The effect of time pressure and task completion on the occurrence of cognitive lockup

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Abstract

Prior studies have suggested that time pressure and task completion play a role in the occurrence of cognitive lockup. However, supportive evidence is only partial. In this study, we conducted an experiment to investigate how both time pressure and task completion influence the occurrence of cognitive lockup, in order to better understand situations that could trigger the phenomenon. We found that if people have almost completed a task, the probability for cognitive lockup increases. We also found that the probability for cognitive lockup decreases, when people execute tasks for the second time. There was no effect of time pressure or an interaction effect found between task completion and time pressure. The results provide further support for the explanation that cognitive lockup up is the result of a decision making bias and that this bias could be triggered by the perception that a task is almost complete.

Introduction

This study is about an inescapable part of action, something all human beings experience to a greater or lesser extent: human error. Human errors can happen in everyday situations with only limited consequences. However, errors can also happen in high-performance environments like in aviation, where they can have tremendous effects and be life threatening. For instance, when pilots forget to enable their landing gear when landing and as a result crash. Hence, it is important to investigate why human errors in aviation are made and how errors can be avoided.

In the past, several cognitive explanations and theories have been proposed to understand why pilots deviate from normative activities (e.g. Wickens and Hollands, 2000; Dekker, 2003). The European project HUMAN (www.human.aero) strives to pave a way for making this knowledge readily available to designers of new cockpit systems, in order to be able to design cockpits that prevent pilots from making errors. They identified cognitive lockup to be among the most relevant mechanisms for modern and future cockpit human machine interfaces. Cognitive lockup is the tendency to deal with disturbances sequentially (Moray and Rotenberg, 1989). As a result of cognitive lockup operators are inclined to focus on the current task and are reluctant to switch to another task, even if that task has a higher priority (Neerincx, 2003). The following flight incident illustrates the possible consequences of cognitive lockup. During landing, the pilot of flight 401 of Eastern Air Lines (1973) was warned about a problem with the landing gear. To win time, the pilot canceled the landing, set the plane in the autopilot mode and started solving the problem with the landing gear. This problem fully occupied the pilot and multiple warnings about a decreasing altitude (a low-altitude alarm, a remark of the air-traffic controller) were ignored. As a consequence, the plane crashed, resulting in the death of most people on board.

Experimental studies exist where cognitive lockup was manifested in the data (Moray and Rotenberg, 1989; Kerstholt, Passenier, Houttuin and Schuffel, 1996), however, an explanation for the occurrence of the phenomenon was not given. The following literature overview provides accounts for the occurrence of the phenomenon.

Reduced situational awareness as trigger for cognitive lockup

A popular concept (Meij, 2004) is the idea that a reduced situational awareness (SA) might cause cognitive lockup. Kerstholt and Passenier (2000) argued that if operators become less aware of the actual situation, for instance, due to automation, they may not be able to understand the links between the various subsystems they have to control. If operators lack the knowledge of the underlying systems cognitive lockup is more likely to occur. Kerstholt and Passenier suggested that knowledge of the underlying systems is important in order to increase SA and prevent cognitive lockup.

Jones and Endsley (1996) investigated flight accidents caused by a reduced SA. They found that a great part of the flight accidents was due to a failure to monitor or observe relevant data that were clearly present in the situation. This type of accidents could also have been the result of cognitive lockup, as important tasks were that were triggered while dealing with another problem, were ignored. Therefore, it could be suggested that cognitive lockup is triggered by a failure to monitor the environment. However, Meij (2004) found in his study on cognitive lockup, that cognitive lockup could not be explained by a neglect of environment. Hence, a reduced SA and specifically the failure to monitor the environment seem not to be an underlying mechanism of cognitive lockup.

High cognitive workload as explanation for cognitive lockup

Cognitive workload refers to the information processing demands imposed by the performance of cognitive tasks (Johnson and Proctor, 2004). In order to predict the cognitive load of a specific task, Neerincx (2003) developed the cognitive task load (CTL) theory. This theory proposed three underlying factors of cognitive task load: (1) time occupied, (2) number of task set switches, which is the number of active tasks in execution or planned to do, and (3) level of information processing. Neerincx (2003) suggested that cognitive lockup would occur when time occupied and the number of task set switches are high. Grootjen, Neerincx and Veltman, (2006) conducted experiments in order to validate the CTL theory. In these real-life experiments participants had to deal with emergencies that appeared on a ship. They found that when all three factors were high people experienced cognitive overload; they did not know what to do. However, no evidence of cognitive lockup was found. Furthermore, Grootjen et al. (2006) found that in the overload situation, participants switched much more between tasks than in the optimal strategy. This result is likely to indicate that a high workload does not influence the occurrence of cognitive lockup.

In the same vein, Meij (2004) investigated whether a lack of cognitive resources could be an explanation for cognitive lockup. He argued that tasks that require a more complex diagnosis process are expected to demand more cognitive resources and thus cause a higher cognitive workload and might cause cognitive lockup. He found, however, that the level of complexity of information processing did not affect the degree of cognitive lockup. Hence, Meij (2004) indicated that cognitive lockup is not caused by the fact that people lack the cognitive resources to switch. This result underscores that it is likely that a high workload does not cause cognitive lockup.

Too high switching costs as explanation for cognitive lockup

When people switch between tasks, people are slower and less accurate than when they repeat tasks (Jersild, 1927; Monsell, 2003) and these switching costs have been attributed to a variety of processes. Pashler (1994) suggested that switching costs arise because of a cognitive bottleneck to process or select information. This means that when a cognitive process is devoted to a primary task, this process can not start for a second task. This second task has to wait, yielding switching costs. Schumacher (1999) and Meyer and Kieras (1997a, 1997b) argued that switching costs arise due to an executive control mechanism. They proposed a class of adaptive executive control models in which it is assumed that people have flexible control over the course of secondary task processing stages. They argued that the fact that switching costs arise is not due to a cognitive bottleneck but is rather optional and strategic. The reconfiguration to another task takes time and thus, switching costs arise.

Meij (2004) proposed that people might decide to stick to their current task because the switching costs that accompany task switching are perceived as too high. He found that cognitive lockup was reduced when it was obvious that the benefits of a switch to another task were higher than the costs of a switch. He argued that the participants were biased in their decision-making process, as the costs of switching to another task had to be disproportionally low before participants decided to abandon the current task. Although the results showed that the tendency for cognitive lockup was considerably reduced when the costs to switch were low, the tendency for cognitive lockup was still present. Therefore, Meij suggested that besides switching costs, other factors that trigger cognitive lockup are involved.

A decision making bias as trigger for cognitive lockup

A decision making bias refers to the fact that decision making can be influenced by a prejudice or 'one-sided' perspective. A bias can be unconscious or conscious in awareness. Meij (2004) believed that cognitive lockup is due to a decision making bias. When dealing with a task people decide to switch or not to switch to another task when triggered. This decision might be biased due to for instance a misperception of expected benefits. As a result, people could decide not to deal with an additional more urgent task until the ongoing task is dealt with. To find out whether cognitive lockup results from a decision making bias, Meij (2004) conducted several experiments with a fire control task. In this task participants had to extinguish fires on a ship in a computer simulation. When a fire appeared the participants had to detect the fire by clicking on the fire. After detection, participants had to extinguish the fire by selecting the right treatment. He used this task because in his first experiment he successfully demonstrated that cognitive lockup could be found using this task.

Meij (2004) proposed that both task completion and prior investments, such as money, time and effort, might bias the decision to switch to another task. Meij found that when prior investments are high and the task was near completion (high task completion), the probability for cognitive lockup increased. Remarkably, he also found that when prior investments are high and task completion is low, people have the tendency to abandon their task. Hence, the probability for cognitive lockup decreased. Meij argued that in the high prior investments condition perceived time pressure may be higher than in the low prior investments condition. This is because the available time in relation to invested time is lower in the high prior investments condition. Therefore, he attributed the effect of prior investments to the perception of time pressure. He suggested that when time pressure is perceived as high and the ongoing task is almost completed, people are more likely to stick to the ongoing task than in situations where time pressure is high and the ongoing task needs considerable activities in order to complete it. Thus, the results of Meij's experiments (2004) are likely to indicate that cognitive lockup is due to a decision making bias. This decision making bias seems to be triggered when time pressure and task completion are high.

Current study: the effect of time pressure and task completion on cognitive lockup

From the literature overview it seems that cognitive lockup is the result of a biased (un)conscious decision to focus on the current task and ignore others. Time pressure and task completion seem to influence this biased decision. The aim of this study is to investigate how both time pressure and task completion influence the occurrence of cognitive lockup. Therefore, this study extends the results found by Meij (2004). Furthermore, the aim is to identify critical situations in cockpit environments that allow for designing cockpit systems that help pilots avoid critical situations and decrease the probability for cognitive lockup. In the following subsections we translate the research question into hypotheses.

Time pressure. Time pressure is the perception that time is scarce. According to Beevis (1999) people experience time pressure when the time required to execute tasks is more than 70% of the total time available for the tasks. Beevis (1999) suggested that people experience high time pressure when 85% of the available time is required to execute the tasks. In this case performance is often impaired in that some tasks are not (well) executed. Other researchers (e.g. van der Kleij, 2009; De Dreu, 2003; Durham et al., 2000; Karau and Kelly, 1992; Kelly and Loving, 2004) indicated the following consequences of time pressure. At the individual level, time pressure leads to (1) faster performance rates, because people stop considering multiple alternatives, (2) lower performance quality, due to the engagement in superficial rather than thorough and systematic processing of information, and (3) more heuristic information processing, as a result of refraining from critical probing of a given seemingly adequate solution or judgment. At group level, increasing levels of time pressure narrows team members' focus on a limited range of task-salient cues in both team interaction patterns and team task performance. This narrow focus of attention that often manifests as a restricted information exchange is due to a filtering process (Kelly and Loving, 2004). Groups working under time pressure attend to all of the information available but then selectively discuss only information that seems especially relevant (Kelly and Loving, 2004). They also found that under high time pressure group members see task completion as their main interaction objective, and the group attempts to reach consensus and complete the task as quickly as possible, but at the sacrifice of quality. Groups under mild or no time pressure can, in contrast, consider a wider set of task features, devote their resources to performing on the task as well as possible, and tend to employ more effortful systematic information processing that gives serious considerations to all possible alternative solutions for a task (Kelly and Loving, 2004). Interestingly, DeDonno and Demaree (2008) found that the mere perception of time pressure as well as real time pressure impair performance.

Thus, time pressure can trigger heuristic information processing that make people focus on an ongoing task (van der Kleij, 2009; De Dreu, 2003; Durham et al., 2000; Karau and Kelly, 1992; Kelly and Loving, 2004). As a result, time pressure might influence the tendency to stick to the ongoing task and influence the occurrence of cognitive lockup. However, in situations where time pressure[1] was high Grootjen et al. (2006) found a high cognitive workload, but they found no relation to cognitive lockup. Therefore, we expect that the effect of time pressure alone is not strong enough to capture people in their current task. We propose the following hypothesis:

1. **Time pressure** has no effect on cognitive lockup. That means, in case people deal with a task, and another more urgent task is triggered, people switch to the more urgent task just as often under time pressure as when there is no time pressure.

Task completion. Task completion literature (Garland and Colon, 1993; Boehne and Paese, 2000; Humphrey S.E., Moon, H., Conlon, D.E., Hofmann D.A., 2004) shows that people have the tendency to complete a task even if it is economically unwise to do so. Garland and Colon (1993) and Boehne and Paese (2000) found that this tendency is strongest when 90% of the task is completed compared to 10% or 50% completion of a task. Meij (2004) found an effect of task completion on cognitive lockup. People tend to complete a task when they are almost finished (high task completion) even when a more urgent task is triggered. We expect that the results of Meij (2004) are replicated in this study. Therefore, we propose the following hypotheses:

2. **Task completion** has an effect on cognitive lockup.
    a. When task completion is high, the probability for cognitive lockup increases. That means, in case people deal with a task, and another more urgent task is triggered, people tend to stick to the current task, when they have almost completed this task.
    b. When task completion is low, the probability for cognitive lockup decreases. That means, in case people deal with a task, and another more urgent task is triggered, people tend to switch to the more urgent task when the first task is not nearly completed.

[1] In the research of Grootjen et al. (2006) time pressure was high when the percentage of the available time for a task that people are occupied with the task was high.

Interaction between time pressure and task completion. Meij (2004) suggested that when task completion and time pressure are high the tendency for cognitive lockup increases. When time pressure is high but task completion is low, the tendency for cognitive lockup decreases. In fact, he investigated the interaction effect between prior investments and task completion and attributed the effect of prior investments to the perception of time pressure. Thus, Meij never investigated the effect of time pressure and task completion. Therefore, in this study, we test whether high time pressure and high task completion indeed increase the probability for cognitive lockup and that high time pressure and low task completion decrease this probability, as suggested by Meij. We propose the following hypotheses.

3. There is an interaction effect between **task completion and time pressure** on cognitive lockup.
   a. When time pressure is high and task completion is high, the probability for cognitive lockup is highest compared to all other conditions. That means, in case people deal with a task, and another more urgent task is triggered, people tend to finish the first task before switching to the more urgent when they feel time pressure and have almost completed the first task.
   b. When time pressure is high and task completion is low, the probability for cognitive lockup is lowest compared to all other conditions. That means, in case people deal with a task, and another more urgent task is triggered, people tend to switch to the urgent task before executing the first task when they feel time pressure, but still need to complete many stages to complete the first task.

This study extends the study conducted by Meij (2004) as we expect to provide further evidence for the explanation that cognitive lockup is caused by a decision making bias, and that this bias could be triggered by time pressure and task completion.

Method

Participants

The experiment counted 46 participants. The participants consisted of:

- TNO trainees/employees (15)
- students of the University of Utrecht (20)
- (ex)members of the Hockey Club Rotterdam (6)
- other (5)

All participants were experienced computer users and most of them were highly educated. They were all between the age of 18 and 35 years old. Psychology students received course credits for participation in the experiment. All participants could win 20 Euro when they had the highest score in the experiment.

Apparatus and material

The experiment included two laptop computers with headphones. Java software was installed on the computers to run the experimental task and a training session. Before the experiment, participants received a hardcopy manual printed on paper with A4 format. During the experiment, participants could use a question-tree (see Figure 2) printed on paper with A4 format for reference purposes.

Procedure

The experiment was conducted at TNO in a computer room, at the University of Utrecht in a laboratory, and in a private setting with the use of laptops. The experiment took ca. 30 minutes per participant: 15 minutes for a training (including test scenarios) and 15 minutes for the experiment.

The participants received an information letter upfront the training and an informed consent document after the training. The aim of the training was to familiarize the participants with the experimental task. The training involved reading the training manual, which was accompanied by a verbal instruction and executing test scenarios on the computer. After the training the participants were asked whether they felt comfortable with performing the task. If so, the experiment was started. If not, questions could be asked and the test scenarios could be done again until the participant was comfortable with executing the task

The experimental task was a computer simulation in which participants had to fight fires on a ship. The fire-fighting software was chosen because Meij (2004) already demonstrated that with this fire-fighting task cognitive lockup could be found.

Experimental task. In the experimental task participants had to fight fires on a ship. Two types of fires existed:

- normal fires, which were indicated by a red triangle
- urgent fires, which fires were indicated by a blue triangle in a yellow background

Next to the fire type, fires had specific features. For example, a fire could be an oil fire, a fire could be life threatening, injured people could be involved, and/or smoke could trouble the sight of the firemen. Therefore, each fire required a specific action based on the fire's specific features. To find out the fire specifics, participants could ask four predefined questions. These questions appeared as buttons on the screen. To ask a question, participants had to press the question button. Figure 1 shows the screen that was visible to the participants once a fire was present. When a question was asked, the system closed for four seconds to answer the question with Y (Yes) or N (No) for a normal fire. In case of an urgent fire the system closed for one second to answer the question. This was because an urgent fire was more dangerous for the ship and needed quick handling. Please note that when the system was closed nothing could be done. Based on the answers generated by the system, participants could select the appropriate action to extinguish the fire. Figure 2 shows the question-tree which indicates the appropriate action. Seven predefined actions could be chosen. The action buttons also appeared on the bottom of the screen, once a fire was present (see Figure 1). An appropriate action extinguished the fire; a wrong action shut down the system for seven seconds. Thereafter, a new action could be selected, if time allowed it.

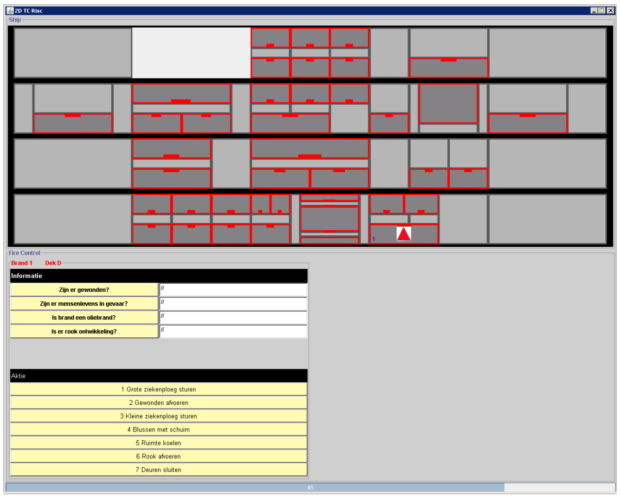

Figure 1: Screen of the ship visible to participants once a fire was present.

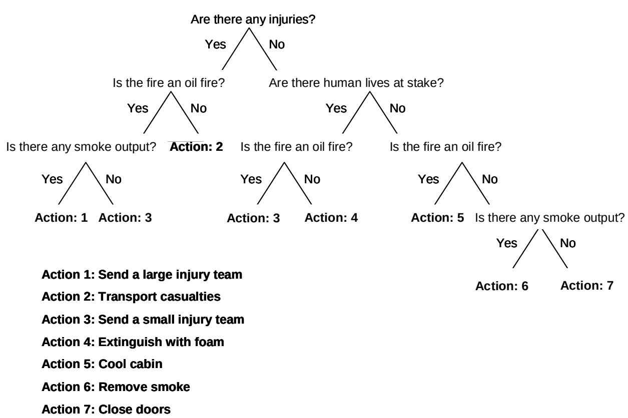

Figure 2: Question-tree and relevant actions to extinguish fires.

Participants knew how much time they had to extinguish the first fire, as this was indicated by the timer at the bottom of the screen. The time to stop a second fire was not indicated. This was done to make the decision to switch to the second fire similar for the different test scenarios (see scenarios). In case the time available would be shown for the second fire as well as, participants could depend their decision to switch on the time available for both fires. In the high task completion condition relatively little time would be left for the first fire and therefore relatively more time would be left to extinguish the second fire, which would give the incentive to finish the first fire. In the low task completion condition relatively much time would be left to extinguish the first fire, and relatively less time would be left to extinguish the second fire. This would give the incentive to switch to the second fire. As a result the switch incentives in these situations would not be comparable. This problem was solved by not showing the time available for the second fire.

If participants extinguished a fire in time they could win points. However, if they did not extinguish the fire in time, points were deducted and a burn down was the result (see Table 1). This was done to emphasize the fact that an urgent fire was more urgent than a normal fire, as more points could be won or lost by respectively extinguishing or missing an urgent fire. If one fire burned down, another fire could still be extinguished if time allowed it.

In the test scenarios (see scenarios) the second fire was always an urgent fire. The time was set in such a way that if a participant finished the first fire before switching to the urgent fire, the urgent fire would burn down. This was also done to emphasize the fact that an urgent fire was urgent. If it was not handled quickly it burned down. This also meant that if participants suffered from cognitive lockup (finishing the first fire instead of extinguishing the urgent fire first), they would have had a lower score than participants who did not suffer cognitive lockup. To ensure the motivation of the participants a reward of 20 Euro was promised to the participant with the highest score. Participants only saw their score at the end of the experiment.

Table 1: Fire-fighting scores.

Action	Points
Extinguish normal fire	1
Extinguish urgent fire	3
Burn down normal fire	-1
Burn down urgent fire	-3

Experimental design

The main goal of this experiment was to investigate how time pressure and task completion influence the occurrence of cognitive lockup. In order to enhance the sensitiveness to find cognitive lockup, we operationalized cognitive lockup in two ways. In the first definition cognitive lockup was only found when participants did not switch to the urgent fire, when dealing with the first fire. In the second definition cognitive lockup was found when participants significantly delayed their switch to the urgent fire. Therefore, the second analysis was more sensitive to find cognitive lockup than the first analysis.

1) Cognitive lockup 1 was defined as completing the first fire before extinguishing the second more urgent fire. Cognitive lockup 1 was measured as the mean percentage of scenarios in which cognitive lockup occur.
2) Cognitive lockup 2 was defined as delayed switching to the second more urgent task once presented, while executing a first task. Cognitive lockup 2 was measured as the action time to switch to the urgent fire, once present (a significantly delayed action time indicates cognitive lockup).

In order to investigate the influence of time pressure and task completion on cognitive lockup, time pressure and task completion were manipulated within-subjects.

Task completion. Task completion was defined as the percentage of the total number of stages of a task that have been completed. People have the tendency to stick to their current task when 90% or more of the total stages of a task have been completed (Boehne and Pease, 2000; Garland and Colon, 1993). We investigated whether people refrain from switching to an urgent second task, when they have almost completed a first task. Therefore, task completion was manipulated by the onset of the urgent fire. The onset depended on the number of questions that had been asked in order to extinguish the first fire. In the high task completion condition the urgent fire appeared after three questions had been asked. In this condition task completion of the first task was 75%, as 75% of the total stages of the task had been completed (three questions answered out of four). This percentage was chosen because this was the pre-final stage for extinguishing the first fire, and closest to 90% task completion as mentioned by Boehne and Pease (2000) and Garland and Colon (1993). In the low task completion condition the urgent fire appeared after one question had been asked. In this case task completion was 25%, as 25% of the total stages of the first task had been completed (one question answered out of four).

Time pressure. Time pressure was defined as the percentage of the available time to execute a task that is required to execute the task. People experience time pressure when 70% or more of the available time is required for the task (Beevis, 1999). People experience high time pressure when 85% of the available time is required for the task (Beevis, 1999). The average time to fight a fire depended on the number of questions that had to be asked to extinguish a fire. Based on the pilot results it appeared that for a normal fire the time required to extinguish a fire based on four questions was 22,1 seconds; based on three questions this was 18,6 seconds and based on two questions this was 14,3 seconds. We investigated whether time pressure on a first task would refrain people from switching to a second more urgent task. Therefore, time pressure was manipulated. This was achieved by increasing or decreasing the time available for fighting the first fire.

In the high time pressure condition the available time to extinguish the first fire was 25 seconds for fires that needed four questions and 20 seconds for fires that needed three questions. Fires that needed two questions were not present in the test scenarios (see scenarios). In this way time pressure was ≥ 88%, as 88% or more of the available time was required for the task. As a result, in the high time pressure and high task completion scenario the available time to extinguish the first fire was almost over when the urgent fire appeared. Therefore, participants had to choose for the urgent fire at the cost of a burn down of the first fire in this condition. Thus, they could never obtain the total payoff of four points in this scenario. They could also choose to extinguish the first fire first, but in that case the urgent fire would burn down as explained before.

In the low time pressure condition the available time to extinguish the first fire was 55 seconds for all fires. In this condition time pressure was ≤ 40%, as 40% or less of the available time was required for the task. The available time of 55 seconds was chosen because perceived time pressure of the first fire could be influenced by the appearance of the second more urgent fire. To make sure that participants would perceive little time pressure in the low time pressure condition, 55 seconds allowed the participants to start with the first fire, and when the urgent fire appeared to switch to the urgent fire and once the urgent fire was extinguished, to switch to the first fire again and extinguish the first fire. Thus, in the low time pressure scenarios the maximum score of four points could be obtained. Table 2 summarizes the test conditions in terms of task completion and time pressure.

Table 2: Test conditions.

Test condition	Time pressure (%)	Task completion (%)
Low-Low	≤ 40	25
Low- High	≤ 40	75
High-Low	≥ 88	25
High-High	≥ 88	75

Scenarios. The experiment consisted of 25 scenarios. The scenarios included 8 test scenarios (2 times all test conditions) and 17 irrelevant scenarios. The irrelevant scenarios were designed in order to accomplish uncertainty, so the participants would not understand the test scenarios. The test scenarios can be described as follows:

1. In the scenario where time pressure was low and task completion was low, participants had 55 seconds to fight the first fire. The urgent fire appeared when they had asked one question of the first fire. The urgent fire needed to be extinguished in 17 seconds. If participants decided to extinguish the first fire first, the available time allowed participants to start with the urgent fire, after they had extinguished the first fire, but they would never be able to extinguish it. In this way the participants would not be demotivated, which would be the case when the urgent fire had already burned down, while still fighting the first fire.
2. In the scenario where time pressure was low and task completion was high, participants had 55 seconds to fight the first fire. The urgent fire appeared when they had asked three questions of the first fire. The urgent fire needed to be extinguished in 13 seconds. In this way it was impossible to extinguish the first fire first, and afterwards extinguish the urgent fire.
3. In the scenario where time pressure was high and task completion was low, participants had 20 seconds to fight the first fire. This was because the first fire could be extinguished after three questions. The urgent fire appeared when they had asked one

question of the first fire. Like scenario 1, the urgent fire needed to be extinguished in 17 seconds.

4. In the scenario where time pressure was high and task completion was high, participants had 25 seconds to fight the first fire. This was because the first fire could only be extinguished after four questions. The urgent fire appeared when they had asked three questions of the first fire. Like scenario 2 the urgent fire needed to be extinguished in 13 seconds.

The scenarios (test and irrelevant scenarios) were presented in random order to avoid order effects. Only the test scenarios were analyzed.

Statistical design

The experimental design was a repeated measures design, as each test condition consisted of two scenarios. Thus, the participants received all test conditions twice. Therefore, we used a 2x2x2 repeated measures ANOVA with attempts, time pressure and task completion as factors to analyze the data.

Before the experiment was executed, we conducted a power analysis in order to examine the number of participants needed for the experimental design. The power analysis for a factorial ANOVA suggested a sample size (N) of 45 to achieve a power of 0.80 for detecting a medium effect size (0.26) and alpha set at 0.05. Hence, this design required a sample size of 45 participants to be able to conduct further statistical analysis. Based on this result, 46 participants were recruited.

Results

Sample data

In the experiment 46 cases with two repeated measures were recorded. Three records were removed as one participant did not follow the experiment instruction correctly and pressed action buttons without asking questions. Therefore, this data could not be analyzed as the urgent fire was not triggered. Table 3 shows the number of valid records per test condition.

Table 3: Number of valid records per test condition.

Test condition		Number of records	
Time Pressure	Task Completion	Attempt 1	Attempt 2
Low	Low	46	46
Low	High	45	45
High	Low	46	46
High	High	45	46

Cognitive lockup 1

Figure 3 shows the mean percentage of scenarios in which cognitive lockup 1 (CL1) was found, taking time pressure and task completion into account. In other words, the Figure shows the mean percentage of scenarios in which the normal fire was extinguished before the participants switched to the more urgent second fire.

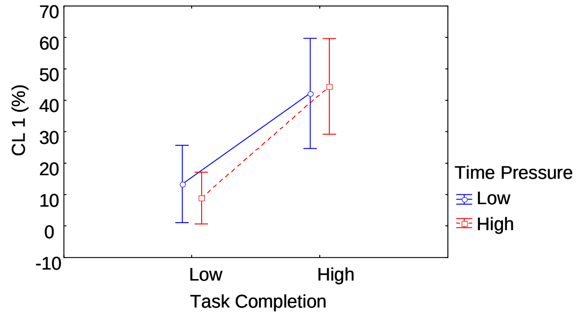

Figure 3: The mean percentage of scenarios in which CL1 was found.

The main effect of task completion on CL1 was significant, $F(1,44) = 36.857$, $p < .001$. This means that the percentage of scenarios in which CL1 was found was significantly higher in the high condition (Mean = 43%) compared to the low condition (Mean = 11%). In other words when participants had almost extinguished the first fire (one question to go to find out the correct action) more people finished the first fire before switching to the urgent fire than when the participants still had three questions to go to find out the correct action. There was no effect of time pressure or an interaction effect found between task completion and time pressure on CL1. Next to these results, a significant main effect was found for the factor attempts (not shown in Figure 3). The participants received all test conditions twice. The results show that the mean percentage of scenarios in which CL1 was found was significantly higher in the first attempt (Mean = 34%) compared to the second attempt (Mean = 21%) $F(1,44) = 10.203$ $p < .003$. This indicates a learning effect.

Figure 4 shows the results for attempt 1 and 2 separately. For both attempt 1 and 2, a significant main effect for task completion was found $F(1,44) = 26.362$, $p < .001$ and $F(1,44) = 24.750$, $p < .001$, respectively. No effect was found for time pressure. In addition, no interaction effect between time pressure and task completion was found.

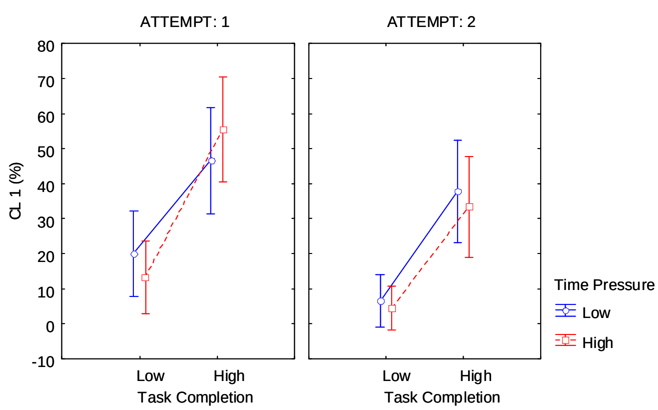

Figure 4: The mean percentage of scenarios in which CL1 was found for attempt 1 and 2.

Cognitive lockup 2

Figure 5 shows the mean reaction times of participants to switch to the second more urgent fire, while fighting the first fire. Cognitive lockup 2 (CL2) was found when the reaction times were significantly longer in a specific condition.

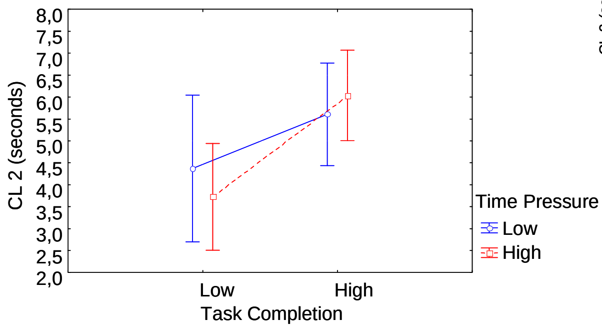

Figure 5: Time needed in seconds to switch to the urgent fire.

The main effect of task completion on CL2 was significant, F(1,44) = 15.182, p < *.001*. This means that the participants needed more time to switch to the urgent fire in the high condition (Mean = 5,9 seconds) compared to the low condition (Mean = 4,1 seconds). In other words, when participants had already asked three questions of the first fire, it took significantly longer to switch to the urgent fire compared to the situation where they had only asked one question. The average time to 'switch' to the first fire, once it was present, was 1,1 second. There was no effect of time pressure or an interaction effect found between task completion and time pressure on CL2. Next to these results, a significant main effect was found for the factor attempt (not shown in Figure 5). The participants received all test conditions twice. The results show that it took longer to switch to the urgent fire in the first attempt (Mean = 5,8 seconds) compared to the second attempt (Mean = 4,1 seconds; F(1,44) = 15,444 p < *.001*). This indicates a learning effect.

Figure 6 shows the results for attempt 1 and attempt 2 separately. For both attempt 1 and 2, a significant main effect for task completion was found F(1,44) = 5.922, p < *.019* and F(1,44)= 14.404, p < *.001* respectively. No effect was found for time pressure. In addition, no interaction effect between time pressure and task completion was found.

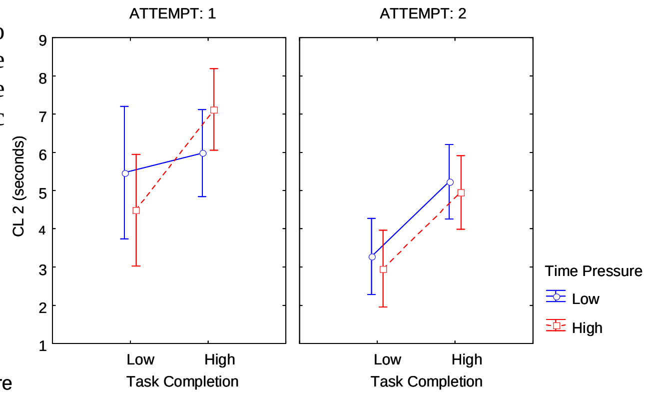

Figure 6: Time needed in seconds to switch to the urgent fire for attempt 1 and 2.

General Discussions

The main goal of this experiment was to investigate how both time pressure and task completion influence the occurrence of cognitive lockup. Firstly, we hypothesized that time pressure alone would not have an effect on cognitive lockup (hypothesis 1). The results of the experiment support this hypothesis. In case people deal with a task, and another more urgent task is triggered, people switch to the more urgent task just as often and just as fast under time pressure as when there is no time pressure. This result implies that although time pressure can trigger heuristic information processing and thereby influence decision making (e.g. van der Kleij, 2009; De Dreu, 2003; Durham et al., 2000; Karau and Kelly, 1992; Kelly and Loving, 2004), people are able to assess the priority of different tasks while dealing with a task, and switch to the most important task if necessary. They are not captured in their current task when facing time pressure.

We should mention that in the high time pressure and high task completion condition there was an incentive to extinguish the normal fire first, before switching to the urgent fire. As a result, this incentive stimulated the chance to find cognitive lockup. The incentive existed because a choice had to be made between the normal fire and the urgent fire. While dealing with the normal fire, participants could see that if they switched to the urgent fire, they would miss the normal fire. However, if they extinguished the normal fire, there was only a chance that they would miss the urgent fire. The participants did not know that the maximum number of points could never be obtained, as they would indeed miss the urgent fire, when they extinguished the normal fire first. Participants with a risk avoiding strategy would switch to the urgent fire as this fire could be missed if they did not switch immediately (two points versus minus two points). However, participants that were very confident with extinguishing the fires and who had a risky result maximizing strategy could try to extinguish both fires instead of one (four points versus two points). They would extinguish the normal fire first. In this way, there was an incentive to finish the normal fire first in the high task completion and high time pressure condition. While this incentive was present, nevertheless participants decided to switch to the urgent fire in the high time pressure and high task completion condition as often as in the low time pressure and high task completion condition. This underscores our finding that time pressure has no influence on the occurrence of cognitive lockup.

Furthermore, we should notice that we used a static time deadline to manipulate time pressure. Other ways exist to induce time pressure. For example, a more dynamic task can be used in which deadlines evolve with different speed. This type of dynamic time pressure might have different effects on performance (Kerstholt and Willems, 1993). As a consequence, the results of this study only apply to settings in which time pressure is induced by a static deadline. Further research is needed to analyze the effect on behavior when time pressure is dynamic.

Secondly, we hypothesized that task completion would have an effect on cognitive lockup (hypothesis 2). The results of the experiment support this hypothesis. The results show that there is a main effect of task completion on cognitive lockup (CL1 and CL2). People that have almost completed a task tend to finish this task even when a more urgent task is triggered. In other words, when task completion is high the probability for cognitive lockup increases (hypotheses 2a). People that still need to complete many stages before a task is completed tend to switch to the more urgent task, when triggered. Thus, when task completion is low the probability for cognitive lockup decreases (hypotheses 2b). These results were found despite a learning effect. We found that cognitive lockup was less present during the second attempt of a test scenario compared to the first attempt. We believe that this was due to a learning effect. People learned from the feedback they received in the first attempt of a scenario, and if needed they changed their strategy in the second attempt. However, the task completion effect remained significant in the second attempt. Thus, although participants lost points when they completed the first fire and as a result missed the urgent fire in the first attempt of the high task completion scenario, they did not change their strategy when the scenario was executed again.

It could be argued that the participants might not have perceived the urge of the urgent fires and as a result stayed with the normal fires. Although the urgent fires had a very different icon, behaved differently (system closure of one second instead of four after a button had been pressed) and generated more (less) points when extinguished (burned down) than normal fires, the categorization might not have been meaningful enough for the participants. However, participants showed in the high time pressure and high task completion condition, in which they had to choose between the urgent and normal fire, that they switched to the urgent fire as often as in the low time pressure and high task completion condition. Such behavior would not have been expected when categorization and consequences were not clear.

This study replicates the results of Meij (2004) as he also found an effect of task completion on cognitive lockup. Furthermore, this finding extends the results reported by Boehne and Pease (2000) and Garland and Colon (1993). In their experiments they found the tendency to complete a task when the task has already been completed for 90%. The present study shows that this tendency is already present when a task has been completed for 75%. In our experimental setup this was achieved when three task stages had been completed out of a maximum number of four stages. It could be argued that participants perceived a higher task completion percentage as only one stage was still required to complete the task.

These results imply that the perception that a task is almost competed could lead to critical situations when another more urgent task is triggered. This urgent task might be ignored as a result of cognitive lockup. In order to avoid cognitive lockup we believe that the tendency to complete a task when it is almost completed should be broken. For instance, this might be done by altering the perception that a task is almost completed or by unlearning this tendency. Further research is needed to investigate how to break the tendency to complete a task when it has almost been completed and a more urgent task is triggered.

Finally, according to the results of Meij (2004) we hypothesized that there would be an interaction effect between time pressure and task completion (hypothesis 3). The results do not support this hypothesis as the interaction effect between time pressure and task completion on cognitive lockup (CL1 and CL2) was not significant. The result implies that time pressure does not enhance the task completion effect, as expected. Thus, when task completion is high the probability for cognitive lockup is not increased when people face time pressure. The present study shows that the interaction effect found by Meij (2004) between prior investments and task completion on cognitive lockup cannot be explained by the perception of time pressure when prior investments are high, as he suggested. An alternative explanation cannot be given as prior investments were not investigated in this experiment. Further research should be done to find an explanation for the effect of prior investments on cognitive lockup and why this factor interacts with task completion.

The results of this study provide further support for the explanation that cognitive lockup up is the result of a decision making bias and that this bias could be triggered by the perception that a task is almost completed. This has important implications for the designs of cockpits, as it indicates that decision support tools seem more important in reducing the probability for cognitive lockup than, for example, tools that reduce cognitive workload. The decision support tool should assist pilots to focus on the most urgent task. However, a critical situation exists when the pilot has almost completed a task and a more urgent task is triggered. The decision support tool might be ignored, as a result of cognitive lockup. To avoid critical situations it is important that this decision support tool also helps pilots to break the tendency to complete a task when it is almost finished and another more urgent task is triggered. In this way pilots can act appropriately and deal with the most urgent task.

Training

Although the experimental design was not specifically built to investigate an effect of training, a significant learning effect was found. Participants showed less cognitive lockup (CL1 and CL2) the second time they executed the test scenarios, compared to the first time. As mentioned before, we believe that participants learned from the feedback they received in the first attempt of a scenario. When participants decided to stick to the first fire, it resulted in a burn down of the urgent fire. Their payoff in that scenario would have been minus two. As participants executed the test scenarios twice, they adjusted their strategy in order to improve their payoff. This finding supports the results reported by Kerstholt and Passenier (2000). They suggested that if people understood the underlying system, cognitive lockup was less likely to occur. Training might therefore be a factor that influences cognitive lockup as it increases the knowledge of a system and thereby reduces the probability for cognitive lockup. For the design of cockpits this implies that the decision to automate processes should be done carefully. This is because automation might decrease the understanding of underlying systems as operators are not involved anymore in the normal process (Wickens and Hollands, 2000; Kerstholt and Passenier, 2000). As a result, the likelihood for cognitive lockup might increase. Further research should be done to provide evidence for the suggested effect of training on the occurrence of cognitive lockup.

Task domain and participants

It can be argued that the experiment was conducted in a specific task domain (fire-fighting task) and with a specific set of participants and that generalizing the results should be done carefully. We assume that cognitive lockup is a general cognitive mechanism or heuristic that is domain independent and can happen to every human being. This assumption is based on the fact that heuristics that are used to solve well defined problems are general-purpose or domain independent heuristics, in that they can be applied to a wide range of situations or domains and do not involve specific capabilities (Groom, 2002). Well defined problems are well specified and the knowledge required to find the solution is present in the instructions given, e.g. a puzzle (Groom, 2002). The fire fighting task used in this experiment can be regarded as a well defined problem. As cognitive lockup was found in this problem solving setting, cognitive lockup is assumed to be a general purpose heuristic. This implies that although the results are obtained in a fire-fighting domain, they can be applied to any other domain. The same applies for the sample that has been used. The participants of the experiment were Dutch, between 18-32 years old and most of them were highly educated. As we assume that cognitive lockup does not depend on specific capabilities, we suggest that the results from this sample can be applied to human beings in general.

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