Causal Attribution and Control: Between Consciousness and Psychical Half-Shadow Application to Flight Operations

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Abstract. The key of the development of HMI technologies lies in the acquisition of knowledge and the integration of disciplines by industrials that are in the scope of cognitive neurosciences. The purpose of this paper is to provide new models to be applied in human centered design loops for cockpit in aeronautics. Two different problems are introduced: (1) the purpose of consciousness in action control, (2) the transformation induced by automation in term of agency. For each of this problem, we detail how the problem is currently tackled by cognitive ergonomics society, and how neurosciences could help in the comprehension of the different mechanisms involved. Perspectives are proposed for each of this issue.

Keywords: Action Control, Agency, Automation, Cognition, Consciousness.

1 Introduction

In the 21st century, one of the most significant challenges with most cockpit design is human error. However, "human error" is a misleading expression that has too often been used to sweep away the real issues under the rug. It further suggests that pilots are careless, poorly trained, or otherwise unreliable, whereas in fact numerous studies in the field of human factors in aeronautics have now demonstrated that the vast majority of so-called "human errors" result from the challenges involved in understanding and in controlling poorly designed interfaces.

Why pilots have trouble coping with technology remains a crucial problem. In this paper, we defend the argument that the recent findings in neurosciences could help to resolve this problem. Indeed, the key to the development of HMI technologies lies in the acquisition of knowledge and in the integration of different disciplines such as cognitive psychology and the neurosciences by industrials. Effective technologies for Human Machine Interaction (HMI) must be informed by knowledge generated by recent advances in cognitive neuroscience in order to meet current application and industrial challenges.

In the following sections, two different problems will be introduced: (1) the purpose of consciousness in action control, (2) the transformation induced by automation in term of agency. For each of this problem, we will detail how the problem is

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currently tackled by cognitive ergonomics society, and how neurosciences could help in the comprehension of the different mechanisms involved.

2 Consciousness and Action Control

Pilots routinely have to cope with hugely demanding complex systems, and thus continuously face both data and technology overload. Occasionally, this cognitive overload results in failure to cope. Ironically, the response to such human failures to cope has almost always resulted in the development of even more complex procedures and safeguards, which paradoxically increase the very complexity that caused the initial failure. Thus, the pilot is but the tip of a technological iceberg built from layers and layers of accumulated suboptimal solutions to problems that are the resultant of inadequate human interface designs. In this context, a first question refers to human ability to process the vast amount of data in which they are immersed so as to arrive at effective performance. Particularly, this section aims at tackling the role of consciousness in this process.

2.1 Human Factors Approach: Endsley Model

Questions about the function(s) of consciousness have long been, and are always, central to discussions. In the field of Human Factors and Ergonomics, it is admitted that consciousness plays an important role in the control of many everyday — but complex — behaviours. The recent introduction of the theory of Situation Awareness (Endsley, 1995) aims at explaining the relationship between human agents and the technologies they interact with by considering consciousness as a central determinant of controlled action. Endsley' model of reference stands situation awareness as an instantaneous state of knowledge of the world that can be splitted in several hierarchical levels where the first constitutes the core from which the following one depends. In this model, situation awareness determines, in an independent and serial way, decision making and action, and does not take into account affordances and action capabilities. This theoretical model is also the basis of a normative design and evaluation approach in which situation awareness has to be the most complete and reliable as possible considering an absolute reference. If an inadequate situation awareness is considered as one of the main factors in accidents attributed to human error, on the opposite it is assessed that a complete and accurate situation awareness is crutial when human actions are required in the control of technological complexity. Thus, situation awareness is defined as the most important factor to improve mission efficiency. For the two last decades, this theory has served as the foundation of a normative design and evaluation approach in the design of HMI.

Nowadays, and particularly thanks to some recent works in the field of neurosciences (but for all that neglecting the importance of older studies from Gestalt or Soviet psychology), this model is strongly controverted. To go back the expression from Amalberti (1996), "the serial model perception-understanding-anticipation-decision-action, that supposes a one way top-down dependency is disarmingly naïve and it exists a parallelism and interdependencies that are amplified by expertise".

2.2 Insight from Neurosciences: The Role of Implicit Processes

Consciousness is perhaps the oldest and most controversial area within experimental psychology. Quite quickly, however, observations in both the laboratory and the clinic suggested that mental life is not limited to conscious experience. Kihlstrom, Barnhardt, and Tataryn (1992) suggested that an experiment examining unconscious perception done by C.S. Peirce and Joseph Jastrow in 1884 was the first psychological experiment performed in America. Peirce and Jastrow's experiment, in which they themselves were the subjects, concerned people's ability to discriminate minute differences in the pressure placed on their fingertips. The task amounted to deciding which of two pressures was the heavier and then rating confidence in that decision. Peirce and Jastrow's results demonstrated that discrimination was at an above-chance level even when conditions were such that they considered their decisions to be pure guesses, suggesting a possible dissociation between effects in performance and awareness. There is now a body of evidence suggesting that it is indeed true. Neuroscientists have proved that the brain can represent and process some information outside the focus of attention or below the level of awareness (see for instance Debner & Jacoby, 1994; Destrebecqz & Cleeremans, 2001; Dienes & Perner, 1999; Greenwald, Abrams, Naccache, & Dehaene, 2003; Merikle, Smilek, & Eastwood, 2001). In this context, it is becoming increasingly common for scientists to argue that we 'know more than we can tell' in most of the situations of our everyday life, including language acquisition and use as well as skill learning in general, perception and memory.

The role of consciousness in action control has also been largely debated. A significant body of data emerging from cognitive neuroscience have shown that conscious experience is not involved in the control of behavior (e.g., Fourneret & Jeannerod, 1998; Goodale, Pelisson, & Prablanc, 1986). Famous examples involve pictorial illusions, particularly size-contrast illusions. Aglioti and colleagues (Aglioti, Desouza & Goodale, 1995), for example, showed that the scaling of grip aperture in flight was remarkably insensitive to the Ebbinghaus illusion, in which a target disk surrounded by smaller circles appears to be larger than the same disk surrounded by larger circles (Figure 1). Maximum grip aperture was scaled to the real not the apparent size of the target disk. According to these theorists, conscious experience serves the selection of action types, while the control of 'online' guided action proceeds via a quasi-independent non-conscious route (Milner & Goodale, 1995).

More recently, and in response to such claims, critics from an intermediate position have suggested that the image of 'zombie systems' guiding action fails to take into account the possibility that there is genuine experience occurring and controlling the actions (Jackson & Shaw, 2000). In this context, some investigators have reported that pictorial illusions affect some (but not all) aspects of motor control (e.g., Gentilucci et al., 1996; Franz, Bulthoff & Fahle, 2003), whereas others have not found any dissociation between the illusions and the scaling of grip aperture (e.g., Plodowski & Jackson, 2001). Such findings cast doubt on the dissociation between conscious experience and motor control. The complexity of this issue increases furthermore when considering that (1) time plays a central role in consciousness, at different levels and in different aspects of information processing (e.g., Cleeremans & Sarrazin, 2007); and (2) different forms of awareness arise when an unexpected event occurs versus when controlling routine actions (e.g., Block, 2005).

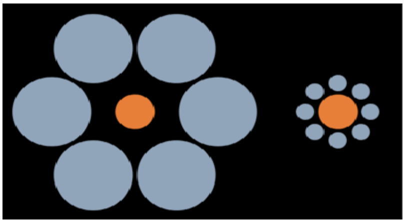

Fig. 1. Ebbinghaus illusion

In this context, it seems crucial to answer the following question: What is the role of consciousness in the control of action whether it concerns routines or some forms of adaptations to unexpected events? The next section provides our appraoch of this complex problem.

2.3 Integration of Neurosciences Issues for HMI Design

We propose a radically different model of situation awareness as it applies to human centered design loops for cockpit interaction in aeronautics. This model is rooted in the idea that the best manner through which human-machine interactions can be improved consists not in increasing situation awareness but rather in removing awareness from the dynamical loops that take place during interactions. In other words, one should strive to make such interactions as implicit, automatized, and thus self-evident as possible. In this frame, situation awareness intervenes only when an unexpected event occurs and is centered on a problem; a situation very well explained by Leroy-Gouhran (1964) with the concept of "*psychical half-shadow"* when he indicates " *it is certain that most of the chains that we unroll the whole day ask for only little consciousness… it takes place in a psychical half-shadow out of which the subject only comes when unexpected events appear in the time course of sequences. For all the movements we make successively while shaving, eating, writing, driving, the return to consciousness, even exceptional, is very important… one can neither imagine a behaviour asking for a continuous lucidity, nor a totally conditioned behaviour without any conscious intervention; the former would ask for a re-invention of every part of the smallest movement, the latter would correspond to a totally pre-conditioned brain*".

Our (dynamical) approach considers the implicit recognition of significative patterns for action as a basic solution to the problem of the synchronization between activity and environment. In this context, modelling the frontier between conscious and non conscious processing and identifying the computational principles that govern the passage of a representation in the field of consciousness, would be particularly useful for HMI designers who needs to master when an interaction has to be cognitively controlled and when it has to be unrolled in a routine. Two basic questions has to be considered: (1) how conscious awareness enables control on our own actions, (2) how representations become conscious for or as a result of high level processing, These twin questions are crucial questions about which HMI designers need to have technological solutions. We will tackle these two questions by conducting relevant experiments, first in a simplified laboratory environment, and then in a cockpit simulation, in order to identify the computationnal principles that define the boundary between conscious and non-conscious control exerted by operators (i.e., a pilot) in a complex technological system (i.e., an aircraft).

Concerning the first question, a major motivation to integrate such considerations in human-system interaction engineering for the control of complex technological systems stems from the emerging consensus about the function of so-called access consciousness (A-consciousness). A-consciousness refers to our ability to report and act on our experiences. For a person to be in an A-conscious state entails that there is a representation in that person's brain whose content is available for high-level processes such as conscious judgment and reasoning. As there is wide agreement around the idea that conscious representations serve the function of making it possible for an agent to exert flexible, adaptive control over action, the characterization of this function is critical in the specific context of cockpit interactions design.

With regards to the conditions that determine the access to consciousness, which is connected with the second question, several findings converge to suggesting that the time available for processing is a central determinant of the extent to which a representation is conscious. Thus, consciousness takes time, as it takes time for any dynamical system to settle upon a state that best satisfies the many constraints imposed by diverse sources of such constraints, such as the environment with which the agent interacts, the goals and intentions of the agent, the properties of the action systems that it can control, and so on. But the satisfaction of these many constrains takes place at different time scales, so that the content of conscious awareness can change according to the time that a pilot has for information processing. This situation is probably exacerbated in a situation of automation supervision. Hence, a better understanding of the cognitive and sensory factors, and of the dynamical interactions which determine the contents of our conscious experience is a critical aspect for improving cockpit interactions.

3 Technology Automation and Agency

A second crucial question refers to the transformation induced by automation technology, from a human operator perspective. There is perhaps no facet of modern society in which the influence of automation technology has not been felt. ? This is especially true when one considers interactions with aeronautical systems. We have usually focused on the perceived benefits of new automated or computerized devices. This is perhaps not surprising given the sophistication and ingenuity of design of many such systems (e.g., the automatic landing of a jumbo jet, or the docking of two spacecraft). The economic benefits that automation can provide, or is perceived to offer, also tend to focus public attention on the technical capabilities of automation.

However, our fascination with the possibilities afforded by technology often obscures the fact that new computerized and automated devices also created new burdens and complexities for the individuals and teams of practitioners responsible for operating, troubleshooting, and managing high-consequences systems. Whatever the merits of any particular automation technology, it is clear that automation does not merely supplant human activity but also transforms the nature of human work. Understanding the characteristics of this transformation is vital for successful design of new automated systems.

3.1 The Classical Approach of the OOTL Performance Problem

When new automation is introduced into a system, or when there is an increase in the autonomy of automated systems, developers often assume that adding “automation” is a simple substitution of a machine activity for human activity (substitution myth, see Woods & Tinapple, 1999). Empirical data on the relationship of people and technology suggest that this is not the case and that traditional automation has many negative performance and safety consequences associated with it stemming from the human out-of-the-loop (OOTL) performance problem (see Endsley & Kiris, 1995; Kaber, Onal & Endsley, 2000).

Classically, the out-of-the-loop performance problem leaves operators of automated systems handicapped in their ability to take over manual operations in the event of automation failure (Endsley & Kiris, 1995). The OOTL performance problem has been attributed to a number of underlying factors, including human vigilance decrements (see Billings, 1991), complacency (see Parasuraman, Molloiy & Singh, 1993) and loss of operator situation awareness (SA) (see Endsley, 1996). Cognitive engineering literature has discussed at length the origins of vigilance decrements (e.g., low signal rates, lack of operator sensitivity to signals), complacency (e.g., over trust in highly reliable computer control) and the decrease in SA (use of more passive rather than active processing and the differences in the type of feedback provided) in automated system supervision and has established associations between these human information processing shortcomings and performance problems. However, though all of these undoubtedly play an important role in the out-of-the-loop performance problem, we consider that these different factors have masked a preliminary question: what is the difference between action resulting from my intention, beliefs or desires and others’ action or involuntary action? What is the difference between being an agent or not? What is the difference between supervisors in control and complacent supervisors?

3.2 Insight from Neurosciences: OOTL Problem and Sense of Agency

As a matter of fact, the role of the human actors evolve from direct control to supervision with automation technology. In this sense, a crucial transformation concerns the authority sharing between the human operator and the system as claimed by Baron: *“Perhaps the major human factors concern of pilots in regard to introduction of automation is that, in some circumstances, operations with such aids* *may leave the critical question, who is in control now, the human or the machine?" (Baron, 1988).*

This problem of sense of control has been poorly investigated in the HMI context. In contrast, in recent years, this problematic has known a particular interest in the neurosciences area under the concept of agency. When we act, we usually feel ourselves controlling our own actions and causing the resulting effects. This phenomenological image of ourselves as agents is classicaly called "sense of agency" (de Vignemont & Fourneret, 2004; Gallagher, 2000), and is recognised as an important part of normal and human consciousness. How can we distinguish our actions and their effects from those of other people, how do we refer the origin of an action to its own agent, remain essential questions. Most people can readily sort many events in the world into those they have authored and those they have not. This observation suggests that each person has a system for authorship processing, a set of mental processes that monitors indications of authorship to judge whether an event, action, or thought should be ascribed to self as a causal agent (Wegner, Sparrow, & Winerman, 2004). Laboratory studies have attempted to shed more light on this mechanism and empirical data in recent psychology (e.g., Aarts, Custers, & Wegner, 2005 ; Moore, Wegner & Haggard, 2009), psychopathology (e.g., Franck & al, 2001; Frith, Blakemore & Wolpert, 2000) and neuroscience (e.g., Farrer & al., 2003; Tsakiris & Haggard, 2005) have been accumulated. Interestingly, a variety of sources of information (e.g., one's own thoughts, interoceptive sensations, external feedback, etc.) could be involved in the authorship processing. Several indicators have been already proposed, including body and environment orientation cues (e.g., Vallacher & Wegner, 1985), direct bodily feedback (e.g., Gandevia & Burke, 1992; Georgieff & Jeannerod, 1998), direct bodily feedforward (e.g., Blakemore & Frith, 2003; Blakemore, Frith & Wolpert, 1999), visual and other indirect sensory feedback (e.g., Daprati & al., 1997), social cues (e.g., Milgram, 1974), agent goal information (e.g., Langer & Roth, 1975) and own behavior relevant thought (e.g., Wegner, 2002; Wegner & Wheatley, 1999). In our opinion, research on agency opens interesting novel avenues of research.

3.3 Integration of Neurosciences Issues for HMI Design

Our belief is that the investigation of the agency mechanism may be fruitful in the comprehension of the OOTL performance problem. We assume that the introduction of the concept of agency in human factors issues open a new way to understand how automation influence operator performance. There are three central motivations to consider that the investigation of the agency mechanism may be fruitful in the comprehension of the OOTL performance problem. Firstly, causal attribution is a central mechanism in our dailylife. As famously claimed by David Hume, causality is the cement of the universe. In our daily life, perception of causality can help us understand how two events relate to each other and how our actions influence the world. Central to the sense of causality is the sense of agency, the experience we have of causing our own actions. Clearly, interaction with computerized and automated devices could confuse this issue of agency. Partially autonomous machine agents, increased system complexity and the use of automation technology may all contribute to transform the nature of human activity and to distance humans from many details of the ongoing operation. The interposition of more and more automation between pilot and aircraft tends to distance pilots from many details of the flying, decreasing their feeling of control. Secondly, accounts of agentive experience could have implications for conceptions of future systems. Indeed, how to design systems to allow the crew to remain “in the loop” becomes a first concern, but is also an extremely difficult problem that needs to take agentive experience seriously. Different solutions may be envisaged when designing human-machine interface. In our opinion, model of agency should help to elaborate concrete design recommendations (see for example, Berberian, et al., in press) and provide guidelines for better automatic system design. Thirdly, accounts of agentive experience should help to evaluate current/future human-machine interface in term of potentiality to remain the crew “in the loop”. The ability to measure the sense of agency quantitatively is important, since it allows the sense of agency to be used as a measure in evaluating human-automation performance (see Berberian et al, 2012). For example, when we get on an airplane, we believe (and hope!) that the pilot feels in personal control of the aircraft. Accounts of agentive experience give the possibility of testing whether this is actually true. In this sense, models of agency could lead to the introduction of a new methodology for the evaluation of the potentiality for an human-machine interface to keep the operator in the loop, even online monitoring of agentive experience (i.e, neural correlates of agency).

4 Conclusion

In this paper, we have argued that neurosciences could help in the development of effective technologies for Human Machine Interaction. Insights from neurosciences could offer new way to understand some very well-known ergonomics problems, as the OOTL problem, and help IHM designers to deal with these problems. At the extreme, neurosciences could also dramatically change our apprehension of the human machine interaction (awareness and action control), IHM designers’ tools and methodology. Neurosciences open interesting novel avenues of research and links between human factors teams and neurosciences laboratories has to be strengthened in order to meet current application and industrial challenges.

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