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The use of adaptable automation: Effects of extended skill lay-off and changes in system reliability

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ABSTRACT

This experiment aimed to examine how skill lay-off and system reliability would affect operator behaviour in a simulated work environment under wide-range and large-choice adaptable automation comprising six different levels. Twenty-four participants were tested twice during a 2-hr testing session, with the second session taking place 8 months after the first. In the middle of the second testing session, system reliability changed. The results showed that after the retention interval trust increased and self-confidence decreased. Complacency was unaffected by the lay-off period. Diagnostic speed slowed down after the retention interval but diagnostic accuracy was maintained. No difference between experimental conditions was found for automation management behaviour (i.e. level of automation chosen and frequency of switching between levels). There were few effects of system reliability. Overall, the findings showed that subjective measures were more sensitive to the impact of skill lay-off than objective behavioural measures.

1. Introduction

The concept of adaptable automation has been considered a promising approach because it allows for a more flexible workload management by enabling the operator to choose freely the level of support offered by the automatic system (e.g. Parasuraman and Wickens, 2008). Such automation design permits operators to compensate for suboptimal working conditions, including task overload or underload, extended working hours, and environmental stressors (e.g. noise), which may all eventually result in increasing fatigue and an augmented risk of performance decrements (Hockey, 1997). The operator may select a higher level of automation because he or she wishes to be relieved of some tasks during the presence of some forms of suboptimal working conditions. For example, there is empirical evidence that automation may help operators maintain performance during loss of sleep (Reichenbach et al., 2011). A suboptimal working condition that has been given rather little attention in research until now is the issue of skill lay-off over an extended period of time. The non-use of skill may occur for two main reasons: some tasks are only carried out periodically (e.g. during start-up or shut-down procedures of process control systems) or a system is used regularly but only under high levels of automation with reduced operator involvement (e.g. operator manages a system in supervisory control). In both instances, this may result in loss of skill or deskilling (e.g. Wiener, 1988; Casner et al., 2014). Adaptable automation may provide support by offering high levels of automation which allows the operator to assign tasks that he or she finds difficult to complete to the automatic system.

In automation research, there are only a modest number of studies that have used non-static forms of automation such as adaptive or adaptable automation (e.g. Kidwell et al., 2012; Sauer et al., 2012). Whereas in adaptive automation, the machine decides which level of automation should be offered to the operator (e.g. on the basis of operator performance), in adaptable automation, the level of automation is selected by the human operator (e.g. Parasuraman and Wickens, 2008). The design of adaptable automation is characterised by the number of levels the operator can choose from (small choice vs. large choice) and the range of levels of automation (LOA) available (narrow range vs. wide range). The number of levels available and the kind of support they offer have been described in various models of automation (e.g. Sheridan and Verplank, 1978; Endsley, 1995). A recent review of automation models may be found in Vagia et al. (2016).

Wide-range and large-choice adaptable automation allows the operator to respond flexibly to different task demands. In the present study, the operator was able to make use of both elements of

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adaptable automation. Despite these obvious benefits of adaptable automation, there may also be a downside to it. While adaptable automation provides support to the operator in the form of high levels of automation, this may have negative effects on operator skills in the long term (deskilling due to non-practice) even though it helps maintain performance in the short term (e.g. the machine may compensate for poor operator performance). Since short-term benefits may only be obtained at the cost of long-term disadvantages, this may be considered a dilemma.

The issue of forgetting and skill loss has long been a topic in the field of ergonomics (e.g. Duncan, 1971). In addition to forgetting and skill loss associated with extended periods of non-practice, there are several other areas in which it is of concern, including impairments that are age-related (Czaja and Sharit, 1993), fatigue-induced (Philip et al., 2003) or stress-related (Hancock and Vasmatzidis, 2003). These may occur in the form of temporary performance decrements (e.g. fatigue-related) or permanent decrements (e.g. age-related), which bears some resemblance to the distinction between competence and performance (Matthews et al., 2000). The threat of skill loss can be combatted by several measures, such as by overlearning during training (e.g. Driskell et al., 1992) and but also by using rest breaks (e.g. Tucker, 2003). The use of automation might also compensate for the negative effects of skill loss and help maintain performance. The problem of skill decay resulting from non-practice has been the subject of a number of studies. An important conclusion of such work was that performance on procedural tasks was particularly strongly impaired by extended periods of non-practice (e.g. Hagman and Rose, 1983; Annett, 1979). Research modelling the complexity of human-machine systems in the laboratory found similar performance decrements after the lay-off period (e.g. Arthur et al., 1997; Sauer et al., 2000). In this work, it also emerged that the magnitude of the performance decrement was influenced by type of task, with diagnosing faults in a process control environment being more strongly impaired than keeping the system in a stable state (e.g. Sauer et al., 2000). Interestingly, the opposite pattern (i.e. system control performance was more strongly impaired than diagnostic performance) was observed in another study, which may be due to the availability of adaptable automation (Chavaillaz et al. 2016b). Both studies are highly relevant to the present work since they were similar in the retention interval and in the task environment employed. In particular, the more recent study by Chavaillaz et al. is to be considered the primary reference study since it also modelled adaptable automation. In the context of managing highly automated human-machine systems performance decrements occurring may be due to a complex pattern of effects involving variables such as trust, self-confidence, automation reliance, complacency, and system reliability. These variables are generally considered important in automation design and are also included in pertinent models (Wickens et al., 2004).

Trust may be considered being the extent to which the operator believes that the technical system will help him or her achieve task-related goals during uncertain operational conditions (Lee and See, 2004). Trust towards machines may involve explicit and implicit processes (Merrit et al., 2013). A recent review on trust in automation demonstrated that trust levels may be influenced by a wide range of factors that can be summarised into three major categories: dispositional trust (e.g. personality), situational trust (e.g. self-confidence) and learnt trust (e.g. past experience with system; Hoff and Bashir, 2015). The present study examined a factor from the third category. It was expected that trust as an attitude towards the reliability of the automatic system would be influenced by the actual reliability level of the system. Operators may sometimes face difficulties when calibrating their trust to the actual level of system reliability (e.g. Wiegmann et al., 2001). The level of trust has important implication for operator behaviour in that automation may be over- or underestimated (misuse or disuse; Parasuraman and Riley, 1997). Recent work has also shown that trust levels can be increased by indicating to the operator the probability of an alarm being correct (i.e. likelihood alarm system; Wiczorek and Manzey, 2014). Surrounding the issue of trust calibration, it may be of particular interest how extended lay-off periods affect trust ratings but also behavioural manifestations of trust. Such behavioural manifestations include reliance on automation (e.g. LOA chosen by operator) and complacency (e.g. insufficient system monitoring). There is little research that has addressed this issue although long periods of skill lay-off are not uncommon in industrial settings. To our knowledge there is only one study that examined the effects of lay-off period on trust (Chavaillaz et al., 2016b). It showed stable patterns of trust ratings over an 8-month lay-off period.

While trust is considered an important influencing factor of automation use, operator self-confidence may also moderate the relationship between trust and automation use. For example, if trust in automation exceeds the self-confidence of the operator in his or her ability to manage the system manually, operators would rely on automation rather than manual system control (Lee and Moray, 1994). Conversely, operators would opt for manual system control if their self-confidence in being able to manage the system manually exceeded their trust in automation. First evidence from a study measuring operator self-confidence after an extended lay-off period suggests a decrease in ratings at the second testing session (Chavaillaz et al., 2016b).

Use of automation is one of the primary behavioural manifestations of trust (e.g. Lee and See, 2004). This has sometimes also been referred to as reliance (e.g. Dzindolet et al., 2003) or dependence (e.g. Wickens et al., 2015). Opting for high level of automation would clearly be a strategy for operator to relieve themselves of high workload and to assign those tasks to the machine which they find difficult to complete (e.g. because they forgot how to do them after the retention interval). Due to the general paucity of research on (wide-range) adaptable automation, there is even less work on the specific issue of skill retention. There is, to our knowledge, only one study that examined this question. The results of this study suggest that operator reliance on automation was high and very stable over the extended lay-off period (Chavaillaz et al., 2016b). This also applied to the frequency with which automation levels were changed.

Being defined as an insufficient monitoring of an automatic system that has negative consequences on operator performance (Parasuraman and Manzey, 2010), complacency has emerged in a number of studies, in which automatic support systems had failed (e.g. Bahner et al., 2008). Little is known about how complacency is affected by long periods of non-practice of skills. The only other study examining skill lay-off under adaptable automation failed to take a measure of complacency (Chavaillaz et al., 2016b). There is a study (not using adaptable automation) that also examined a measure related to complacency (i.e. information sampling behaviour) before and after a lay-off period (Sauer et al., 2000). The findings suggest that information sampling behaviour significantly increased after the retention interval implying that there was no evidence for complacency being on the increase.

Changes in system reliability may have effects on several parameters including trust, performance, and confidence (Wiegmann et al., 2001; De Visser and Parasuraman, 2011). Furthermore, it may be of relevance whether the reaction will depend on the direction this change will take (i.e. increase vs. decrease). For example, it may make a difference whether there was an increase or a decrease in reliability experienced by the operator (e.g. prior to the current reliability level of 70% the operator either experienced 50% or 90%