Annual Reviews in Control 000 (2017) 1–13

Contents lists available at ScienceDirect

Annual Reviews in Control

journal homepage: www.elsevier.com/locate/arcontrol

Review article

The out-of-the-loop Brain: A neuroergonomic approach of the human automation interaction

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ARTICLE INFO

Article history:
Received 11 July 2017
Revised 22 September 2017
Accepted 23 September 2017
Available online xxx

Keywords:
OOTL phenomenon
Automation
Vigilance
Neuroergonomics

ABSTRACT

The world surrounding us has become increasingly technological. Nowadays, the influence of automation is perceived in each aspect of everyday life. If automation makes some aspects of life easier, faster and safer, empirical data also suggests that it could have negative performance and safety consequences regarding human operators, a set of difficulties called the “out-of-the-loop” (OOTL) performance problem. However, after decades of research, this phenomenon remains difficult to grasp and counter. In this paper, we propose a neuroergonomics approach to treat this phenomenon. We first describe how automation impacts human operators. Then, we present the current knowledge relative to this OOTL phenomenon. Finally, we describe how recent insights in neurosciences can help characterize, quantify and compensate this phenomenon.

Contents

1. The problem with automation

Progress in automation technology has profoundly changed our modern society. Almost all aspects of our lives are impacted while even more radical changes are expected in the future with increasing computer performances. The way such developments will shape the future is not entirely clear, but the inexorable drive toward even more automation will continue.

What is clear at the moment is that automation makes some aspects of life safer, easier and faster. It leads to superior productivity and efficiency. Wiener and Curry (1980) depicted the image of automation as follows:

> *“Quiet, unerring, efficient, totally dependable machines, the servant of man, eliminating all human error, and offering a safe and cost-effective alternative to human frailty and caprice. The traditional*

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https://doi.org/10.1016/j.arcontrol.2017.09.010
1367-5788/

Please cite this article as: B. Berberian et al., The out-of-the-loop Brain: A neuroergonomic approach of the human automation interaction, Annual Reviews in Control (2017), https://doi.org/10.1016/j.arcontrol.2017.09.010

dream of traditional engineers has been to solve the problem of human error by eliminating its source."

This fascination regarding the possibilities afforded by technology often obscures the fact that automation has profoundly changed the nature of human work. Understanding the characteristics and the dynamics of this transformation is vital for successful design of new automated systems.

1.1. From manual control to supervisory control

Adding "automation" has been considered for a long time as a simple substitution of human activity for machine activity (substitution myth, see Woods & Tinapple, 1999). Unfortunately, such assumption corresponds to a vague and bleak reflection of the real impact of automation: automation technology transforms human practice and forces people to adapt their skills and routines (Dekker & Woods, 2002). Particularly, whereas the human operator was initially involved in manual control functions including process planning, decision making, selecting responses and implementing strategies, he is now relegated to the role of passive information processor. He has to monitor the actions of the system, to understand these actions, to watch for deviations and failures, and to take over when necessary (Moray, 1986; Sheridan & Verplank, 1978). There is no denying that such transformation underlines a certain irony since designers who try to eliminate the operator still leave the operator to do the tasks designers cannot automate (see Bainbridge, 1983). Moreover, as pointed out by Flemisch, Heesen, Hesse, Kelsch, Schieben, and Beller (2012), in addition to control, authority, ability and responsibility are also modified according to the level of automation within the human–machine system.

This new form of interaction between humans and machines produced new loads and difficulties for the humans responsible for the operating systems. Especially, empirical data suggest that these changes have many negative performance and safety consequences associated with it stemming from the human out-of-the-loop (OOTL) performance problem (e.g. Billings, 1991; Endsley & Kiris, 1995; Kaber & Endsley, 1997; Sarter & Woods, 1995; Wickens, 1992; Wiener & Curry, 1980). For decades, this OOTL performance problem has appeared as a critical issue for system designers. In this article, we aim at reviewing the current knowledge about this phenomenon, the limits of the current approach and the potential benefits to integrate recent insights in neuroscience to progress in its comprehension.

2. OOTL: a well-known phenomenon?

The OOTL phenomenon corresponds to a deterioration of the operator's performance when interacting with highly automated system. The terms "total confusion" (Bureau d' Enquête et d' Analyse, 2002, p167; National Transport Safety Board, 1975, p17), "surprise effect" (Bureau d' Enquête et d' Analyse, 2012a, p10, 2016, p44) or "no awareness of the current mode of the system" (Bureau d' Enquête et d' Analyse, 2012b, p178) indicate a similar process—a mental state in which the operator has lost his or her situation awareness and is not able to monitor the system efficiently. At an operational level, the OOTL performance problem induces a performance decrease whenever trying to transfer manual control over the system. Amongst other problems, an operator who is OOTL might take longer or be completely unable to detect an automation failure, decide if an intervention is needed, and find the most adequate action. In the current context of the continued increase in automation, understanding the sources of human–system interaction difficulties is crucial.

2.1. Becoming out-of-the-loop

The control theoretical perspective is a useful concept when considering human-machine systems, particularly for understanding when and how control can be lost, which is highly undesirable in safety critical systems. The concept of control can be seen as a control loop in the light of Neisser's perceptual cycle (Neisser, 1976). As human beings we perceive through our senses, analyze and make decisions via cognitive functions and act using our limbs. Importantly, humans act upon feedback from previous events and perceptions and are thereby always part of several control loops simultaneously. More precisely, in the language of control theory, a system has a desired state, means for adjusting the system toward that desired state, and then, a feedback loop, in which the actual state of the system is compared with the desired state, so that additional correction can be performed if there is a mismatch. The combination of this control plus feedback is called the control loop, and when a human is manually operating the equipment, the human is an essential element of the control loop hence the saying: "the person is in the loop". On the other hand, when a high level of automation is implemented, the automation takes care of the lower level actions and the human operators simply watches over the system, presumably ever-alert for deviations and problems. In other words, operators are relegated to passive information processors: they are "out of the loop".

To summarize, the OOTL phenomenon corresponds to a **lack of control loop involvement** of the human operator. Automation technology has created an increasing distance between the human operator and the loop of control, disconnecting him from the automation system. Such a removal leads to a decreased ability from the human operator to intervene in system control loops and assume manual control when needed in overseeing automated systems (see following sections).

Interestingly, automation has been shown to impact operators' information acquisition, information analysis, decision making, and action (Parasuraman & Wickens, 2008). Thus, a major issue in implementing automation relies on its impact on operator situation awareness (SA). During the last decades, a large body of research has been dedicated to this issue. The following section aims at reviewing briefly the main results obtained.

2.2. Situation awareness and OOTL

Situation awareness (SA) can be thought of as an internalized mental model of the current state of the operator's environment (Endsley, 2016). Interestingly, the loss of situation awareness underlies a great deal of the out-of-the-loop performance problem (for a recent review, see Endsley, 2017; Parasuraman & Wickens, 2008). Particularly, OOTL phenomenon is characterized by both a failure to detect and to understand the problem, and by difficulties to find appropriate solutions.

Several works indicate a lack of operator awareness of automation failures and a decrease in detection of critical system state changes when involved in automation supervision (Endsley & Kiris, 1995; Metzger & Parasuraman, 2001; Parasuraman & Riley, 1997; Wickens, 1992). As an illustration, Galster, Duley, Masalonis, and Parasuraman (2001)) found that passive monitoring with airborne control of aircraft separation, which would be the case under mature Free Flight, led to a marked decrease in conflict detection performance by Air Traffic Control officers (ATCos) under high traffic load. At the same time, when acting as monitors of an automated system, operators are usually slow in detecting system failure (Endsley, 1996). For example, Willems and Truitt (1999) found that under passive monitoring, response times to questions probing traffic awareness became longer, and recall of data blocks poorer with increasing traffic load.

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