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Serial or overlapping processing in multitasking as individual preference: Effects of stimulus preview on task switching and concurrent dual-task performance

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ABSTRACT

Understanding the mechanisms and performance consequences of multitasking has long been in focus of scientific interest, but has been investigated by three research lines more or less isolated from each other. Studies in the fields of the psychological refractory period, task switching, and interruptions have scored with a high experimental control, but usually do not give participants many degrees of freedom to self-organize the processing of two concurrent tasks. Individual strategies as well as their impact on efficiency have mainly been neglected. Self-organized multitasking has been investigated in the field of human factors, but primarily with respect to overall performance without detailed investigation of how the tasks are processed. The current work attempts to link aspects of these research lines. All of them, explicitly or implicitly, provide hints about an individually preferred type of task organization, either more cautious trying to work strictly serially on only one task at a time or more daring with a focus on task interleaving and, if possible, also partially overlapping (parallel) processing. In two experiments we investigated different strategies of task organization and their impact on efficiency using a new measure of overall multitasking efficiency. Experiment 1 was based on a classical task switching paradigm with two classification tasks, but provided one group of participants with a stimulus preview of the task to switch to next, enabling at least partial overlapping processing. Indeed, this preview led to a reduction of switch costs and to an increase of dual-task efficiency, but only for a subgroup of participants. They obviously exploited the possibility of overlapping processing, while the others worked mainly serially. While task-sequence was externally guided in the first experiment, Experiment 2 extended the approach by giving the participants full freedom of task organization in concurrent performance of the same tasks. Fine-grained analyses of response scheduling again revealed individual differences regarding the preference for strictly serial processing vs. some sort of task interleaving and overlapping processing. However, neither group showed a striking benefit in dual-task efficiency, although the results show that the costs of multitasking can partly be compensated by overlapping processing.

1. Introduction

In the modern work environment as well as in every-day life, we are often confronted with two or more tasks at the same time, be it programming a navigation aid while driving, reading newspaper while watching TV, or simultaneously controlling several displays in air traffic control. Such multitasking puts high demands on the human information processing system. This involves different phenomena and processes such as task switching, overlapping processing of information from different tasks, or coping with responding to two tasks in close succession or at the same time. In order to study human multitasking, several paradigms have been used, including anticipated, cued or voluntary task switching (Jersild, 1927; Kiesel et al., 2010), the psychological-refractory-period (PRP) paradigm (Pashler, 1994a; Telford, 1931), and the concurrent dual-task paradigm (Jastrow, 1891; Navon & Gopher, 1979). More recently, also different paradigms to study effects of enforced multitasking and task switching caused by interruptions have emerged (Trafton & Monk, 2008).

All of these paradigms focus on somewhat different aspects of multitasking. The *task switching* and *interruption* research addresses issues of strict sequential task performance which arise when individuals have to cope with multiple task demands but cannot work on the several tasks concurrently or in parallel. This, e.g., involves situations where the tasks are presented at different locations, have the same input devices for responses, or where the human is in an overload situation. The results of this research have provided evidence for several performance costs involved in task switching mainly due to time needed for task-set reconfiguration when switching back and forth between task

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(Kiesel et al., 2010; Monsell, 2003) or re-activation of task-goals after unanticipated interruptions (Altman & Trafton, 2002). Wickens, Gutzwiller, and Santamaria (2015) have provided a first model for predicting decision processes in this sort of sequential multitasking when individuals can freely decide when and for how long they perform each out of two or more tasks.

In contrast, the *PRP* paradigm investigates limits of overlapping processing when two discrete tasks are presented with temporal overlap. As with the task switching paradigm the main focus of this paradigm has been on detailed analyses of effects of multitasking on timing of responses when combining two relatively simple cognitive tasks. The results suggest that overlapping processing of different tasks is possible for certain stages of information processing (e.g. perceptual processes, processes of response execution) but that also a sort of central limitation exits which makes it impossible or at least difficult to perform response selection processes at the same time either due to a structural bottleneck (Pashler, 1994a) or a limited central capacity (Meyer & Kieras, 1997; Navon & Miller, 2002; Tombu & Jolicœur, 2003).

The *concurrent dual-task* paradigm has often been used in human factors research to understand how well humans can concurrently perform different tasks. In contrast to the task switching, interruptions and PRP research which focusses on basic cognitive mechanisms involved in multitasking, the paradigm has mainly been used for analyzing effects of concurrent multitasking on a more holistic performance level using relatively global performance measures of multitasking efficiency and task interference. Their results provide evidence that dual-task interference is mainly determined by the similarity of cognitive resources required by the different tasks (e.g. Navon & Gopher, 1979; Wickens, 2002).

The current research capitalizes on all of these different lines of research and tries to link some of the ideas and insights gained with these different paradigms. Two experimental paradigms are introduced that combine enforced task switching (experiment 1) and voluntary task switching (experiment 2) with a preview to the stimulus of the other task. Situations where humans have to perform several tasks concurrently with all relevant task stimuli principally available, can often be found in real-life, e.g. when answering a phone call while working on emails. Such situations, in principle, provide the option to choose between different modes of multitasking (Wickens & McCarley, 2008) by enabling not only to work on both tasks in a strictly serial manner but alternatively to make use of task interleaving strategies (including overlapping or parallel processing) to optimize multitasking performance. We were specifically interested in two aspects. First, to what extent humans would make use of the option of overlapping processing in such situations. Based on evidence from all lines of multitasking considered above, we expected to find individual preferences for serial vs. overlapping modes of multitasking. The second aspect relates to the impact of the use of overlapping processing with respect to the overall multitasking efficiency in this situation. We will elaborate on both aspects before turning to the actual experiments.

1.1. Individual preferences for different modes of multitasking

Recent research suggests that humans are in principle flexible in applying serial or overlapping strategies of task processing in multitasking situations. Most of this evidence has been accumulated from research with the PRP paradigm suggesting that performance costs arising in multitasking situation are not due to strict structural limitations but often related to strategic choices determined by different task characteristics (e.g. Janczyk, in press; Lehle & Huebner, 2009; Lehle, Steinhauser, & Huebner, 2009; Miller, Ulrich, & Rolke, 2009; Ruiz Fernández, Leonhard, Rolke, & Ulrich, 2011; see for a review Fischer & Plessow, 2015). However, beyond this, there is more, albeit not very systematic evidence from all different lines of multitasking research suggesting that individuals might differ with respect to whether they "naturally" prefer a serial or an overlapping mode of multitasking.

First evidence goes back to the original work on task switching by Jersild (1927). Without having computers, the sequence of two verbal tasks was presented to the participants in form of printed lists including, intentionally or not, the option of a preview of the upcoming task stimuli. In contrast to the very robust finding of switch costs in more recent research (Monsell, 2003), Jersild (1927) pointed out a considerable variance in the data due to "… the fact that some subjects made a gain, others a loss in doing the shift test." (p. 23). Jersild (1927, p. 24) suggested that the overall gains achieved by a subgroup of participants were due to overlapping processing, i.e. a processing of the stimulus of the next task, while still executing the response to current task stimulus. This suggests that, whereas some participants have used the preview option to optimize their performance, others obviously did not use this option and worked in a strictly serial manner on the two alternating tasks. However, this anecdotal observation was not analyzed further in a systematic way. Spector and Biederman (1976); Exp. 1) replicated the benefits of a preview option but did not look at individual differences in using it. In addition, they treated the availability of preview just as a disturbing factor that can mask switch costs and did not provide it in their succeeding experiments. This has set the ground for the subsequent task switching research which never again has addressed the effects of preview and possible individual differences in using it.

A second set of evidence includes observations from PRP research, particularly in studies where participants got intensive practice and/or were provided with some degrees of freedom about how and in what sequence to respond to two simple tasks presented simultaneously or in short succession. For example, Schumacher and colleagues assessed how the typically observed prolongation of the response time to the second task when presented in very short succession to the first one, would be affected by extensive task practice (Schumacher et al., 2001). Their results provide evidence that task practice can result in "virtually perfect time-sharing" without any response slack. Yet, this effect only emerged for a subgroup of five (out of 11) participants who were responsible for the overall statistical significance. Schumacher et al. (2001) attribute this finding to individuals differing in their "personal preference for cautious or daring task scheduling" (p. 105), with the former strategy characterized by "minimal overlap in processing for the two tasks" and the latter one characterized by a "great deal of processing overlap" (p. 107). On a theoretical level, the idea of such differences has been incorporated in models which describe the central bottleneck as a strategic instead of a structural one (e.g. Meyer et al., 1995). Related evidence from the PRP paradigm includes the common finding that often 10–30% of participants do not work strictly serially on the two tasks but tend to group their responses (e.g. Pashler & Johnston, 1989; Schubert, 1996; Ulrich & Miller, 2008). Though those "response groupers" do not necessarily show indications of overlapping processing, they seem to interleave both tasks instead of processing them in strictly serial order. Remarkably, the percentage of response groupers usually increases in conditions where the presented task sequence remains ambiguous due to very short or no stimulus onset asynchronies implicating a higher degree of freedom for self-organization with respect to the response order (e.g. Pashler, 1994b; Pashler & Johnston, 1989).

Finally, some direct evidence for individual preferences for serial vs. overlapping modes of processing in multitasking situations stems from early research of Damos and colleagues (Damos, Smist, & Bittner, 1983; Damos & Wickens, 1980). In a classical concurrent dual-task paradigm, participants had to concurrently perform two simple discrete tasks in a completely self-organized manner, i.e. without any prescription how to organize their task processing. Analyzing the time structure of response sequences, Damos and Wickens (1980) found six out of 16 participants using a strategy of overlapping processing or task interleaving while another eight participants worked on the tasks in a strictly serial manner. Another study of Damos et al. (1983) confirmed this general finding of individual differences based on a larger number of participants.

Altogether, these observations drawn from different lines of multitasking research consistently point to the existence of two types of