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Task alternation in complex settings: Cognitive issues

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Abstract

Complex work settings often involve an array of sub-tasks. Part of the difficulty of performing in such environments is the need to switch between tasks. However, no systematic investigation of the impact of switching on memory performance is available. In this study, performance in serial memory tasks was examined with regard to the effect of task switching. The results from a series of experiments suggest that switching between memory tasks is beneficial, although this effect can be reduced when the to-be-remembered information does not cue the choice of task unambiguously. It is argued that understanding the factors affecting performance in task switching situations would help increasing efficiency and diminish risks of human error in complex work environments.

Introduction

Most work environments involve multiple tasks that need to be performed in sequence. Anyone familiar with a personal computer will readily call instances of such behaviour to mind: the switching between applications, computer-induced (operating system switching from ongoing application to another to request the user's intervention), or self-generated (from word processing to email software). Task switching is also a common activity in more complex work environments such as the aircraft cockpit where sequential behaviours are often a guarantee of safety (e.g. checklists, well learned visual scanning routines, etc.). One important question for people working in such environments as well as for cognitive psychologists attempting to understand the mental mechanisms involved in task switching is whether task switching has any effect on the efficiency of performance. If one must perform two tasks (A & B) more than once, would performance differ in a particular task A in sequences such as AABB and ABAB compared to when task A is repeated? In this paper, we discuss the issues related to task switching in sequential behaviour with regard to concepts of cognitive psychology as well as ergonomics, and we summarise some of our laboratory studies.

Switching and sequential behaviour

Experimental work has led psychologists to consider order or temporal context as a distinct characteristic of information: Not only can information be defined by *what* it is, but also by *when* it occurs (e.g. Healy, Cunningham, Gesi, et al., 1991). With regards to the selection of relevant information in our environment, recent evidence suggests that the similarity of processes between two activities (e.g. in involvement of seriation), not only their similarity of contents (type of information to process) dictates disruption in human memory (e.g. Jones, Farrand, Stuart & Morris, 1995). Several characteristics of performance in tasks requiring memory for order have been found to be similar in verbal and spatial tasks (Avons, 1998; Parmentier & Jones, 2000). Since order is an intrinsic component of all complex activities (language, motor control, etc.), switching between elements of a sequence comes as a natural consequence, and yet little systematic investigation has been carried out on this issue.

Switching between simple tasks

Many models of workload or memory implicitly assume that going from one activity to another does not represent any challenge for the cognitive system as long as the two tasks do not overlap in time, even though some evidence contradicts this view.

Some empirical research has been conducted on task switching using attentional tasks, that is, involving no or little memory load but, rather, involving rapid decision making or Stroop-like tasks (e.g. Allport et al., 1994; Rogers & Monsell, 1995). The key comparison in these studies is between performance in a situation involving the repetition of a task and performance in a situation in which that task is preceded by another. The key finding is that participants are slower to respond to a stimulus immediately after a task switch than when they are repeating the task.

Although the existing studies on task switching all point to a number of factors that affect the ability to alternate between two relatively simple tasks, the implications of such research are not easily transferable to applied settings. Of course, the investigation of very precise cognitive mechanisms often requires the use of tasks that are highly controllable and therefore considerably different from those observed in complex work environments. However, the tasks used in the existing literature differ from the ‘real world’ in another aspect than their level of complexity: their low or absent memory load. Memory load is an important and dominant characteristic of complex tasks, however. The lack of systematic investigation of task switching between memory tasks is therefore relatively surprising. In the next section, we briefly present some of our work tackling this issue.

Switching between memory tasks

In a series of laboratory studies, we attempted to explore the effect of alternation on performance in tasks involving a memory load. One aspect of our work has been to contrast performance in two types of task: verbal and spatial. Verbal and spatial cognition are required in many settings (e.g. air traffic control operation, aircraft flightdeck, etc.). The supposed verbal and spatial activities independence (e.g. Baddeley, 1986; Wickens, 1992) has, in some extent, influenced the design of human-computer interfaces in order to avoid interference through the overloading of an information channel. In this context, and given the emergence of task switching as a human-computer interaction, it appears necessary to understand better the mechanisms involved in switching between memory tasks.

We studied performance in two tasks of serial memory, one involving crosstalk interference, the other not. Crosstalk interference can be defined as the interference due to an ambiguity between a stimulus and the task that must be applied to it. This occurs when stimuli do not cue any task in particular but several. In our *crosstalk condition*, 7 consonants (fixed set) were presented sequentially from different spatial locations (black squares from a fixed set of locations) on a computer screen (see Figure 1). After the stimuli presentation, the consonants were re-displayed simultaneously, but re-arranged randomly among the locations (so that recalling one type of information in order would not be equivalent to recalling the other in order). Participants recalled items by clicking on the stimuli according to the order in which either the consonants or the locations were presented. In the *no-crosstalk condition*, the spatial task involved the presentation of black squares containing no letter information. In the verbal task, the consonants were presented sequentially from the centre of the screen (no variation of the spatial information). To make sure participants would not just get lost and lose track of what they had to do in the crosstalk condition, different colours of screen background were associated with each task (e.g. white background for the verbal task).

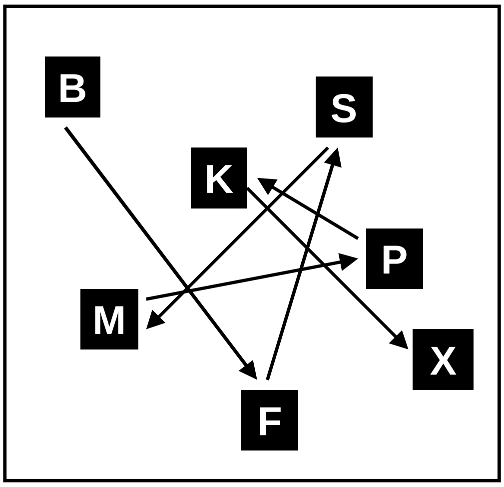

Figure 1. Example of the display presented in the crosstalk task (arrows added to illustrate the order of presentation in this example).

Using these tasks, we compared a number of different experimental designs. We present here two of them. In a low frequency of alternation design (or block design), participants performed four trials of each task before switching to the other (AAAABBBB…). Another type of design involved comparing performance in a particular task in a situation of continuous switching (ABABAB…) and in a situation of continuous repetition (BBBB…). The results of these experiments are described below, starting with those of the block design experiments.

The results from the block design experiments revealed that not only task switching did not result in a performance cost (measured by average accuracy level across the seven items of a list); it was significantly beneficial. A second important aspect of the data was that performance was not affected by the presence or absence of crosstalk. In other words, whether some dimension of the stimuli must be ignored (in the case of crosstalk, e.g. when doing the verbal task, locations are irrelevant and are to be ignored) or not (no crosstalk), levels of recall are similar. This is interesting for it differs from the results observed in the literature using more attentional tasks (e.g. Allport et al., 1994; Rogers & Monsell, 1995; Mayr & Kliegl, 2000), in which one of the main current theories is that inhibition of an irrelevant dimension of a stimulus makes the immediately subsequent activation of that dimension difficult (i.e. the negative priming effect). In our experiment, this effect was not observed. This does not mean that negative priming effects cannot affect switching performance when using memory tasks, as indicated by the results of another series using the continuous switching paradigm described earlier.

Using the tasks described above, we also compared performance in a continuous switching condition (ABAB…) to that in a continuous repetition condition (e.g. AAAA…). With the no-crosstalk condition (that is, when no inhibition component is involved), we replicated the advantage of alternation found earlier. Again, this advantage was found for both the verbal and the spatial tasks. However, in the presence of crosstalk interference, no advantage was observed: performance was similar in the switching and repetition conditions.

The picture emerging from these experiments suggest that two principal phenomenon are at play: one improving performance immediately after a task switch, and one opposing the first (negative priming). There are however two questions such a view raises: (1) Why does negative priming affect switching performance with one design (continuous switch) and not with the other (block design)? and (2) what mechanism is responsible for the beneficial effect of alternation?

We turn to the negative priming issue first. In the case of the continuous switching paradigm (ABAB…) using the no-crosstalk tasks, one would not expect an effect of negative priming since stimuli present only one dimension (location or letter) and so no other dimension must be ignored. In this case, the factor leading to an advantage of alternation is not opposed by negative priming of the task-set. When crosstalk is introduced, and so an inhibition component is added to the task, it may be argued that ignoring one dimension of the stimuli (e.g. letters) will make the immediate subsequent activation of that dimension harder. In this case, a negative priming effect of the task-set works against the beneficial effect of alternation. The result of these two effects cancelling each other out is an absence of effect when comparing performance in alternated and repeated trials. In a design involving blocks of four trials of the same type before each task switch (AAAABBB…), again the absence of crosstalk will allow the benefit of alternation to appear. One may predict that once crosstalk interference is added to the task, the negative priming effect hypothesised in the continuous switching experiments should also appear in the block design paradigm. However, this inhibition might become more automatic and require less and less controlled resources as participants inhibit the same information over and over within a block of four trials. Thereby, as controlled inhibition is no longer required, switching does not lead to negative priming anymore. Although such view is hypothetical, there is evidence in the literature indicating that negative priming effects disappear when the irrelevant information is identical over a few trials before becoming relevant (e.g. McDowd & Oseas-Kreger, 1991).

Regardless of the issue of negative priming, the beneficial effect of switching remains to be accounted for. Not only is such advantage in contradiction with has been observed elsewhere with simpler tasks (e.g. Allport et al., 1994; Rogers & Monsell, 1995), it also seems rather counter-intuitive. Indeed, few people would presume that their performance is better when they switch from a task to another continuously, although a certain degree of change of activity can help keeping people alert. Further investigation is required before we can establish what mechanism(s) underlie the performance increase associated with task switching. What is clear, however, is that switching between memory tasks is functionally different from switching between attentional tasks.

In summary, our exploration of mental switching between two memory tasks suggests that switching does not necessarily result in a cost of efficiency. Rather, it can be associated with improvements in performance efficiency.

Implications

The research presented above, if not allowing specific recommendations regarding a particular flight procedure or instrument use as yet, does point out that task switching should not be overlooked. Switching does affect people's ability to perform a task, whether that task involves a memory load or not. Our findings as well as the existing literature on task switching using relatively simple tasks suggest that when a task requires the person to ignore some aspect of the stimuli, the immediately subsequent active processing of that same aspect is negatively affected. This would suggest that when a pilot memorises information related to the identity of waypoints or other information displayed on the navigation display, there a risk that subsequent processing of the location of that information will be affected negatively.

The effect mentioned above, known as negative priming is a much researched topic within cognitive psychology. What is not so well established is that such a phenomenon is involved in task switching, as least when stimuli convey several types of information (e.g. identity of a waypoint and its spatial location) and must be processed in memory. The present research reveals however that such effects are opposed by a factor that seems associated with task switching. The nature of this factor is not understood as yet. Early evidence suggests that changes of contextual information (such as a change in the background colour of a display) is not the cause of the performance benefit entailed by task switching.

Conclusion

The research presented above focussed on task switching. Up until now, little has been understood about the effects of switching between memory tasks differing in terms of their content (e.g. verbal or spatial). Further investigation will be necessary to clarify the exact cognitive mechanisms involved in switching between memory tasks. However, research efforts should also consider task switching from the point of view of processes. Evidence demonstrates that similarity of contents does not represent the whole picture of interference in memory and that processes constitute an important predictive factor (e.g. Jones, Alford, Bridges et al., 2000). Switching between cognitive processes rather than content should therefore be investigated also. In a more general context, research should look at the similarity of contents versus processes in all types of multi-tasking scenarios: concurrent tasks (two or more tasks must be performed concurrently), task interruptions (a task is put ‘on hold’ and resumed after an interruption is processed), and task switching.

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