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Effects of extended lay-off periods on performance and operator trust under adaptable automation

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A B S T R A C T

Little is known about the long-term effects of system reliability when operators do not use a system during an extended lay-off period. To examine threats to skill maintenance, 28 participants operated twice a simulation of a complex process control system for 2.5 h, with an 8-month retention interval between sessions. Operators were provided with an adaptable support system, which operated at one of the following reliability levels: 60%, 80% or 100%. Results showed that performance, workload, and trust remained stable at the second testing session, but operators lost self-confidence in their system management abilities. Finally, the effects of system reliability observed at the first testing session were largely found again at the second session. The findings overall suggest that adaptable automation may be a promising means to support operators in maintaining their performance at the second testing session.

1. Introduction

Automation is becoming a common work partner in various domains, such as aviation, industrial process control, or information retrieval. It frequently replaces human activities of various forms, such as acquiring and analysing data, making decisions, implementing or monitoring processes (e.g., Parasuraman et al., 2000). Its benefits are widely recognised, for instance in terms of performance and safety (Lee and See, 2004), but automation may also present drawbacks, including reduced situation awareness, increased complacency, out-of-the-loop problem, and a potential loss of critical skills caused by a lack of engagement with task management (Wickens et al., 2004). In addition to the problems associated with automation use, there are other factors that may be detrimental to operator performance, such as not operating a system for a long period of time (e.g., Arthur et al., 1997), The problems associated with extended lay-off periods may represent new challenges if operators are simultaneously faced with the task of managing highly automated systems.

1.1. Lay-off period and skill maintenance

The regular practice of skills plays an important role in maintaining performance levels. Therefore, performance decrements are often observed when skills cannot be practised for a prolonged period of time, a phenomenon referred to as deskilling, skill decay, or skill loss (e.g., Wiener, 1988, cited in Wickens et al., 2004). There is plenty of evidence for skill decay as a direct consequence of an extended lay-off period in lab-based research with various foci, including memory (e.g., Roediger et al., 2010), motor control (e.g., Savion-Lemieux and Penhune, 2005), and solving complex mathematical problems (e.g., Kwon et al., 2005). Procedural tasks seem to be particularly affected by extended lay-off periods (e.g., Annett, 1979; Hagman and Rose, 1983; Anderson et al., 2011). This apparently inexorable skill decline over time has been examined in various work areas, including medical work (e.g., Einspruch et al., 2007), watchkeeping skills on ship's bridges (O'Hara, 1990), military assignments (e.g., Rose et al., 1984; Sanders, 1999; Schendel and Hagman, 1982), and periods of unemployment (e.g., Edin and Gustavsson, 2008).

Some research aimed at real-world domains has attempted to model the complexity of real work environments by using multi-task simulations in a lab-based context. In a study using a space-flight simulation called 'Space Fortress', it emerged that, after 4 weeks of non-practice, operator performance decreased (Arthur

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et al., 1997). A simulation of a chemical plant was employed in another study, which showed that performance decreased with increasing duration of the lay-off period, using retention intervals of about 1 week, 2 months, and 6 months (Duncan, 1971). Interestingly, the observed performance decrements were limited to operators with low task abilities, suggesting that the level of operators' general task competence can modify the effect of lay-off period.

A particular advantage of using multi-task simulations is that it also allows the identification of task-dependent differences. A study using a process control simulation showed that a lay-off period of 8 months resulted in performance decrements in certain tasks (e.g., fault diagnosis) while performance improvements were observed in others (e.g., manual system control, Sauer et al., 2000). Such counterintuitive improvement may appear in very well practiced tasks which are less sensitive to an extended lay-off period (Rose, 1989). The study also showed that the effects observed over the skill retention period were affected by the training regime received. Arthur et al. (2010) observed similar influences of training schedule design on skill decay for operators managing a simulation of modern naval warfare. Although having received the same amount of practice, operators in the concentrated training condition (i.e., 10 h over five consecutive days) showed weaker performance than operators in the extended training condition (i.e., 10 h over two weeks).

In order to reduce skill decay during lay-off periods, overlearning of skill (i.e., continuous practice of a skill although the required performance level is already reached) has been successfully applied (e.g., Schendel and Hagman, 1982). Similarly, refresher training (i.e., an additional training session between the initial training and the testing phase) has been found to be an effective measure to maintain skill levels (e.g., Kluge and Frank, 2014). The literature suggests that effective training methods help operators develop critical skills to complete the tasks without major performance decrements, supporting Duncan's (1971) finding about the criticality of operators' skill levels (i.e., only operators with low skill level suffered from performance decrements during the lay-off period). It also suggests that a prolonged skill retention interval represents a risk to performance maintenance but other factors, like operator training and operators' general task competence, may abate any such risks.

1.2. Automation and skill maintenance

The problem of skill maintenance also plays an important role in the design of automation. Even if operators managed a highly automated system for a period as short as 2 h, skill decline can already be observed as soon as operators have to return to manual control (Manzey et al., 2012). Automated systems may have positive and negative effects on skill maintenance. On the one hand, the use of automation may result in loss of skill because operators cannot practise their skills if the automatic system carries out the task. On the other hand, operators who have lost skills due to long periods of non-practice (whether caused by automation or not) may benefit greatly from support by the automatic system to complete the task (e.g., a driver rarely using a car is likely to feel more appreciative of the parking assist system). The first of these two situations may be referred to as the ‘loss of skill’-problem (Wickens et al., 2004); the second as showing benefits of ‘human-machine teamwork’. Both issues are relevant in automation design. Therefore, it is important to design automation such that the “skill loss” problem is minimised, while the benefits of human-machine teamwork are maximised.

Different models have been developed to provide guidance in automation design. Sheridan and Verplank (1978) proposed a model with ten incremental levels of automation (LOA) representing the spectrum of human-machine task allocation. Operators receive no support from automation at LOA 1, whereas tasks are fully automated at LOA 10. Parasuraman et al. (2000) introduced a model addressing which stages of information processing are automated. They distinguished four stages, namely information acquisition (IAC), information analysis and display (IAD), action selection (AS) and action implementation (AI); the automation of each stage can be of different level. Similar to Parasuraman et al., Wickens et al. (2010), (see also Onnasch, 2015; Onnasch et al., 2014) proposed a classification of automated systems based on their degree of automation (DOA). DOA takes both LOAs and stages of information processing into consideration to determine how intensively a system is automated. For instance, a system automated at a high level in the early stages could present a similar DOA to a system automated at low level in the later stages. The choice of a certain LOA or DOA determines the task allocation between the human and the machine. According to the literature, medium levels of automation may be best suited to reduce skill loss since they provide the best outcomes when operators have to return from automated to manual control (e.g., Endsley and Kaber, 1999; Lorenz et al., 2002; Manzey et al., 2012).

The above findings were all observed under static automation (i.e., the task allocation between the human and the machine remained invariable over time, Sheridan, 2002) with operators working at the same support level (i.e., the same LOA/DOA) across the working session. The question arises as to whether operators would benefit from more flexible automation. In such automation design, the authority to change task allocation is given either to the human operator or to the system (adaptive automation, Scerbo, 2006). In comparative studies, adaptable automation provided better outcomes for performance (in the control of unmanned vehicles, Kidwell et al., 2012) and for non-performance measures (e.g., more active control of the system by the operator and higher self-confidence, Sauer et al., 2012) than adaptive automation. Adaptable automation may be advantageous for compensating some skill decay since it can provide very quick support when operators increase the level of automation (e.g., change from full manual control to full automated control). Furthermore, it can reduce uncertainty about system behaviour (Miller and Parasuraman, 2007) because in contrast to adaptive automation (where changes in automation levels are sometimes difficult to anticipate and understand by operators) such problems are usually not encountered by operators when using adaptable automation. Furthermore, it may reduce the negative effects of strain through more operator discretion in system management because theories in work psychology point out the advantages of leaving some discretion to the operator in the task completion (e.g., Karasek and Theorell, 1990). More operator discretion is clearly offered under adaptable automation than adaptive automation.

1.3. Automation trust, reliability, and self-confidence

According to Wickens et al. (2004), operators are more inclined to rely on automation than on their own skills when they trust it. In the context of automation, trust may be defined as “the attitude that an agent will help achieve an individual's goals in a situation characterised by uncertainty and vulnerability” (Lee and See, 2004, p.51). Few studies have investigated the evolution of trust over time. Lee and Moray's (1992) study required participants to manage a central heating simulation supported by an automated support system 60 times over three days. Results showed that acute (i.e., one-time) system failures produced an instantaneous but also short-lived drop in trust, whereas a prolonged decrease in trust was observed during the chronic (i.e., prolonged) failure. Similarly, Riley