Analyzing the Potential of Graphical Building Information for Fire Emergency Responses: Findings from a Controlled Experiment

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Abstract. To better support firefighters during emergency response processes, novel information technologies are frequently being presented in research and practice. While such approaches are often technology-driven in nature, we present a task-centered approach to identify the actual information demand during emergency response scenarios. As an important example, we examine the search and rescue task. Combining the theory of situation awareness with findings from cognitive science, we hypothesize that providing graphical information about the building and the location of victims increases firefighters' task performance in comparison to a verbal briefing. Findings from a controlled experiment that was developed in cooperation with a state firefighting academy show that such information might indeed facilitate the task performance. A continuous access to such information during the entire mission was found to be less effective, though. Our findings have implications for the development of novel information technologies and call for an adaption of current working routines.

Keywords: Firefighter information technologies, Situation awareness, Cognitive Science, Laboratory experiment.

1 Introduction

Newly emerging firefighter information technologies (FITs) such as digital plans [1, 2], unmanned aerial vehicles [3, 4], on-site emergency response systems [5, 6], augmented reality devices [7, 8], or intelligent protective clothing [9, 10] open up novel opportunities to gather, process, and present real-time information about the site of a fire emergency. They are hence supposed to bear a significant potential to facilitate the making of context-dependent decisions and, accordingly, to support the emergency response process. Currently, however, novel FITs are developed and proposed mainly based on their innovative capabilities and the presumably resulting potential to support the emergency response process. Recent studies indicate that such technology-driven approaches run a risk to neglect the specific nature of emergency response processes and might miss the actual demand for information [11].

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During emergency responses, firefighters make time-critical decisions in a dynamic environment. By improving the information base, new and emerging information technologies might facilitate the decision-making process. However, there also exist tight constraints, for instance with respect to the time and the margin for error. The provided information hence needs to be succinct, easy to process and straightforwardly understandable without distraction. To make sure that firefighter information technologies indeed meet the demand that exists on site, it appears thus necessary to investigate, (i) which kind of information is effective in enhancing the performance of firefighters during their operations and (ii) how information technologies should be designed to deliver the information adequately. Yet, so far literature hardly discusses under which circumstances (and subject to which task-specific requirements) novel FITs are viewed as beneficial by prospective users.

With the work at hand, we intend to contribute to the closure of this literature gap. Narrowing the scope, we focus on examining, which kind of information is effective in supporting the search and rescue task. This task was identified as an appropriate study object during a roundtable discussion with instructors of a firefighting academy for several reasons: first, the task frequently occurs during daily emergency responses. Second, firefighters typically suffer from an insufficient information basis during this task. Third, emerging FITs like digital plans and on-site emergency response systems are proposed in literature to better support this task (among others). In our study, we examine the following research questions: "*Does an up-front presentation of a graphical building plan and the location of a victim during the mission briefing improve the search and rescue task compared to a verbal description? Does the continuous availability of a graphical plan during the mission further improve the task?*"

To achieve rigorous results, we conducted a controlled experiment, in which 69 firefighter squads were provided with information about the building and the victim location in different formats and with different forms of availability. The experiment was conducted in cooperation with a Bavarian firefighting academy, which made available a building that has been designed for fire emergency response training purposes and resembles a typical small apartment house in Germany. The design of the experiment is informed by findings from cognitive science on the processing of information formats and on cognitive overload. The experiment results indicate in how far graphical building information is effective in enhancing typical fire emergency response operations. Accordingly, they provide an empirically grounded basis for the design of firefighter information technologies such as digital plans, on-site emergency response systems, or augmented reality devices, which shall make available such information to firefighters during the emergency response. As domains with high stress levels, strict timing constraints, and low margins for error hardly have been in the focus of research so far, the results of our study furthermore complement existing findings from cognitive sciences.

In section 2, we discuss the background of our study. Furthermore, we develop the hypotheses and the research model underlying the design of our experiment. In section 3, we describe the experiment design. Section 4 presents the obtained results. We discuss the results and the implications for academia and practice in section 5. In section 6, we conclude by summarizing the findings and outlining future research directions.

2 Background, Hypotheses, and Research Model

During fire emergency response operations, firefighters make time-critical decisions in highly dynamic situations. Because of the existing time constraints, they often must decide on a basis of insufficient information. Improving the information basis and increasing the so-called situation awareness is hence supposed to be a critical success factor to achieve better and/or quicker decisions [12, 13]. The theory of situation awareness can be applied to various domains, in which actors make time-critical decisions in stressful situations. Besides emergency responders like firefighters, it has also been applied to pilots and soldiers. Generally, situation awareness is established in a three-level process of perception, comprehension, and projection [12]. In the perception phase, the actor must capture all relevant aspects of the situation. In a simplified example, a firefighter would have to realize that there is smoke coming from an open window on the second floor or that the house door is closed. In the comprehension phase, the actor must try to connect the different aspects to build a holistic understanding of the situation. The firefighter would have to understand that there is a fire, which could be reached by breaking the door or using a ladder to reach the window. Finally, based on perception and comprehension, the actor can make projections about the near future. The firefighter could predict that the fire might spread to other rooms and could be reached faster through the window. All three levels of situation awareness demand qualitatively and quantitatively sufficient information. In this context, information technologies such as the FITs mentioned in the previous section can be an effective means to deliver this information. Looking at the research conducted on situation awareness in emergency response management, however, there is a strong focus on large-scale phenomena like the handling of extraordinary disasters or the coordination of multiple agencies [14, 15]. To our best knowledge, the theory has not yet been applied to study daily routines of firefighters such as search and rescue of victims.

2.1 Development of Hypotheses

To identify how information needs to be presented in such a scenario to increase situation awareness, we consulted relevant literature of cognitive science. Various studies in this field indicate that especially graphical information can be used to effectively and understandably provide information to humans. The graphical format often proved to be superior to other forms of presentation like natural language or written words. Generally, humans seem to better recall pictures and other graphical information than the identical information coded in words [16-18]. As an explanation for this, Kaplan, Kaplan and Sampson [16] showed that the human brain double-codes pictures (i.e., both verbally and visually). This mental connection between graphics and words enables people to better recall the information. A special form of graphical information are diagrams. Due to the support of numerous perceptual interferences and the grouping of related information, they can further improve comprehensibility [19]. Mousavi, Low and Sweller [20] showed that another improvement can be achieved by connecting the graphical information with corresponding verbal explanations. According to Mayer and Sims [21], these effects specifically apply to inexperienced persons. Since firefighters typically are not acquainted with the concrete situation and environmental conditions when responding to an emergency (in our scenario the apartment they will be operating in), they can also be characterized as inexperienced. Deducing from the above findings of cognitive science, we assume that firefighters with access to graphical information about a building shall be able to better recall this information during a mission. Accordingly, they should also be able to perform search and rescue tasks better. With our study, we apply the general findings of cognitive science to the practical and very special domain of firefighters. Firefighters typically work under high emotional stress and time pressure in chaotic situations. Yet, according to instructors of the firefighting academy who supported this study, the use of graphical information during responses has by now hardly been identified as a means to overcome these problems in practice. By applying existing findings of cognitive science to this special and comparably unexplored domain, we hence test (and might further increase) their general validity.

The specific characteristics of the firefighter domain, however, also imply a risk that firefighters' cognitive abilities might not suffice to process all information they are receiving. This problem is referred to as cognitive overload [22]. In an emergency, responders are confronted with countless environmental and emotional impressions that need to be processed. Once reaching the point of cognitive overload, they may not be able to completely perceive and memorize information like the graphical building plan examined in our study. For these reasons, we assume that making graphical information available continuously during the mission further enhances the task performance as the information would not have to be memorized but could be looked up when needed. We hypothesize that such a higher degree (of availability) of graphical information will have a positive effect on its usability and, accordingly, the task performance.

2.2 Research Model

To capture the background of our study more precisely, we integrate our assumptions into a research model. We postulate that different degrees of graphical information provide differing support for firefighters during their tasks. Particularly, we expect the different degrees of information to have an impact on their usability for firefighters. Usability as such can be further operationalized into three aspects: the effectiveness (i.e., the accuracy with which a task is fulfilled), the efficiency (i.e., the effectiveness in relation to the effort needed to complete a task), and the satisfaction (i.e., the users' comfort while performing a task) [23, 24]. Following this definition, we concretize our three hypotheses as follows (the resulting research model is summarized in Figure 1):

- **H_1**: Firefighters provided with a higher degree of graphical building information will be able to perform the task more accurately.
- **H_2**: Firefighters provided with a higher degree of graphical building information will need less time to perform the task accurately.
- **H_3**: Firefighters provided with a higher degree of graphical building information will be more satisfied while performing the task.

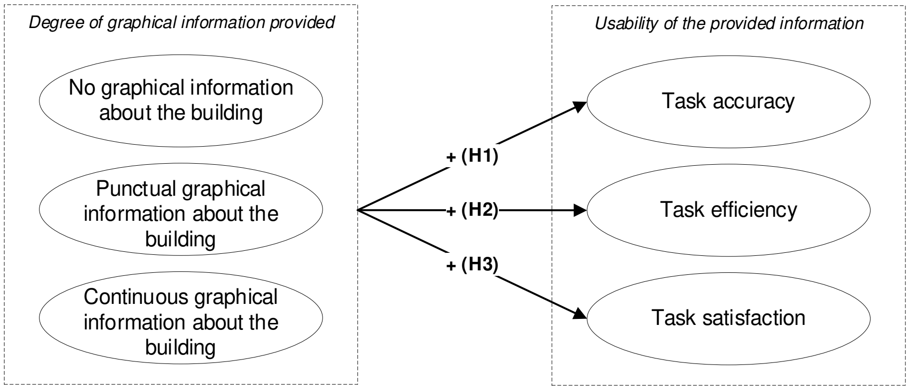

Figure 1. Research model

3 Research Procedure

To examine H_1-H_3, we conducted a controlled laboratory experiment. Next, we present the design of this experiment to evaluate H_1 and H_2. Thereafter, we describe the questionnaire that accompanied the experiment and was used to examine H_3.

3.1 Controlled Laboratory Experiment

Our experiment was developed and conducted in cooperation with the Bavarian state firefighting academy in Würzburg, Germany. In this academy, firefighters from all over Bavaria are trained in several tasks like salvage rescue, firefighting, and incident command. By means of the academy's specialized training facilities, we were able to simulate a realistic scenario under safe conditions. Despite providing a realistic scenario, the environment nevertheless allowed us to control surrounding factors in order to conduct a laboratory experiment following the guidelines given by Cox and Reid [25].

The experimental setting was developed in a collaboration with a group of instructors of the firefighting academy. Beginning with a roundtable session in late 2017, we identified various everyday tasks in which firefighters typically suffer from a lack of information. As one of the most critical of these scenarios, the instructors introduced the search and rescue of a victim during an apartment or house fire. Based on this scenario, we developed our concrete experiment in a second roundtable session.

In our experiment, a squad of firefighters responded to an apartment fire in the basement of a two-story building. The building was represented by the academy's fire training building (cf. Figure 2). It emulates a typical residential building and was specifically designed to simulate apartment fires by means of remotely controlled gas-fires and simulated smoke from fog machines. Inside the burning apartment, a life-size dummy depicted a missing, unconscious person. The squad responding to the apartment fire consisted of a squad leader and a team of two firefighters. The squad leader commanded the response by first investigating the scene and then briefing the team. In the experiment, the squad leader was represented by a member of our research team. In so doing, we could control the equality of the briefings. The team's performance, consequently, was not influenced by the abilities of its squad leader but only by the received information. The firefighter team got a briefing on the situation and was then commanded to enter the burning apartment to search and rescue the missing person. The positions of the team were taken by random firefighters wearing self-contained breathing apparatuses (SCBA). Other positions of a real-life squad like the operator of the fire engine and a second team of firefighters on standby have not been included in the experiment, because they would have had no connection to our experimental interventions.

The subjects who acted as team members were retrieved from firefighting courses, which took place from March to July 2018. Due to capacity restrictions, places in those courses are limited and distributed among all Bavarian fire departments. This resulted in a diverse, random sample of subjects. Each team consisted of two subjects and was randomly assigned to one of three equally sized groups [25]: G_0, G_1, and G_2. **G_0** was the control group. Teams of this group received a verbal briefing and command without any graphical resources, which represents the current state of the art for such rescue missions. The teams were briefed with the following standardized phrase: "There's an apartment fire in the basement, one person is missing but we know their presumable location. Heading down the stairs, there are four doors: one ahead, two on your left, and one at your left back. To reach the person, you must take the farer left door. Then cross the following corridor straight ahead. In the room after the corridor, you must go to the right around a room divider. There, you should find the person. Intervention team for search and rescue with the first hose line to the basement via the stairs, go!"

G_1 was the first treatment group. As treatment, teams of this group received punctual access to a sketch-map of the apartment during the briefing. As shown in Figure 2, the map contained the apartment's layout including stairs, walls, doors and the victim's location. The squad leader briefed them with the identical phrase that was also used in the control group. This time, however, he visualized the verbal information in the map, for example by pointing toward the doors the team was supposed to go through. After the briefing, the team entered the building without any further access to the sketch-map.

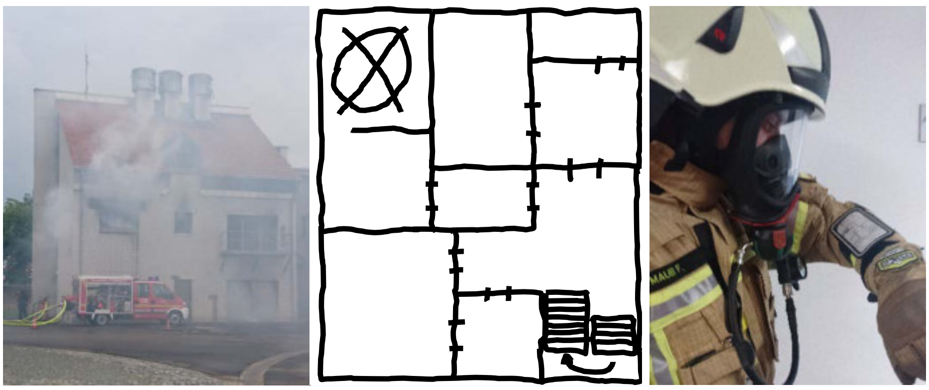

Figure 2. Fire training building (left), sketch-map (middle), and small-scale copy on the team leader's sleeve for continuous access (right)

G_2 was the second treatment group. The treatment received by teams of this group was continuous access to the before-mentioned sketch-map. Like the teams of G_1, they were briefed with the standardized phrase supported by the graphical information of the map. In addition, they also took the graphical information with them during the rescue mission. To simulate an information device, they were equipped with a small-scale copy of the sketch-map that was wrapped in a protective cover and fastened on the team leader's sleeve (cf. Figure 2). As discussed in section 5, the real-world application of our treatments – especially the continuous access to the map – will inevitably require the use of information technology. As an approximation to measure the resulting effects, however, we decided to stick with the paper-based solution.

To examine **H_1**, we compared the average task completion rates of the three groups. A task was rated as completed if the team could find the dummy and bring it outside. To examine **H_2**, we took the time the firefighters needed to complete the task. Precisely, we took the time the teams needed to find the dummy inside the apartment. The period began once the first team member crossed the door sill and ended once the first team member reached the dummy. Since there was no visual contact with the team, an instructor (who was following the team for security reasons anyway) radioed to the squad leader once the dummy had been found. By comparing the average times needed to find the dummy for the three groups (task completion time), we could test **H_2**. Finally, to examine **H_3**, we captured the task satisfaction of the participants by means of a questionnaire as described in the next subsection. Tables 1 and 2 summarize the experimental design.

Table1. Summary of the different groups

Groups
G_0: verbal only information
G_1: verbal + punctual graphical information
G_2: verbal + continuous graphical information

Table 2. Summary of the tests of Hypotheses

Test of Hypotheses
H_1: task completion rate
H_2: task completion time
H_3: After-Scenario Questionnaire (cf. 3.2)

Following the requirements of a laboratory experiment, we took several measures to ensure the internal and external validity of our results [25]. Regarding internal validity, we tried to make our treatments the only varying factor between the different groups. Consequently, we controlled the surrounding conditions as far as possible. First, all teams had to perform the identical task. The dummy had been positioned at the identical spot in the same room for all teams. The doors on the way were equally closed, and the rooms had been equally filled with smoke. All in all, the briefing at the beginning of the task was the only varying factor between the groups.

Also, the search and rescue task was chosen with the goal to ensure internal validity in mind. In a firefighting task, for example, several other factors like hose management and extinguishing technique might have affected the task completion time much more than our treatments. In our scenario, on the other hand, the teams' orientation abilities inside the apartment were the major determinant for how long it took to find the dummy. As another measure, we ensured that the participants had no prior knowledge of the apartment or the task. The teams were separated and not allowed to watch other teams during their briefings or the tasks itself. This way, we could rule out learning effects and keep the conditions equal for all teams. Finally, we captured several control variables like the firefighters' experience, age, and other in the questionnaire to rule out differences based on those factors (cf. Section 3.2).

We maximized external validity mainly by choosing the fire training building as a realistic site. Since it was specifically designed to simulate apartment fires, the task could be reproduced as realistically as possible under safe and controlled conditions. Remotely controlled gas-fires provided heat and real flames. Multiple fog machines simulated realistic smoke and limited the sight to only a few centimeters. Loudspeakers played acoustic stimuli like the crackling of the fire. All in all, the surrounding conditions of the experiment were closely comparable to those of a real-world emergency. Besides, the scenario itself was developed in roundtable sessions with instructors of the firefighting academy and characterized as a realistic everyday scenario for firefighters. Furthermore, the sample of subjects contributed to ensuring external validity. All participants were firefighters that also conduct this kind of tasks in real operations. We hence assume that our results are transferable to comparable real-life emergency operations of firefighters.

3.2 After Scenario Questionnaire

To capture feedback from our participants and assess their task satisfaction, we used a questionnaire. In its first part, we asked about general and demographic information. This way, we wanted to record several control variables that could have an influence on our results. To assess the firefighters' experience, we asked both team members for how long they have been members of a fire department and for how long they have been trained to wear SCBA. Besides that, we captured the average number of emergencies and SCBA-operations they are responding to per year. Furthermore, we asked for the command level they are normally working in and the type of fire department they are working for. Finally, the age and gender of our participants were captured. This first part of the questionnaire was filled out prior to the task.

In the second part of the questionnaire, we wanted to assess the participants' task satisfaction to examine **H**$_3$. This part was filled out by the firefighters right after completing their task. Due to previous experiences in questioning firefighters in or shortly after stressful situations, we wanted to keep this part as short and simple as possible. Consequently, we decided to use the easy, yet well-established After-Scenario Questionnaire (ASQ) [26]. The ASQ consists of three items that we slightly adapted:

- Overall, I am satisfied with the ease of completing the task in this scenario
- Overall, I am satisfied with how long it took to complete the task in this scenario
- Overall, I am satisfied with the available supporting information when completing the task in this scenario

All three items had to be rated by the teams on a seven-point scale ranging from 1 (strongly disagree) to 7 (strongly agree), as well as an n/a-point. To gather additional qualitative feedback, we included open-ended questions about what the firefighters perceived as positive and negative about the available information.

4 Results

During the experiment, we observed the performance of 150 firefighters that were composed to 75 teams. We could, however, not use all 75 observations for various reasons. For example, one team already knew the fire training building from a previous visit, another accidentally activated an emergency shutdown button, and one team was interrupted by a technical fault. All in all, we had to delete six observations from our initial sample, which resulted in an adjusted sample of 69 teams. Those remaining teams were equally distributed among the three groups, resulting in 23 observations per group.

Regarding our control variables, the participants were 27 years old on average, mainly male (>98%), have been members of a fire department for 12 years, and trained to wear SCBA for 7 years. On average, they respond to 26.48 emergency operations per year. Of those operations, they are wearing and actually applying SCBA 3.62 times a year. Looking at the command level, 24 of our participants had a team member qualification, 56 had a team leader qualification, 50 had a squad leader qualification, and the highest qualification of eight was the one of a platoon leader. Finally, most of our participants (>98%) were members of voluntary fire departments. To rule out possible influences, we calculated the correlation coefficients between our control and dependent variables. None of those coefficients are significant, however.

As stated before, our dependent variables are the task completion rate, the task completion time, and the three items of the ASQ (satisfaction with ease, satisfaction with time needed, and satisfaction with available information). We summarize the means and standard deviations of those factors for the three groups in Table 3. For all factors, there are first impressions of superiority for $\mathbf{G_1}$ and $\mathbf{G_2}$, which had graphical information available. Most dominantly, the means of the task completion times of $\mathbf{G_1}$ and $\mathbf{G_2}$ were lower than that of $\mathbf{G_0}$. Looking at the ASQ items, $\mathbf{G_1}$ showed the highest agreement, whereas $\mathbf{G_0}$ showed the lowest. Interestingly, it was not $\mathbf{G_2}$ with continuous graphical information that showed the best results, as our hypotheses implied. Instead, $\mathbf{G_1}$ with only punctual access to graphical information performed better.

Table 3. Descriptive summary and test statistics

	Group 0		*Group 1*		*Group 2*		*t-tests (p-values)*		
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	G_0 *vs* G_1	G_0 *vs* G_2	G_1 *vs* G_2
Task completion rate (0 or 1)	0.87	0.34	0.96	0.21	0.87	0.34	0.15	0.50	0.15
Task completion time (sec.)	340	100	285	78	289	67	0.02*	0.03*	0.41
ASQ 1	4.30	1.74	5.22	1.59	4.61	1.62	0.04*	0.27	0.10
ASQ 2	4.43	1.38	5.17	1.40	4.57	1.50	0.04*	0.38	0.08
ASQ 3	5.52	1.73	5.96	1.58	5.83	1.56	0.19	0.27	0.39

Legend: ASQ items from 1=disagree to 7=agree; *: $p < 0.05$, one-tailed testing, N=69, each group n=23)

To examine the statistical significance of those impressions, we employed t-tests to check for differences between the groups. Since our hypotheses implied an increased task completion rate, decreased task completion time, and increased task satisfaction for $\mathbf{G_1}$ and $\mathbf{G_2}$, we used one-tailed, unpaired t-tests. The test results are summarized in Table 3. As can be seen, there were no significant differences between the groups regarding task completion rate. Consequently, $\mathbf{H_1}$, which implies that a higher degree of graphical building information would help firefighters to perform their task more accurately, cannot be accepted. We could not identify any significant differences between control group $\mathbf{G_0}$ and treatment groups $\mathbf{G_1}$ and $\mathbf{G_2}$.

For task completion time, Table 3 indicates that the teams of both treatment groups $\mathbf{G_1}$ and $\mathbf{G_2}$ were significantly faster than the teams of control group $\mathbf{G_0}$. However, a significant difference between the two treatment groups could not be observed. For a more detailed insight into the task completion times, we generated boxplots that are shown in Figure 3. The more robust measures of the boxplots confirm the beforementioned results. The medians and quartiles of $\mathbf{G_1}$ and $\mathbf{G_2}$ are consistently below the ones of $\mathbf{G_0}$. The only visible difference between the treatment groups is the slightly higher median of $\mathbf{G_2}$. Overall, $\mathbf{H_2}$, which implies that firefighters provided with a higher degree of graphical building information would need less time to complete their task, can be partially accepted. Both forms of graphical information did make a significant difference compared to the verbal instruction. The degree of graphical information (i.e., punctual or continuous access) showed no further impact.

Looking at the task satisfaction, there are two significant differences in the ASQ item values (cf. Table 3). Members of $\mathbf{G_1}$ were more satisfied with the ease of completing the task and the time needed to complete it than members of $\mathbf{G_0}$. On the other hand, there were no significant differences regarding the satisfaction with the available information. In addition, the values of $\mathbf{G_2}$ show no significant difference to the other groups at all. Consequently, $\mathbf{H_3}$, which implies that a higher degree of graphical building information increases firefighters' task satisfaction, can again be partially accepted. The punctual access to graphical information during the briefing did raise the task satisfaction, while the continuous access to graphical information during the mission did not.

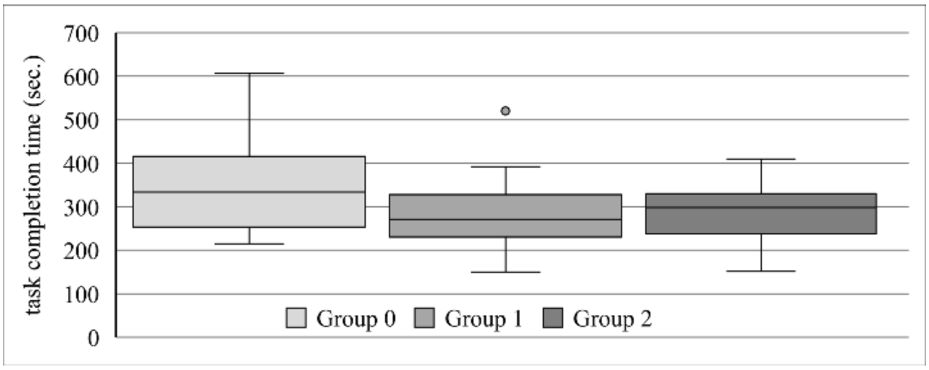

Figure 3. Boxplots for task completion time by groups

5 Discussion

In this section, we discuss our results in more detail. The discussion is informed by qualitative feedback gathered during the experiment, insights from reviewing the results with instructors of the firefighting academy, and scientific literature.

As shown in the previous section, our results only partially support the hypotheses. Regarding the task completion rate, there were no significant differences between the groups at all. Looking at the firefighters' qualitative feedback, all teams that were not able to complete their task stated physical exhaustion as the reason. They all managed to find the dummy but had to give up on their way out. None of the tasks failed due to insufficient information or lost orientation. Consequently, it seems that there has been no impact of our treatments toward the task completion rate.

With punctual graphical information, however, the firefighters could perform their task faster and were more satisfied than with verbal information. This outcome also corresponds to qualitative feedback from the participants. In $\mathbf{G_0}$, they criticized that they received *"too much information in a short time"* and that the information was *"misleading."* In $\mathbf{G_1}$, on the other hand, they praised the *"short overview"* that was *"well understandable"* and allowed a *"better orientation."* Opposed to our hypotheses, the continuous access to the graphical information did not bring further improvements. The firefighters belonging to $\mathbf{G_2}$ could perform their task faster than those of $\mathbf{G_0}$. The task satisfaction, however, was not significantly different. Between $\mathbf{G_1}$ and $\mathbf{G_2}$, there were no differences, at all. Possible reasons for this can again be found in the qualitative feedback. In $\mathbf{G_2}$, the firefighters saw a too strong *"distraction"* and *"fixation"* to the map that led to the problem of *"blindly relying on it"* and *"overlooking things."* Consulting the instructors of the firefighting academy, we identified the low complexity of the building as an additional explanation why there were no advantages in the continuous access to the graphical information. The layout of the apartment and the way to the dummy as it is displayed in Figure 2 might have been simple enough that the firefighters did not experience cognitive overload [22]. According to the instructors, though, a real-world apartment fire is rarely more complicated. It seems that for the scenario of apartment fires, a short look on the map simply suffices. In larger events with more complicated layouts like multiple burning apartments or a burning hospital, however, they see potential in the continuous access to the information.

Looking at the practical adoption, our experiment did not include the creation of the sketch-map. Since we wanted to provide the teams with standardized briefings for internal validity, the squad leader position was taken by a member of the research team. In reality, the squad leader would have to ask the house owner or neighbors for information about the building and draw the map according to it. The time effort of drawing must, of course, be opposed to the time gained by completing the task faster. According to the instructors, however, the squad leader would question knowledgeable attendants anyway. He would also have some short time to draw a map while the team is grabbing their equipment and preparing to enter the building. Of course, the much more favorable solution would be that the graphical building information is available already in advance to an emergency. This would save time and is not depending on the availability of attendants. One solution would be that house owners provide their local fire department with building plans and the department stores them in a database.

As stated before, the application in practice might benefit from using information technology. Of course, the first treatment of punctually presenting the graphical information may also work with simpler means like pen and paper. It is, however, unclear if the squad leader could be able to draw a sketch-map faster with electronic means like a drawing software on a tablet computer which provides predefined design elements. This should be examined in further experiments. In the previously discussed case that the graphical information might be available prior to an emergency, the pure amount of data would call for the use of information technology. Corresponding FITs that are discussed in literature are digital plans [1, 2] and on-site emergency response information systems [5, 6]. Making the information available continuously will, however, require the use of additional, more intricate information technologies. On the one hand, the information would have to be duplicated in real-time. While the sketch-map is given to the team, another instance of it should remain with the squad leader for his commanding duties on site. On the other hand, the map taken by the team would have to be heat-resistant, waterproof and readable in dark smoke. Instead of the paper approximation that we used in our experiment (cf. Figure 2), different FITs might be used in practice. Displays could be integrated into the sleeves of intelligent protective clothing [9]. Also, augmented reality systems could be used to display the graphical information in the firefighters' breathing masks [7]. A third approach was proposed by one of the participants. For the search for fires and victims, firefighters often carry infrared cameras with them. The displays of those cameras could also be used to show the sketch-map. This way, the firefighters would not have to carry any additional devices with them but could use systems they are already used to. It might indeed be the simplest, yet most acceptable solution for the practitioners. The performance of all those technological solutions should be examined in future research.

All in all, our results hold several implications for both academia and practice. Regarding academia, we present a task-centered approach to identify information potentials for a specific scenario and propose suitable technological solutions for firefighters. This constitutes an alternative approach compared to the mostly technology-driven development of FITs. The overall procedure can be transferred to many other problems. First, other scenarios from the firefighter domain can be examined in a similar way. From salvage rescues after car accidents to forest fires, there are many possible scenarios. Besides, the procedure can be applied to scenarios of other first responders like police or rescue departments as well. In the work at hand, we build on the theory of situation awareness. While this theory is well established in emergency management, it has by now mainly been used to examine higher levels of severity. In our study, we demonstrate its applicability in a comparably small-scale and everyday scenario. To increase situation awareness, we furthermore combine this theory with findings from cognitive science. In so doing, we also show the applicability of those findings in the special domain of firefighting and could even partly confirm them.

Regarding implications for practice, we showed a potential adaption of the firefighters' conventional procedure of getting to work as fast as possible, even with insufficient information. In our experiment, we could demonstrate the positive effects of improved situation awareness. By providing the firefighters with suitable and easy to process information like a sketch-map, the task completion time could be significantly reduced. Consequently, it might make sense for the squad leaders to take a little more time to establish situation awareness in order to gain overall time advantages. The involved instructors of the firefighting academy also support the findings of the experiment. They meanwhile integrate those findings into the squad leader courses held at the academy. They try to sensitize the firefighters for the importance of situation awareness even in time-critical operations and discuss how it can be established. All in all, our study demonstrates the potential of specific information for the firefighters. The developers of FITs can use our findings to provide firefighters with such information.

Although we implemented several measures to ensure internal and external validity, there are some limitations. First, we concentrated on the specific scenario of an apartment fire. Accordingly, our results will only be transferable to real operations of this type. By now, we only used paper approximations to display the information. Employing information technologies might increase or decrease the identified effects. Therefore, as a point of future research, the graphical information should be implemented in according technologies and analyzed in additional experiments. As stated above, the scenario was realistic but not very complex. To examine the potential of continuous access to the information in detail, more complex scenarios than search and rescue during an apartment fire should be analyzed. Furthermore, 98% of our subjects were members of a voluntary fire department. While voluntary and professional firefighters perform equal tasks in Germany, there might still be differences regarding the fitness level or training frequency. To strengthen our results, an additional experiment with professional firefighters might be wise. Finally, our sample of subjects consisted of firefighters from all over Bavaria. Since firefighting tasks and training are comparable in Germany, our results can be transferred to German firefighters. Due to differences in the organization of fire departments and emergency response processes, however, we cannot straightforwardly transfer the results to other countries.

6 Conclusion and Outlook

In an attempt to facilitate the design and implementation of suitable information technologies that provide adequate support for firefighters during critical everyday missions, we presented the results of a controlled experiment, in which we examined the efficacy of different kinds of information during the search and rescue task. During the planning of our study, the search and rescue task was identified as an important task, in which the performance might be affected negatively due to an insufficient information base. At the same time, various FITs have been suggested to also facilitate this task. In our study, we found indications that certain kinds of information about the building and the victims might be effective in enhancing the task performance. However, our findings also provide indications that the continuous access to such information (as it is, for instance provided with augmented reality devices) might not provide a further improvement. Judging from the findings of our study, the design of FITs hence ought to be carefully aligned to the task that is to be supported and the information demands.

In future iterations, we plan to strengthen both the theoretical implications and the conceptual foundations of our research. To examine the robustness of our findings, we will further increase the sample size. Moreover, we plan to re-evaluate our results in different scenarios and settings, for instance with varying building and situation complexity, with members of other types of departments (such as professional firefighters), or in settings where the squad leader only has ambiguous or incomplete information. Based on the gathered results, we plan to implement and test FITs that provide theoretically grounded and empirically proven support for the search and rescue task. To better guide the implementation of such FITs, we also intend to connect our findings to existing literature about indoor-navigation, wearable IT, and other domains, which might deliver additional insights for the task-centered design of FITs.

Although we have not formally tested it, we believe that the proposed procedure to examine the existing information demand and to explore ways to provide an adequate information basis before designing and implementing FITs based on their technological capabilities can also be used to support other tasks during the fire emergency response process. In future iterations, we therefore also intend to deduce a generally usable methodology to design FITs based on relevant theories and empirical evidence. With the presented study, we hope to provide a starting point to change the development of FITs from a primarily technology-driven into a mainly demand-driven process.

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