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Temporal Awareness and Human Performance in Engineering Psychology

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Psychology

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Παντα χωρει και ουδεν μενει

– Heraklitos

‘The only constant is change'

– Isaac Asimov

'If you really are a product of a materialistic universe, how is it that you don't feel at home there? Do fish complain of the sea being wet? Or if they did, would that fact itself strongly suggest that they had not always been, or would always be, purely aquatic creatures? Notice how we are perpetually surprised at time. In heaven's name, why? Unless, indeed, there is something in us which is not temporal.’

– C. S. Lewis in a letter to Sheldon Vanauken on Dec. 23, 1950.

Man cannot escape time. Everything we observe and do happens in time. Time is also an inherent constraint in nearly every human activity, for even simplest tasks often require series of actions which must be properly sequenced and timed for successful outcomes. Although people can make sense of temporal relations in their everyday environs just as well as they can move about in three-dimensional spaces based on two-dimensional images reflected on their retinas, the temporal demands imposed by external events and requirements frequently exceed the inherent time sense of humans. Indeed, it is difficult to imagine how a modern man could make it through an ordinary workday without the help of highly accurate timekeeping instruments (i.e., clocks or watches). The temporal challenges are far greater in many industrial settings or situations where human operators control vast, complex systems, such as transportation (planes, trains, automobiles), process control (manufacturing and energy production), financial institutions (e.g., stock exchanges, the Federal Reserve), or medical facilities (operating rooms and hospital emergency departments). It is in these kinds of complex and dynamic task environments where the psychology of time and engineering psychology meet.

Successful control of complex systems implies that the operators have a 'mental model' of the system (e.g., Conant, & Ashby, 1970;

Norman, 1983; Rouse & Morris, 1986), allowing them to predict the system's behavior and the consequences of their inputs to it. Successful control actions must be based on the operators' understanding of the context of the information and the specific task they are performing, rather than on mere reactions to information presented to them on panels and meters (Hollnagel, 1988). Yet, the examples of difficulties humans have in the control of dynamic situations and systems abound (e.g., Waganaar & Sagaria, 1975; Wickens & Hollands, 2000), as do the often catastrophic consequences of these complications in many high-risk sectors (De Keyser, 1995). Examples of such occurrences include air traffic controllers who 'lose the picture' of the traffic under their responsibility, pilots who 'fall behind' their aircraft, and control room operators who become overwhelmed by unanticipated events (Kemeny, 1979). Many operator errors can also be classified as temporal (De Keyser, 1995; Decortis, De Keyser, Cacciabue, & Volta, 1991), including mis-estimation of sequences of actions and events, mis-estimation of duration of events with precise boundaries, failures to estimate the right moment to take action, failures to anticipate events, and failure to synchronize collective actions. The commonly used class of errors, errors of omission, can also be divided into subcategories based on time. In addition to a true omission (i.e., a missing action), the action may be delayed or performed too early (Hollnagel, 1998).

Psychology of time and timing processes has a relatively long history of sustained research. This substantial body of research can easily be classified by the regions in the temporal spectrum, into milliseconds to about 10 s range, seconds to minutes range, and the circadian range of 23 to 25 hours (Collyer & Church, 1998). Other distinctions between studies can be made based on whether they concern time estimation or production of temporal intervals, and time estimation studies can further be divided into those investigating retrospective timing and those examining prospective timing. Literature relevant to the engineering psychology aspects of time and human performance is comprised of theories and models of timing based on cognitive processes, particularly those of attention and memory (e.g., Zakay, Block, & Tsal, 1999) and the close coupling of temporal cognition, memory, and attention (e.g., Zakay, 1992), and the literature on prospective memory (e.g., Marsh, & Hicks, 1998). Many of these theories are closely related with the concept of executive control, first introduced by Baddeley and Hitch (1974) in their Model of Working Memory (Baddeley, 1990; Richardson, 1996). Baddeley's central executive is often compared to the supervisory attentional system (SAS) described by Norman and Shallice (1980), which is a limited capacity system used for a variety of purposes, including tasks involving planning or decision making. There is hence a plethora of theoretical accounts of temporal cognition to be examined, which also allows for a variety of predictions of human performance to be tested in applied settings.

There is also a rich body of engineering literature examining dynamic systems and providing models for their optimal control. Similarly, the human operator is often also modeled in terms of an optimal controller in an integrated framework of the system to be controlled (Carbonell, 1966; Carbonell, Ward, & Senders, 1968; Tulga & Sheridan, 1980). Yet only relatively recently the role of timing in control of complex systems and ergonomics research has been explicitly recognized (Carmichael, 1997; De Keyser, 1995; Decortis et al., 1991; Hollnagel, 2002; Sougné, Nyssen, & De Keyser, 1993). For example, De Keyser (1990) identified two kinds of temporal envelopes in a start-up process of an electric power plant and Okada (1992) observed rhythmic operation of a simulated nuclear power plant, implying an open-loop control mode using accurate and well-developed mental model and resulting in reduced control error and operator workload.

The role of temporal cognition in human-system interactions may be summarized in the construct of temporal awareness. Grosjean and Terrier (1999) defined temporal awareness as a 'representation of the situation including the recent past and the near future," (p. 1443) echoing definitions of mental models (Rouse & Morris, 1986) and situation awareness (SA; e.g., Endsley, 1995). Temporal awareness may be further hypothesized to be a 'product' of several parallel cognitive processes: an internal ‘clock’ or some timekeeping mechanism (cf. Zakay et al., 1999), and the attentional and perceptual processes that sample the external environment (cf., the perceptual cycle of Neisser, 1976). Because of the inherent limitations of human working memory, maintenance of a good temporal awareness of a dynamic situation necessitates sampling of external cues to the momentary status of the situation or system.

However, human sampling behavior also depends on temporal awareness of the time available and time required to check cues (Rantanen, 2007). It is also possible that temporal awareness contains ‘quality’ information; for example, ‘losing the track of time’ or suspicion that the internal model cannot be trusted would prompt a person to seek to check or update it by looking up some external cues. Hence, overt sampling behavior allows for inferences to be made of covert temporal awareness of the operator or subject

Time is an inescapable part of all human interaction with environments and systems, and anticipatory behavior is becoming increasingly critical as the complexity of these interactions increases. Because systems evolve and change over time, it is clear that the operators must also have a mental representation of the dynamics of the systems they are controlling. Yet the complexity of such task environments settings are uniquely challenging to the operators responsible for processes and systems that are often safety-critical, to the designers of the necessary technologies to support the human operators, and to the researchers trying to understand the many factors and their interactions affecting such human-machine systems. Research focus on the temporal dimension of human-system interactions, however, may offer distinctive advantages in development of cognitive models of human operators' temporal awareness, which in turn will allow for prediction of their performance (influenced by subjective workload) under various operational demands (task load), providing a scientific foundation for further development of large-scale human-machine systems. Focus on time is also advantageous in development of methods of objective human performance measurement that ultimately can be collected and analyzed concurrently with the performance. These closely intertwined research objectives are based on the fundamental notion of the criticality of anticipatory performance in control of complex, dynamic systems. Time is a variable that is common to the human, the task, and the environment, and thus offers a common unit of measurement of human performance in the context of the task. Timing data (i.e., events unfolding in time in simulated scenarios and operational environments as well as timing of operators' overt responses to them) can also be relatively easily obtained under both experimental and naturalistic conditions. Timing data can furthermore be used to infer the goodness of the temporal dimension of the operator's mental model of the task or system being controlled (Rantanen & Nunes, 2005).

The research focus on temporal task characteristics and human temporal awareness aslo transcends particular domains and tasks and is readily applicable to a wide variety of complex and dynamic systems. Temporal performance measures in a variety of tasks and contexts also allows for the testing and evaluation of hypotheses and models put forward in the research literature (e.g., on prospective memory), hence making contributions both to basic psychological research and engineering applications, and helping to bridge the basic and applied ends of the research continuum.

The following research projects by three MS students in Applied Experimental and Engineering Psychology are all closely tied to the research theme described above. Daniel Colombo's project examines a special case of temporal awareness, that of rhythmic behavior, in an abstract, simulated multi-task setting and a laboratory experiment. Katie Coles' project on the other hand is done 'in the wild' in the operational environment of medical emergency department. Such environments do not afford strict experimental controls to isolate causal relationships between variables of interest, but offer a uniquely rich source of data that present unique challenges to their representation and analysis. Finally, Noah Stupak's research focuses on the temporal aspects of human-computer interaction. All of these projects will necessitate development of methods of measurement temporal characteristics of both the task and the human cognition and performance. These methodological challenges alone will advance our knowledge of human temporal cognitive processes as well as the systems with which people interact. The results from these projects will allow for testing different theoretical accounts of temporal cognition; each project will furthermore offer a unique point-of-view to the existing body of research literature. Finally, the results will be directly applicable to real-world problems, ranging from the advantages and dangers of rhythmic performance in repetitive task situations to quantifying the impact of emergency room crowding on physician workload and development of displays for improved human-computer interaction.

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