The role of time on task in multi-task management☆,☆☆

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Extreme resistance to switching tasks can lead to cognitive tunneling. A four-attribute decision model of task management under load was recently built with an assumption of the resistance to switching tasks. Recent theory also suggests switch resistance declines with time on task, and this was tested in the current experiment. Participants managed sequential performance of four concurrent tasks in a multi-attribute task battery. The over-time trends in switch resistance, as related to both cognitive load, and stability of the tasks, were examined. Switch resistance showed no decrease over time overall, contradicting the existing theory. Instead, increases in switch resistance were found with an increased working memory load, and within periods of increased tracking task instability, shedding light on time-on-task effects and cognitive tunneling.

Keywords: Multi-tasking, Time on task, Task switching, Task management, Decision making

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An aircraft pilot has just heard an explosion coming from the engines. Oil pressure is dropping and temperature is rising. She is far from the airport, and must now do high tempo multi-tasking. She must communicate the troubles to air traffic control, consult navigational information to ascertain the nearest feasible landing site, diagnose the seriousness of the problem, and determine whether it has cascaded to other systems and, now flying in the clouds, assure that she maintains a wings level attitude. Four tasks are confronting her in this overload period. How does she manage them and switch her limited cognitive resources between them?

During periods of task overload, such as that above, operators will be confronted by multiple tasks, and may find true time-sharing (concurrent task performance) impossible, lapsing into a sequential processing, or task-switching mode. Under these circumstances, they may engage in maladaptive "cognitive tunneling" (Dehais, Causse, & Tremblay, 2011; Moray & Rotenberg, 1989), staying for a longer than desirable time on an engaging task, to the exclusion of others.

Elsewhere (Wickens, Gutzwiller, & Santamaria, 2015), a model of discrete task switching or task management has been proposed. The model predicts, within an ensemble of three or more tasks: (a) the likelihood that an *ongoing task* (OT) will be left (switched from) to move to an *alternative task* (AT), and (b) which of the waiting alternative tasks will be switched to. These choices are based upon a multi-attribute rating of four task attractiveness features: ease (inverse of difficulty), priority, interest, and salience. The degree to which these four attributes favor one task over the alternatives predicts the likelihood that an alternative task is switched to, or (if it is the OT) that the task promotes "staying". In the experiment we describe below, our main interest is in a potential influence of a fifth factor on switch likelihood, *time on task* (TOT). As the time spent consecutively performing an ongoing task increases, we ask how the switch resistance to a suite of alternative tasks may vary: in other words, to what extent will switching increase, decrease, or fluctuate over time.

Predicting the Effects of Time on Task

In terms of existing theory, a relatively strong argument has been made for decreasing switch resistance (increased switches away from an OT) as a function of time on task (TOT). Such a decrease in resistance (increase in switching) is based on two theoretically distinct, but related arguments regarding cognitive and energetic effects. The cognitive foundation lies in decision theory. Sheridan (1970, 2007) proposed that in multi-task environments, where an AT is dynamic and perturbed by unpredictable influences in system state (an aircraft in turbulence, or a toddler in the next room), increasing time spent on a concurrent OT will increase the uncertainty of the state of this dynamic AT. The longer duration of time away from the dynamic

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AT (increasing TOT on the OT), the greater the propensity to switch away from the OT to the dynamic task (decreased switch resistance).

An energetics-based theory of the same phenomenon is the “effort depletion” concept of Baumeister and his colleagues (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Baumeister, Vohs, & Tice, 2007). Baumeister et al. assumes that, particularly for more difficult tasks, the cumulative effect of effort expenditure triggers a switch to take a needed break. While there has been debate regarding the decision versus energetic mechanisms in the theory (Kurzban, Duckworth, Kable, & Myers, 2013), Baumeister and Sheridan predict the same general trend – with increasing time on task (TOT), switches away will become more likely.

From an alternative theoretical perspective, this change could be attributed to a cognitive or meta-cognitive mechanism, an “opportunity cost” account espoused by Kurzban et al. (2013). Experiencing increased effort, as demanded by the OT, serves as an inhibitory signal that triggers a need to sample the alternative task, commensurate with the increasing expected value associated with its performance.

Whether from loss of situation awareness, depletion of resources or increasing value of a neglected alternative task, these three mechanisms imply decreasing switch resistance. In contrast, an *increase* in switching resistance, which can fit loosely within the memory for goals theory of interruption management (c.f., Altmann & Trafton, 2002; Trafton & Monk, 2007), has also been suggested. Here, a goal state for an OT is approached, and depends on information accumulation in working memory across an epoch of time. The vulnerability of memory contents should induce a reluctance to abandon the OT (e.g., switch to another task), if progress toward the goal would be sacrificed. Consider the intuitive “just let me finish this paragraph” response to an interruption while reading. In this case, reaching the end of the paragraph represents a means to achieve the goal – a point of consolidation of the meaning of the words and phrases contained within the paragraph (Kintsch & van Dijk, 1978). If interrupted beforehand, the costs are numerous, in that, it may be difficult to resume reading in the correct place, and it is unlikely the main idea of the paragraph will be retained.

The mechanism related to an increase in switch resistance may be relatively insensitive to the length of the task, but there are often subtasks within a longer task. For example, when temporary “subtask” boundaries are reached in an online purchase, e.g., entering the last digit of a credit card number, they often allow working memory to be “dumped”, and maintenance of the relevant information for that subtask can cease. These are points of subgoal completion in the memory for goals theory of interruption management, and routinely serve as natural points of lowered workload (Iqbal & Bailey, 2005), and indicators it may be optimal to switch tasks (e.g., Brumby, Salvucci, & Howes, 2007; Janssen, Brumby, & Garnett, 2010; Monk, Boehm-Davis, & Trafton, 2004; Salvucci, 2005; Trafton & Monk, 2007).

Though we discussed the memory related aspects of task performance as related to switching over time above, a parallel concept of *task stability* can be used to describe subgoal completion boundaries in controlling dynamic systems. Stability derives from control theory (Wickens, 1986). Dynamic systems have stable periods that allow operators to temporarily neglect the specific task duties, often in order to address an alternative task. In driving, for example, an optimal time to switch attention may be when the vehicle is centered in the lane (low error), and not trending away from this position (low positive error rate). As these periods fluctuate over time spent performing the task, so should switch resistance.

Whether these fluctuating periods of switching opportunity are created by memory, or the stability of a system, the predictions are similar in that switching to an AT will be more likely to occur *after* maintenance in memory ceases and task reach stable periods, rather than just prior. In fact, in that prior period, switch resistance may *increase* leading up to the opportunity point, something we call *task end-expectancy.* End-expectancy requires neither memory load, nor stability fluctuations to induce the effect; instead, there must be anticipation, expectancy or knowledge of the upcoming point that defines the “end” of the task, or subgoal, which then influences planning of a switch (possibly increasing resistance, and tunneling, in anticipation of an upcoming break in the task).

In summary, two opposing outcomes of increasing TOT have been proposed: either increasing or decreasing switch resistance. *Decreasing* switch resistance over time should occur whenever there are explicit costs associated with failing to update an AT status, and/or when an OT becomes “effortful” over a sufficient amount of time. (In vigilance tasks, and those imposing extreme mental demand, this can be as short as a few minutes; Warm, Parasuraman, & Matthews, 2008).

In contrast, *increasing* switch resistance over time would be predicted in tasks that impose working memory load, and may be associated with less monotonic fluctuations in dynamic stability. The duration of the period in which that resistance builds, and then “resets” can only be predicted by cognitive task or dynamic systems analysis. Increasing resistance may also be predicted as a task end-expectancy effect, when task/subtask ends can be anticipated, through either experience or perception.

Task Switching in a Multi-task Environment

The current experiment employed the Multi-Attribute Task Battery (MATB II; Santiago-Espada, Myer, Latorella, & Comstock, 2011), a research software program which measures operator performance on four concurrent tasks, an updated version of MATB (Comstock & Arnegard, 1992). This platform has been used previously to examine voluntary task switching in overload, individual differences in switching, and the role of fatigue in switching (Clegg, Wickens, Vieane, Gutzwiller, & Sebok, 2015; Gutzwiller, Wickens, & Clegg, 2014, 2015). Within MATB, a digital communications task allowed us to examine memory load effects on switching. A dynamic tracking task allowed us to examine task stability effects. Coupled with the two remaining tasks (a process control task and a monitoring task), we examined the possible monotonic effects predicted by effort depletion (Baumeister et al., 1998), and by opportunity costs (Kurzban et al., 2013).

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