to life stress: the effects of coping style and cognitive hardiness. *Personality and Individual Differences, 34*(1), 77-95.
- Bourne Jr, L. E., & Yaroush, R. A. (2003). Stress and cognition: A cognitive psychological perspective.
- Carmody, J., Huet, O., & Sterling, R. (1994). Life safety in large underground buildings: principles and examples. *Tunnelling and Underground Space Technology, 9*(1), 19-23.
- Carver, C. S., Scheier, M. F., & Weintraub, J. K. (1989). Assessing coping strategies: a theoretically based approach. *Journal of personality and social psychology, 56*(2), 267, 270, 275.
- Centre for Studies on Human Stress. (n.d.). Coping with stress. Retrieved from <https://humanstress.ca/stress/trick-your-stress/steps-to-instant-stress-management/> (21.09.18)
- Christophersen, R. (2018). Får ikke bygge tilfluktsrom i tunneler. Retrieved from <https://www.bt.no/nyheter/lokalt/i/3jBrK9/Far-ikke-bygge-tilfluktsrom-i-tunneler> (17.09.18)
- Durmisevic, S., & Sariyildiz, S. (2001). A systematic quality assessment of underground spaces—public transport stations. *Cities, 18*(1), 14.
- Gandit, M., Kouabenan, D. R., & Caroly, S. (2009). Road-tunnel fires: Risk perception and management strategies among users. *Safety Science, 47*(1), 106, 108, 113.
- Greene, G. (n.d.). Internal and External Stress. Retrieved from [https://cx.uhc.com/content/cex-consumer/health-library/en/wellness/stress\\_management/relax\\_101/0475\\_3C\\_internal\\_and\\_external\\_stress.html](https://cx.uhc.com/content/cex-consumer/health-library/en/wellness/stress_management/relax_101/0475_3C_internal_and_external_stress.html) (19.09.18)
- Jenssen, G., Roche-Cerasi, I., Hoem, Å. S., & Grøv, E. (2017). Litteraturundersøkelse-Selvredning i vegtunneler Erfaringer med bruk av redningsrom. *SINTEF Rapport*.
- Jenssen, G. D., & Kummeneje, A.-M. S. (2011). *Design av attraktive parkeringsrom*. Retrieved from SINTEF:
- Jenssen, G. D., personal communication (2018, 11.09.18). [Intervjuer etter tunnelbrann (CONFIDENTIAL)].
- Kivi, R. (2017). Acute stress disorder. Retrieved from <https://www.healthline.com/health/acute-stress-disorder> (25.10.18)
- Koupric, M., & Visser, F. S. (2009). A framework for empathy in design: stepping into and out of the user's life. *Journal of Engineering Design, 20*(5), 437-438.
- LeBlanc, V. R. (2009). The effects of acute stress on performance: implications for health professions education. *Academic Medicine, 84*(10), S26-S27, S29.

- McFarlane, A. C. (2010). The long-term costs of traumatic stress: intertwined physical and psychological consequences. *World Psychiatry, 9*(1), p. 3.
- Mohirta, A. (2012). *Natural Lighting and Psychological Barriers in Underground Space*. Ph. D. thesis, Oxford Brookes University, Oxford.
- NIMH. (2016). Post-Traumatic Stress Disorder. Retrieved from <https://www.nimh.nih.gov/health/topics/post-traumatic-stress-disorder-ptsd/index.shtml> (12.11.18)
- Oxford Dictionaries. (2018a). Definition of stress in English. Retrieved from <https://en.oxforddictionaries.com/definition/stress>
- Oxford Dictionaries. (2018b). Definition of stressor in English. Retrieved from <https://en.oxforddictionaries.com/definition/stressor> (17.09.18)
- Ozel, F. (2001). Time pressure and stress as a factor during emergency egress. *Safety Science, 38*(2), 104.
- Proulx, G. (1993). A stress model for people facing a fire. *Journal of Environmental Psychology, 13*(2), 138.
- Ringstad, A. (1994). Perceived danger and the design of underground facilities for public use. *Tunnelling and Underground Space Technology, 9*(1), 5-7.
- Roberts, A. C., Christopoulos, G. I., Car, J., Soh, C.-K., & Lu, M. (2016). Psychological factors associated with underground spaces: What can the new era of cognitive neuroscience offer to their study? *Tunnelling and Underground Space Technology, 55*, 429, 436. doi:10.1016/j.tust.2015.12.016
- Roth, S., & Cohen, L. J. (1986). Approach, avoidance, and coping with stress. *American psychologist, 41*(7), 816-819.
- Samferdselsdepartementet. (2007). Forskrift om minimum sikkerhetskrav til visse vegtunneler (tunnelsikkerhetsforskriften). Retrieved from <https://lovdata.no/dokument/SF/forskrift/2007-05-15-517> (05.10.18)
- Sanders, A. (1983). Towards a model of stress and human performance. *Acta psychologica, 53*(1), 62.
- SINTEF. (n.d.). This is SINTEF. Retrieved from <https://www.sintef.no/en/this-is-sintef/> (10.09.18)
- Soh, C.-K., Christopoulos, G., Roberts, A., & Lee, E.-H. (2016). Human-centered development of underground work spaces. *Procedia Engineering, 165*, 244-245.
- Stress to strength. (2016). Coping with stress. Retrieved from <https://www.stresstostrength.com/coping-with-stress/> (02.11.18)
- Staal, M. A. (2004). Stress, cognition, and human performance: A literature review and conceptual framework. 1.
- Suls, J., & Fletcher, B. (1985). The relative efficacy of avoidant and nonavoidant coping strategies: a meta-analysis. *Health psychology, 4*(3), 250-252.
- Sun, C. (n.d.). Why Some Athletes Choke In Competition. Retrieved from <https://www.crossfitinictus.com/blog/why-some-athletes-choke-in-competition/> (20.09.18)
- Tan, Z., Roberts, A. C., Christopoulos, G. I., Kwok, K.-W., Car, J., Li, X., & Soh, C.-K. (2018). Working in underground spaces: Architectural parameters, perceptions and thermal comfort measurements. *Tunnelling and Underground Space Technology, 71*, 428-439. doi:10.1016/j.tust.2017.09.002
- Ursin, H., & Eriksen, H. R. (2004). The cognitive activation theory of stress. *Psychoneuroendocrinology, 29*(5), 567, 570, 572, 576, 581.
- Weisenberg, M., Schwarzwald, J., Waysman, M., Solomon, Z., & Klingman, A. (1993). Coping of school-age children in the sealed room during scud missile bombardment and postwar stress reactions. *Journal of consulting and clinical psychology, 61*(3), 462, 466.
- Yerkes, R., & Dodson, J. (1908). The relation of stimulus strength to rapidity of habit formation. *J Comp Neurol Psychol, 18*, 459-482.