Overview maintenance in man-machine environments: applications in ship navigation
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7. SUMMARY AND CONCLUSIONS

The main aim of this dissertation was to shed light on overview maintenance, which is crucial for operating in complex man-machine environments. Inspired by studies from related fields, a number of factors were examined that were hypothesised to influence overview maintenance in general man-machine settings, and the ship’s bridge in particular.

This chapter summarises and discusses the results of the research into these factors, and provides starting points for future research and applications in the field.

7.1. BACKGROUND

The ship’s bridge is a good example of a man-machine environment in which overview maintenance is crucial, and in which operators may lose overview. Therefore, the ship’s bridge formed the starting-point of this dissertation. Having set the scene, and having familiarised this man-machine environment and it’s hazards, definitions were formulated of overview maintenance and overview loss. Since ‘having overview’ is not discussed in literature as such, the formulated definitions were used to seek links with related fields of research. Particularly the research into ‘attention narrowing’ provided starting-points for factors that might increase the risk of overview loss.

7.1.1. The importance of overview maintenance on a ship’s bridge

The ship’s bridge is an example of a complex and dynamic man-machine system in which overview maintenance is crucial. This dissertation distinguished three main tasks of watch officers on a bridge: 1) navigation, 2) guarantee of safety, and 3) general interaction. These tasks consist of many subtasks among which the watch officer has to divide his attention. In more detail, the watch officer has to plan and execute appropriate actions, adjust plans, anticipate events, communicate with internal and external parties, and delegate tasks to other crew members if mental workload becomes too high. Above all, the watch officer has to maintain overview. However, the setting of a ship’s bridge contains too much information to oversee at a glance. Therefore, the watch keeper has to alternate his attention among all the relevant information sources and tasks. Engaging information may preoccupy the watch officer, with the result that he may fail to monitor other relevant information sources, and loses overview.

7.1.2. Maintenance and loss of overview: theoretical background

In common sense, having overview means ‘knowing what is going on’. Since this definition is however not clear enough for research, this dissertation defines having overview as *'an understanding of the integrated state of all relevant information sources in the environment'*. This definition is based on three stages: 1) frequently monitoring of all the relevant information, 2) integration of the information that is collected, and 3) understanding what the integrated information means. Understanding is based on a matching process between perceived information and relevant knowledge frameworks in long-term memory. The matching process is mediated by attention and takes place in working memory.
7. Conclusions

This dissertation particularly focused on failures in the first stage, which are failures to attend all relevant information sources in time due to preoccupation with one source of information. This phenomenon is also known as ‘attention narrowing’ and is defined as ‘overattending some information sources at the expense of others’. Attention narrowing can be very dangerous if operators fail to notice important changes in an unattended part of the environment. For this reason, it is important to know what (kind of) factors increase the risk of attention narrowing and overview loss.

To find factors that could be a hazard for overview maintenance, first a literature search was performed. However, since ‘having overview’ is not a commonly used term, literature of more commonly used related topics, such as ‘mental models’ and ‘situation awareness’ (SA), was examined. Both concepts refer to ‘knowing what is going on’ but did not offer many useful links to ‘overview loss’ as defined in this dissertation. It appeared that the concept of a ‘mental picture’ is particularly used in a descriptive sense, and does not necessarily include knowledge or understanding of the whole situation, which is important to ‘having overview’. ‘SA’, which was the second concept that was examined, appeared to refer to knowledge of the whole situation and thus includes the range of attention, although, not explicitly. However, there appeared to be not much consensus about a definition of ‘SA’, and no research was found of factors that may increase the risk of overview loss as defined in this dissertation. Only a number of studies into the phenomenon of ‘attention narrowing’ offered some links to factors that could cause overview loss.

7.1.2.1. Factors that may affect ability to maintain overview: research topics

The factors that were examined in this dissertation in relation to overview maintenance were all inspired by previous research into or related to attention narrowing10.

The earliest studies into attention narrowing found the phenomenon particularly in relation to high activation levels, induced by stress (e.g. Baddeley, 1972; Callaway & Dembo, 1958; Wachtel, 1968) or high (biological) interest (e.g. Hernández-Peón, 1964). The findings raised the question whether operators would also suffer from attention narrowing and overview loss if they would experience high cognitive activation levels, for instance induced by processing complex, difficult, or unfamiliar information. This hypothesis was illustrated by the metaphor of a spot-light or zoom lens (e.g. Erikson & St. James, 1986; Hernández-Peón, 1964; McCormick & Klein, 1990): the more attention is focused on information, the narrower the range of attention, with the result of overview loss.

From more recent studies that also found attention narrowing during problem solving in man-machine environments (e.g. Moray & Rotenberg, 1989), the idea raised that some individuals are better at maintaining overview than others (e.g. Boer & Van Schie, 2000; Kerstholt & Passenier, 2000). However, overview maintenance is a complex higher-order process that consists of a number of subactivities that may depend on the situation or performance context. This raised the question how consistent such an ability to maintain overview would be over situations and performance contexts. There was evidence from a

10 Particularly more recent studies use other labels for a specific kind of attention narrowing that is related to the formulation of hypotheses about a fault. Examples are: ‘cognitive narrowing’ (Sheridan, 1981), ‘cognitive tunnel vision’ (Moray, 1981), and ‘cognitive lock-up’ (Moray & Rotenberg, 1989). These terms are for instance used in research of Boer, and Kerstholt and Passenier.
number of studies that individual ability in higher-order processes is only consistent over situations when subtasks are very similar (e.g. Jennings & Chiles, 1977; Wickens, Mountford & Scheiner, 1981).

To maintain overview, operators have to monitor the whole environment and alternate their attention among all relevant information sources, which is a process that costs effort. Individuals however, have a strong tendency to reduce effort investment (e.g. Johnston & Heinz, 1978). This raised the question whether psychological states, which act on the willingness or ability to invest effort in task performance, affect the ability to maintain overview. Relevant psychological states that were examined were tiredness and motivation. Indeed, tired operators showed a decreased tendency to monitor their environment (Drew, 1940) and a reduced willingness to invest effort in task performance (Krueger, 1991). From literature of attention narrowing in relation to motivation, it appeared that studies had focused in particular on the effects of motivation to perform one task well, which increased the tendency of attention narrowing (e.g. Bahrick, Fitts and Rankin, 1952). This dissertation however, hypothesised that overall motivation would increase ability to maintain overview. Operators who are motivated to perform all tasks well may invest more effort in alternating their attention among all relevant information sources, making them better able to maintain overview.

7.2. Empirical findings

This dissertation examined three main factors in relation to overview maintenance and overview loss: 1) the engaging properties of (components of) information sources or tasks, 2) individual and relatively stable cognitive abilities of the operator, and 3) the variable psychological state of the operator that results from task- and personality properties. These factors were examined in two kinds of studies: general factors affecting overview maintenance were investigated by means of a generalised man-machine laboratory test. Factors that could specifically affect overview maintenance on a ship's bridge were investigated by means of high-fidelity bridge-simulator tests, using nautical experts as participants.

All tests consisted of a number of information sources that operators had to monitor. The information sources, however, were not all simultaneously visible, and operators had to alternate their attention frequently between these sources to maintain overview. In order to give operators a reason to attend the information sources, each source was linked to a task. In general, the tests consisted of a primary information source/task that had to be monitored and performed in time. Additionally, operators were distracted by secondary tasks, which consisted of problems to solve or incidents to manage. These secondary tasks were engaging and had potential to preoccupy the operator so much that he would lose overview.

7.2.1. General applicable results

The first question of this dissertation was whether engaging tasks and information that requires knowledge-based processing (cf. Rasmussen, 1983) increases the risk of overview loss. The second question was whether overview maintenance is a general ability on which individuals differ or a task- and situation dependent ability. The third question concerned the influence of the operator's psychological state on overview maintenance. Psychological states that increase willingness to invest effort in task performance, such as motivation, were
7. Conclusions

Hypothesised to enhance overview maintenance. Psychological states that reduce the willingness to put effort in task performance, such as fatigue, were hypothesised to have the reverse effect and increase the risk of overview loss.

7.2.1.1. Engaging information and overview maintenance

The main hypothesis was that engaging information increases the risk of attention narrowing and overview loss. The experiments in this dissertation indeed provided evidence that engaging activities, such as problem solving and managing unexpected situations, preoccupied participants to such an extent that they failed to monitor their primary information source in time. If information is difficult, operators are even at a greater risk to become preoccupied and lose overview. Instead, familiarity with particular information decreased the tendency to be preoccupied since operators knew how to manage the situation. Increased mental workload during solving difficult problems was highly associated with attention narrowing, as was also found in other studies (e.g. Baddeley, 1972; Callaway & Dembo, 1958). Although operators had the choice to shift their task-performance priorities towards the more important primary information source, they often failed to do so. Overview maintenance was enhanced when operators applied frequent attention alternation between the information sources. There were also indications that random alternation strategies were related to an increased risk of overview loss, since operators performed without any sense for the dynamics of the system.

Knowledge of information characteristics that are a hazard for overview maintenance may increase alertness and affect measures in man-machine environments. To prevent overview loss, it is important that operators of man-machine systems, such as a ship’s bridge, can delegate tasks if they encounter too engaging information and their mental workload becomes too high. Intelligent and automatic operator support that provides information in appropriate and clear chunks that are adapted to human information processing limits may also contribute to safer operation. However, such measures require that operators recognise hazardous situations that may provoke overview loss. Training may be important to become familiar with all kinds of hazards as might occur in the system. Familiarity with many problems may reduce the number of situations that have to be managed at a knowledge-based level. Overview maintenance may benefit from skill-based or rule-based information processing (cf. Rasmussen, 1983), which relies on training. Emphasis on task delegation and clear communication may also enhance safety and reduce the demand on operators. These measures require discipline in continuous critical self-monitoring of the operator on duty, and well adjustment of operator performance to the dynamics of the system and its environment. Even explicit training of attention allocation may offer prospects for improving overview maintenance in complex man-machine environments (e.g. Gopher, 1993). More research is required to establish the findings of this dissertation in more detail, and to focus on the usability of applications.

7.2.1.2. Individual differences in the ability to maintain overview

Two experiments in this dissertation provided evidence that operators have a consistent ability to maintain overview over different task contexts (i.e. a lab context versus a more realistic shipping context) as long as subtasks and processing requirements are very similar in the
situations that are compared. From this finding, we may conclude that overview maintenance is not a specific ability. It is rather a construction of abilities related to performance of basic tasks that underlie the task-ensemble over which the operator has to maintain overview. This conclusion is in agreement with evidence of studies into other higher-order skills (e.g. Jennings & Chiles, 1977; Wickens, Mountford & Schreiner, 1981).

The findings in this dissertation do only offer prospects for selecting future operators on a general ability to maintain overview if the testing situation and the realistic environment where the operator is going to perform are very similar in task paradigm and also in performance measures that are used. These points may be difficult to realise, since realistic situations are not always identical, and thus may require a large amount of abilities to manage each kind of situation. As a result, it may be questionable whether clear-cut lab tests are able to select operators on all kinds of abilities they need to manage realistic situations. To increase the match between performance requirements and operator ability, more research is required into the specific underlying task characteristics that are typical for the system environment where the operator is going to perform (see also Gopher & Kahneman, 1971; Kahneman, Ben-Ishaï & Lotan, 1973). If specific subtask-abilities that form the basis of overview maintenance within a particular system environment can be detected, the reliability of a selection test is a second point that has to be examined.

7.2.1.3. Psychological states and overview maintenance

Two psychological states were examined that act differently on the willingness to invest effort in task performance: motivation and tiredness. Overall motivation was hypothesised to increase ability to maintain overview because of increased willingness to invest effort in monitoring and well performance of all tasks. However, this dissertation provided evidence that operators who were externally motivated by incentives to perform all tasks well, showed more preoccupation with problems than intrinsically motivated operators. Even relatively large punishments for failure to attend the primary information source in time, could not prevent that operators were more focused on performing a secondary task that yielded much less. Apparently, operators adapted their own (non-rational) priority standards if performance of separate tasks was motivated by means of incentives. This resulted in increased preoccupation with the task that required most attention. Although in this dissertation incentives on all tasks were used, the findings are similar to those of a study of Bahrick, Fitss and Rankin (1952), who found increased attention narrowing as a result of incentives on one central task.

This dissertation also examined whether operators were better motivated by rewards or by punishments. Other studies reported contradicting results. On the one hand, avoidance of punishment was reported to motivate individuals best to perform in a particular way (e.g. Tversky & Kahneman, 1981). On the other hand, rewards were reported to have the most motivating effect on performance (e.g. in Baron, 1988; Schmidt, 1998). The experiment in this dissertation did not find evidence for one of the two theories. Although more research is required to better establish the effects of motivation on overview maintenance, financial rewards or punishments on separate tasks may not benefit overview maintenance as does intrinsic general motivation. Intrinsic general motivation may be better obtained by other means. Operators who understand the importance of their task priorities, may be better able to
maintain overview compared to financially motivated operators who are not really motivated to perform their tasks well, but rather to earn as much money as possible.

High effort costs to switch the focus of attention increased vulnerability to lose overview. Operators alternated less frequently between information sources when alternation behaviour was, at particular moments, related to increased effort costs. Since other studies reported tiredness to increase the aversion against effort-investment even more than in normal situations (Drew, 1940; Krueger, 1991), tiredness was hypothesised to be a psychological state that reduces the attention range and increases the risk of overview loss. In contrast to what was expected, even after 21 hours without rest experienced watch officers did not show to be at higher risk to overview loss than when they were rested. However, they were tired enough to increase their safety margins, possibly to compensate their perception of increased risk to make more errors due to tiredness. This phenomenon is also known as risk homeostasis (cf. Wilde, 1982) or risk compensation (e.g. O’Neill, 1977; Peltzman, 1975), and concerns the adaptation of risky behaviour on the perceived risk. Furthermore, the most tired operators started to interrupt their current task performance less frequently, which may be the beginning of an increased risk of overview loss. It is very likely that operators who are more than 21 hours without rest and are tested during time periods that are notorious for dips in alertness, lose awareness of increased risk levels as a result of tiredness, and stop adapting risk behaviour. This may have consequences for overview maintenance. To investigate these issues further, future research into tiredness effects requires longer periods without rest. To establish the effects of tiredness on a ship, future research may also include realistic stressors and long periods of shift-induced fatigue to find more realistic results.

7.2.2. Results of applied studies

As the focus of this dissertation was on maintenance and loss of overview on the ship’s bridge, a number of experiments were performed on a high-fidelity bridge simulator. On the one hand, experimenting in such a realistic environment has the disadvantage that unambiguous and easy interpretable data are hard to obtain. On the other hand, the simulated environment better approaches the complexity of a realistic ship’s bridge environment.

The results of the bridge-simulator experiments supported the general findings of this dissertation. Managing complex, ambiguous, or unfamiliar information increased the risk to lose overview. A visual relationship between the main task and distracting information could not reduce the occurrence of overview loss. This may be evidence that, if overview is lost, the attention range is very narrow. It supports the conclusions of Moray and Rotenberg (1989), who found preoccupation with a problem, which resulted in neglect of other problems that were visible on the same display.

Information close to the operator, both in space and in time, appeared to be better represented in the operator’s view of the situation than more distant information. This may indicate that the range of attention is not focused on a main task, but is self-centred and surrounds the location and activities of the operator. If an operator applies unjust task-performance priorities, his attention range may not be equal to the range that is required for good performance of the total task-ensemble.

Sufficient internal motivation, training, and operator support may help an operator to perform his tasks safely. This dissertation may be a starting point for more research into
factors that increase the risk of overview loss by reducing the range of attention, in general and in applied settings such as a ship’s bridge. More research is required to better establish the factors that influence situation overview in dynamic man-machine environments, and to elaborate possible solutions for safety improvement.

7.3. FINAL COMMENTS

Since the topic of overview maintenance has not been discussed in the literature as such, the studies in this dissertation form a starting point to the examination of factors that can affect overview maintenance. Certainly within the shipping sector, human factors research and research into overview maintenance in particular, deserves more attention. It is remarkable that research within the shipping sector particularly concerns technical and legal questions, while human factors are not as much a topic under investigation.

‘Impossible’ accidents (cf. Wagenaar & Groeneweg, 1987) still occur, and accident analyses often conclude that human components were involved. Human factors research and applications in many man-machine environments may contribute to a reduction of accidents, and so improve safety. Although many research results that derived from aviation studies also apply to other dynamic man-machine environments, there are still a number of factors that are unique for each system environment. These unique factors deserve and should receive more attention in order to get a better understanding of specific problems, and to find suitable solutions.