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Does Task-Set Reconfiguration Create Cognitive Slack?

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C. Oriet and P. Jolicœur (2003) reported 2 experiments in which the perceptual contrast of stimuli was manipulated in a task-switching paradigm. They failed to observe an interaction in the reaction time data between task switching, perceptual contrast, and response–stimulus interval. Using the locus of slack logic, they concluded from these results that early perceptual processing of stimuli awaits the completion of a task-set reconfiguration stage, rather than proceeding in parallel with it. Here, an assumption necessary for this argument is questioned, and it is shown that an existing computational model of task switching, without successive stages for task-set reconfiguration and perceptual processing, produces a similar pattern of data. Thus, C. Oriet and P. Jolicœur's data are compatible with models in which early perceptual processing and task-set reconfiguration take place in parallel.

A number of subtle methods have been developed, using simple stimulus–response tasks, to investigate the causes of performance limitations when subjects have more than one task to carry out. This article examines the findings of Oriet and Jolicœur (2003), who used one such method—the locus of slack logic (McCann & Johnston, 1992; Pashler, 1984; Pashler & Johnston, 1989; Schweickert, 1978)—to conclude that the process of switching from one task to another cannot be carried out simultaneously with basic perceptual processing. The first part of the article outlines the locus of slack logic, the argument made by Oriet and Jolicœur, and an important assumption required by this argument. In order to infer successive stages for task-set reconfiguration and perceptual processing, Oriet and Jolicœur must have first assumed successive stages for reconfiguration and other central cognitive processes. Without this assumption, the locus of slack logic is inapplicable, because there is no need to posit a period of cognitive slack. Next, evidence against this assumption is discussed. Finally, it is shown that the critical empirical finding of Oriet and Jolicœur is reproduced by an existing computational model of task switching in which task-set reconfiguration and basic perceptual processes take place simultaneously (Gilbert & Shallice, 2002). Thus, the authors' conclusions are not strongly supported by their data.

Locus of Slack

The locus of slack logic has most commonly been used in the overlapping-tasks, or psychological refractory period (PRP), paradigm (Pashler, 1994; Telford, 1931). In this paradigm, subjects are presented with two stimuli, separated in time by a stimulus onset asynchrony (SOA). Both stimuli require a speeded response. As the SOA is reduced, reaction time (RT) to the second stimulus (RT2) typically increases (Pashler, 1994). A range of accounts for this phenomenon has been proposed (e.g., Logan & Gordon, 2001; McLeod, 1977; Meyer & Kieras, 1997; Navon & Miller, 2002; Pashler, 1994; Tombu & Jolicœur, 2003; Welford, 1952). For the present purposes, structural bottleneck accounts are most relevant (e.g., Pashler, 1994; Welford, 1952). According to such accounts, the two stimuli require access to at least one bottleneck (i.e., a process that is exclusively devoted to only one input at a time). If this process is already engaged by the first stimulus, the second stimulus must wait.

Typically, the tasks involved in PRP experiments are analyzed into several stages, each involving different processes. According to some accounts (e.g., Pashler, 1984; Pashler & Johnston, 1989), the central stage of response selection requires access to a bottleneck (central because this stage is distinct from peripheral perceptual and motor-execution processes). This hypothesis makes some clear predictions about the effects of factors slowing particular second-task stages. First, consider the effects of a factor slowing the central stage of the second task (i.e., a central factor). At long SOAs, the bottleneck is typically unoccupied when the second stimulus arrives, and the central factor will slow down the bottleneck-requiring central stage by a particular amount. At short SOAs, the central stage of the second task will typically have to wait until the bottleneck is free. Then, when the bottleneck becomes free, the central stage of the second task will begin and be slowed by the same amount as before. Thus, the effects of central factors and SOA are expected to combine additively. Now consider the effects of a precentral factor. This factor affects an early stage of the second task that does not require access to the bottleneck. At long SOAs, the bottleneck is typically unoccupied when the second stimulus arrives, and the precentral factor will slow down the time taken to reach the central stage and hence RT2. Crucially, at short SOAs, the precentral stage need not wait until the bottleneck is free. In some cases, this stage may be completed before the bottleneck is free, regardless of the level of the precentral factor. In such cases, the precentral factor would not be expected to affect RT2, because its effects would have been absorbed into the cognitive slack that occurs while the second task awaits access to the bottleneck. Thus, the effects of precentral factors and decreasing SOA are expected to combine underadditively (see Figure 1). This is an example of the locus of slack

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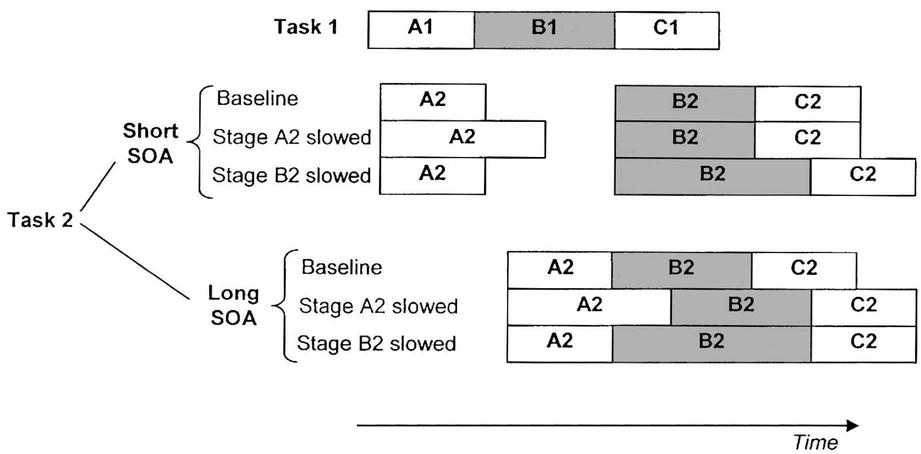

Figure 1. Schematic illustration of the locus of slack logic. Each box represents a stage of processing. Stages A1 and A2 represent early perceptual processes, Stages B1 and B2 represent processes requiring central resources, and Stages C1 and C2 represent late motor processes. While central resources are engaged by Stage B1, Stage B2 cannot begin. With a short stimulus onset asynchrony (SOA), the effect of slowing Stage A2 is absorbed into the cognitive slack that occurs before Stage B2 can begin. This does not occur at a longer SOA. Thus, the effect of slowing Stage A2 is expected to decline at shorter SOAs. By contrast, the effect of slowing Stage B2 is the same, regardless of the SOA. This is the basis for the prediction that factors lengthening prebottleneck second-task stages should have less impact on reaction time at shorter SOAs (i.e., they should combine underadditively with decreasing SOA), whereas factors lengthening postbottleneck second-task stages should combine additively with SOA.

logic.[1] Its predictions have been confirmed in several experiments by Pashler (1984; Pashler & Johnston, 1989), using the precentral factor of perceptual contrast (though see Navon & Miller, 2002; Tombu & Jolicœur, 2003, for arguments that this pattern of data is also compatible with capacity-sharing accounts of PRP phenomena, as opposed to strict bottleneck models).

Task Switching

Oriet and Jolicœur (2003) adapted this logic to the task-switching paradigm (e.g., Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995; see Monsell, 2003, for a review). In this paradigm, two or more tasks are presented sequentially, rather than in an overlapping manner. For example, in the alternating-runs paradigm (Rogers & Monsell, 1995), subjects continuously alternate between short runs of two tasks (AABBAABB, etc.), permitting a comparison between trials where the task is different from the one performed on the previous trial (*switch* trials) and trials where the task repeats (*nonswitch* or *repeat* trials). RT and, generally, error rate are greater on switch than repeat trials—this is the *switch cost*. As the time between trials increases, the switch cost is usually reduced but typically not eliminated (e.g., De Jong, 2000; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Nieuwenhuis & Monsell, 2002).

Oriet and Jolicœur (2003; Experiments 1–2) investigated alternating runs of two digit-classification tasks (odd–even and higher–lower than 5), with two trials before each switch. In separate blocks, they presented stimuli with either low or high perceptual contrast and with a variety of response–stimulus intervals (RSIs), between 0 and 1,200 ms. As expected, RTs were slower for switch than repeat trials and for low- rather than high-contrast stimuli. Oriet and Jolicœur assumed that the effect of low perceptual contrast would be to extend the duration of an early perceptual stage and interpreted the effect of task switching as introducing an extra task-set reconfiguration stage on switch trials. Switch costs were reduced (but not eliminated) at longer RSIs, suggesting that the task-set reconfiguration stage can be (at least partially) completed before stimulus onset, during the interval between trials.

Oriet and Jolicœur (2003) sought to investigate the relationship between the putative stages for early perceptual processing and task-set reconfiguration. They contrasted two models of their relationship. These will be called *parallel* and *sequential* models (see Figure 2). According to the parallel model, early perceptual processing and task-set reconfiguration may take place in parallel. Following the completion of task-set reconfiguration, other processes "that require central resources" (p. 1038) may take place, followed by response initiation. On switch trials, this model predicts an underadditive interaction between perceptual contrast and decreasing RSI. This is because, at short RSIs, a period of cognitive slack will be introduced by the duration of the task-set reconfiguration stage, which postpones the commencement of other stages requiring central resources. At long RSIs, this period of cognitive slack will be reduced, because the task-set reconfiguration stage will be at least partially completed. Oriet and Jolicœur also considered a sequential model, where early perceptual processing and task-set reconfiguration must take place one after the other, followed by response selection and execution. This model predicts additive effects of RSI and perceptual contrast on switch trials, because any factor that affects the duration of the early

[1] More generally, factors affecting prebottleneck stages of the second task are expected to combine underadditively with decreasing SOA; factors affecting stages at or after the bottleneck are expected to combine additively with SOA. The locus of slack logic does not itself make any claim about where the bottleneck is located.

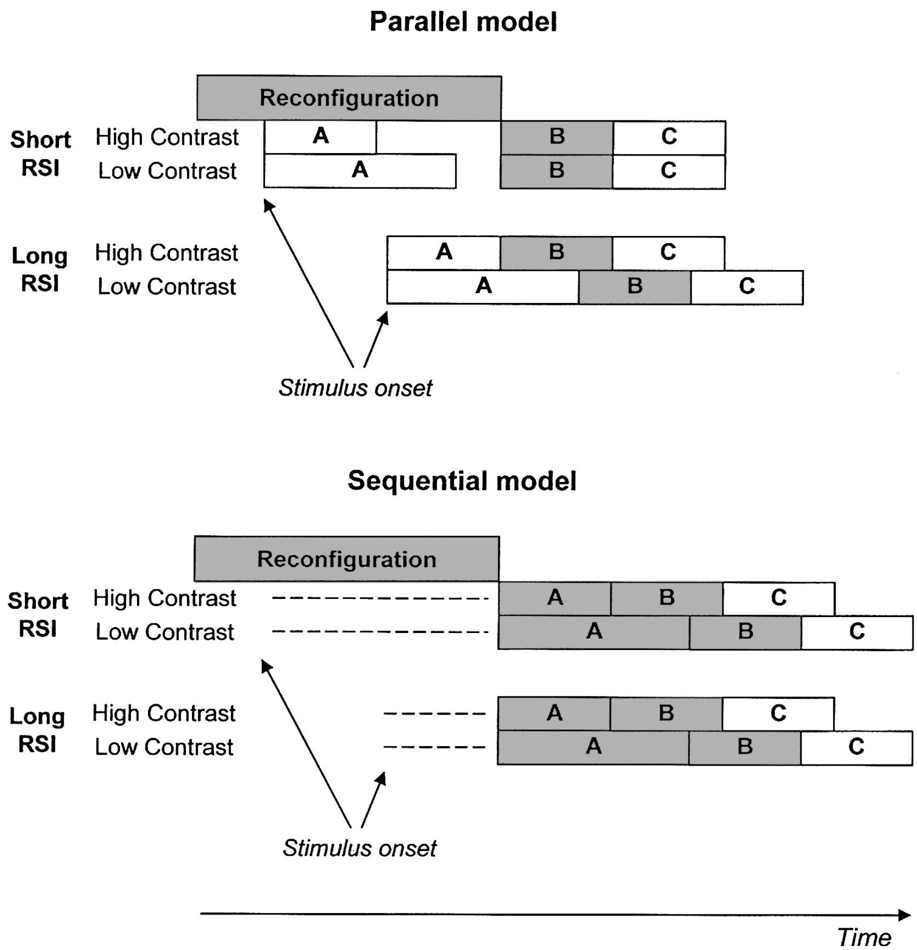

Figure 2. Two models of the relationship between early perceptual processing and task-set reconfiguration considered by Oriet and Jolicœur (2003). Stage A represents early perceptual processing, which is slowed by low-contrast stimuli. Stage B represents a stage requiring central resources, and Stage C represents late motor processes. According to the parallel model, Stage A can take place at the same time as the reconfiguration stage, but Stage B must wait until reconfiguration has finished. Thus, lengthening Stage A at a short response–stimulus interval (RSI) may not affect reaction time (RT), because there is a period of cognitive slack before Stage B begins. However, lengthening Stage A at a long RSI will have a greater effect on RT because there is less slack or none at all. This model therefore predicts an underadditive interaction between perceptual contrast and decreasing RSI. By contrast, the sequential model postulates that even Stage A is postponed until after the reconfiguration stage. Thus, the effect of perceptual contrast on this stage will always affect RT by the same amount, and an additive relationship between perceptual contrast and RSI is predicted. Note that the sequential model might alternatively postulate that the reconfiguration stage is postponed until after Stage A, rather than vice versa (or that both orderings of these two stages are possible). This would lead to the same prediction.

perceptual stage will have similar effects on RT, regardless of the duration of the other stages. Neither model predicts an interaction between perceptual contrast and RSI on repeat trials, because these trials contain no task-set reconfiguration stage and hence no opportunity for cognitive slack. Thus, the critical prediction of the parallel model is a greater underadditivity between perceptual contrast and decreasing RSI on switch than repeat trials. The sequential model predicts no such three-way interaction between task switching, perceptual contrast, and RSI. In two experiments, Oriet and Jolicœur (Experiments 1–2) obtained results consistent with the sequential model: In neither experiment did they observe the three-way interaction predicted by the parallel model. Thus, the authors concluded that task-set reconfiguration imposes a hard bottleneck on processing, which blocks even early perceptual processing.

Interactive Versus Discrete-Stage Models of Task Switching

Oriet and Jolicœur's (2003) results certainly seem to rule out their parallel model, but how strongly does this support the sequential model? Of course, this depends on whether the sequential model is the only alternative to the parallel model described above. According to this parallel model, early perceptual processes take place in parallel with task-set reconfiguration, but other processes requiring central resources await the completion of task-set reconfiguration before they can commence. (Such processes requiring central resources will hereafter be referred to as *response selection* for brevity). This is an important assumption, because it is the sequential ordering of the task-set reconfiguration and response-selection stages that creates a period of cognitive slack, leading to the parallel model's prediction of an underadditive interaction between decreasing SOA and perceptual contrast on switch trials. Thus, although the parallel model considered by Oriet and Jolicœur incorporates parallel stages of task-set reconfiguration and early perceptual processing, the stages of task-set reconfiguration and response selection are organized sequentially. This model was held in opposition to a model where all three processes take place in sequence. However, a third type of model is also possible, where all three processes take place in parallel. This will be referred to as the *interactive model*, because it posits that behavior on switch trials results from the simultaneous, interacting processes of task-set reconfiguration, response selection, and perceptual processing. There is no period of cognitive slack in this model, because the initiation of stages does not await the completion of other stages.

Oriet and Jolicœur (2003) assumed that task-set reconfiguration and response selection cannot take place simultaneously and therefore failed to consider whether an interactive model would also be able to account for their data.[2] But this is an unfortunate assumption to make, because the question of whether task-set reconfiguration and response selection can take place simultaneously is a matter of considerable debate in the task-switching literature (e.g., Allport et al., 1994; Allport & Wylie, 2000; Gilbert & Shallice, 2002; Monsell, Yeung, & Azuma, 2000; Rubinstein, Meyer, & Evans, 2001).

Although many accounts of task switching incorporate separate stages for task-set reconfiguration and response selection (e.g., De Jong, 2000; Rogers & Monsell, 1995; Rubinstein et al., 2001), other models question whether it is theoretically necessary to postulate an extra control process that takes place on switch, but not repeat, trials (e.g., Allport et al., 1994; Allport & Wylie, 2000; Gilbert & Shallice, 2002). According to these latter models, the switch cost is caused by a carryover effect resulting from recent performance of a different, competing task on a previous trial (Allport et al., 1994), or by the retrieval of a now-inappropriate task set, previously linked to the current stimulus (Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2003; Wylie & Allport, 2000). These models deny that the switch cost directly measures the duration of any cognitive process specific to switch trials. Rather, they claim that switch trials are prolonged by the additional time required for the cognitive system to settle into the correct response representation, as a result of enhanced competition.[3] In other words, they explicitly reject the assumption made by Oriet and Jolicœur (2003) in order to derive a prediction from the parallel model (viz., that task-set reconfiguration and response selection represent distinct, sequential stages). Without this assumption, it is not clear that models incorporating simultaneous early perceptual processing and task-set reconfiguration need to make different predictions to the sequential model considered by Oriet and Jolicœur.

Computational Simulations

This section seeks to substantiate the earlier theoretical argument, by demonstrating that the central empirical finding of Oriet and Jolicœur (2003; Experiments 1–2) is reproduced by a computational model in which perceptual processing, task-set reconfiguration, and response selection take place in parallel. The model in question was originally presented by Gilbert and Shallice (2002); its architecture is illustrated in Figure 3. This model simulates the performance of subjects when they switch between word reading and color naming in response to Stroop stimuli such as *RED* presented in a green color (Stroop, 1935). Activity in the word and color input units represents perceptual processing. For example, in order to represent the stimulus described above, the *RED* word input unit and the green color input unit would be activated. These input units send activation along their connections to the word and color output units. The accumulation of evidence for the various response options in these units represents the process of response selection. When the difference in activation between the most active response option and the second most active response option passes a threshold, a response is produced. Processing in the model is iterated in cycles, so that an RT can be recorded for each response (i.e., the number of cycles required to reach the response threshold). Activity in the word and color output units is modulated by a pair of task-demand units, so that the currently relevant stimulus–response pathway (i.e., word reading or color naming) can be selected. The task-demand units themselves receive a top-down control input, which specifies the currently relevant task. This is essentially a modified version of the model of the Stroop task originally described by Cohen, Dunbar, and McClelland (1990).

Task-switching costs arise in the model from two sources. First, there is trial-to-trial priming of the task-demand units, so that patterns of activation and inhibition of these units persist from one trial to the next. Thus, the correct task set will be positively primed on a repeat trial and negatively primed on a switch trial. Second, there is Hebbian learning between the input units and the task-demand units, so that a stimulus associated with one task set will reactivate that task set on a subsequent trial even if a different task is now required. The model therefore does not incorporate any additional stage on switch compared with repeat trials. Performance is simply slowed by competition from previous performance of a different task. This extended competition on switch trials, while the previously appropriate pattern of activation in the

[2] As well as the interactive model, another type of model that could potentially account for these data would be one in which task-set reconfiguration occurs in parallel with perceptual processing and response selection, but the latter two processes are organized serially with respect to one another (e.g., if Stage B started immediately at the end of Stage A at short RSI, in the parallel model depicted in Figure 2). Thus, even if perceptual processing and response selection took place sequentially (see, e.g., Miller, 1988; Miller & Hackley, 1992; Smid, Böcker, van Touw, Mulder, & Brunia, 1996, for discussion), these processes might nevertheless take place alongside task-set reconfiguration, in contrast with the assumption made by Oriet and Jolicœur (2003).

[3] Hybrid models have also been suggested, according to which switch trials are prolonged both by one or more extra processes that do not take place on repeat trials and by slowed execution of the processes that normally take place on repeat trials (e.g., Meiran, 2000a, 2000b).

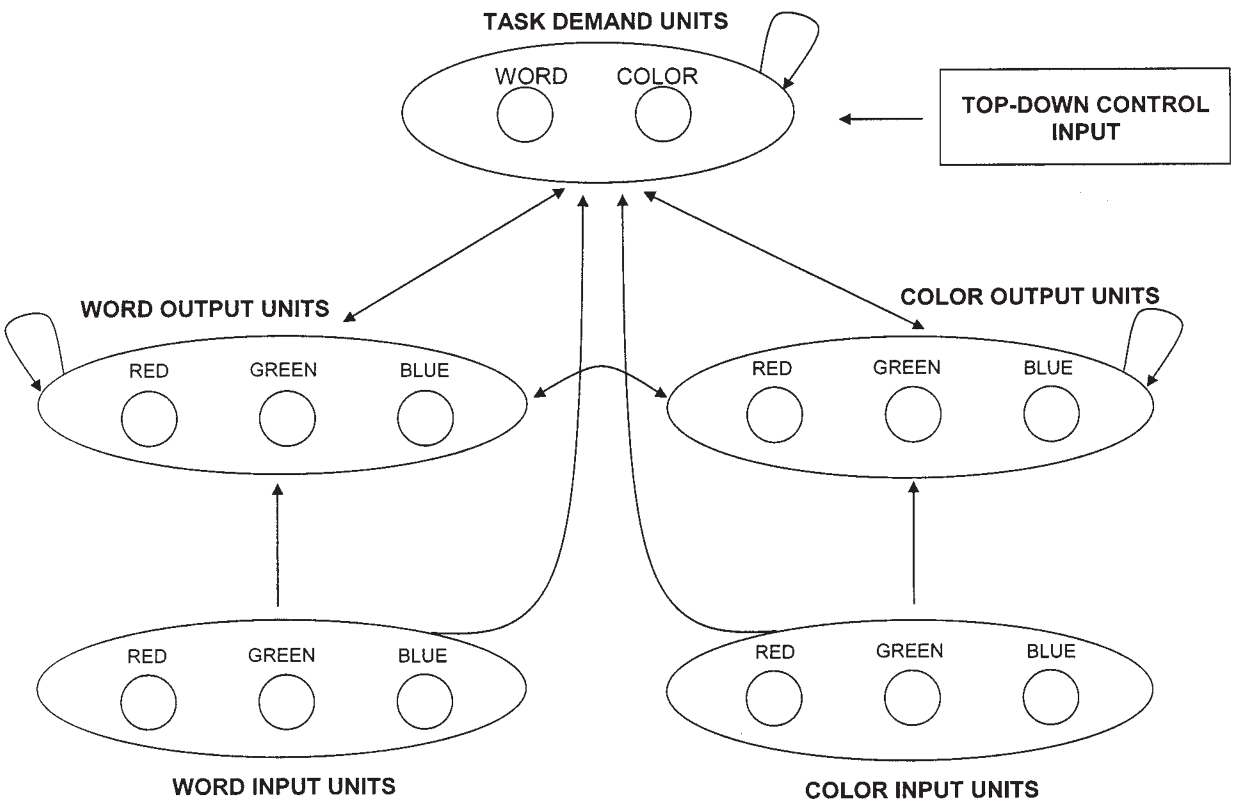

Figure 3. Architecture of the model presented by Gilbert and Shallice (2002). From "Task Switching: A PDP Model," by S. J. Gilbert and T. Shallice, 2002, *Cognitive Psychology*, *44,* p. 305. Copyright 2002 by Elsevier. Reprinted with permission.

task-demand units is gradually replaced with a more appropriate pattern for the current task, is equivalent to the process of task-set reconfiguration. The model simulates a large body of empirical findings from a range of task-switching experiments, including those seen as problematic for this explanation of switch costs (e.g., switch costs confined to the first of a run of trials), suggesting the plausibility of an interactive (rather than discrete-stage) account of the processes involved in task switching.

It was necessary to modify the architecture of the model somewhat, in order to simulate the effects of low-contrast stimuli. In the model's original form, stimulus presentation was simulated by instantaneously setting the appropriate stimulus input units to their maximum values. Perceptual processing was therefore not represented by a process extended over time. In order to make the model more appropriate for simulating the duration of perceptual processes, stimulus presentation was simulated by switching on an external input into the stimulus input units. This is computationally equivalent to the external top-down control input applied to the task-demand units. When the stimulus input units are activated in this way, their activation levels begin to rise at a rate dependent on the strength of the external input (see Gilbert & Shallice, 2002, for implementational details). These external inputs were set at 100 for the high-contrast and 50 for the low-contrast stimuli, although preliminary testing with a range of other values produced similar results. Other than this modification, the model is identical to the one presented by Gilbert and Shallice (2002), and there was no attempt to adjust the parameters of the model to fit the empirical data. Thus, the purpose of these simulations was to capture the qualitative character of the empirical data, rather than to provide a close quantitative fit, because the simulated and empirical tasks were different.

Only the model's simulation of the word-reading task was compared with the empirical data, because this task yields much more robust switch costs. Alternating runs of two trials of each task were simulated, with different stimuli presented on each trial. Simulated RTs (in cycles) at zero RSI were regressed against the empirical data of Oriet and Jolicœur (2003; Experiment 1), in milliseconds, and this regression equation was used to present all simulation data in milliseconds.[4] A maximum simulated RSI of

[4] Empirical data was based on Oriet and Jolicœur (2003; Figure 2). The regression equation used was RT(ms) $= 15.2 \times$ RT(cycles) $- 96$. The simulated RSI, in milliseconds, was obtained by multiplying the RSI (in cycles) by the coefficient of this regression equation. The negative intercept of this equation suggests that some modification of the model's parameters is necessary in order to produce a more realistic fit to the empirical data. This is not surprising, because the tasks and procedure used by Oriet and Jolicœur are different from those originally simulated by the model. Increasing the amount of priming of the task-demand units from one trial to the next was sufficient to yield a more appropriate regression equation (with a positive intercept), without affecting the central findings reported here.

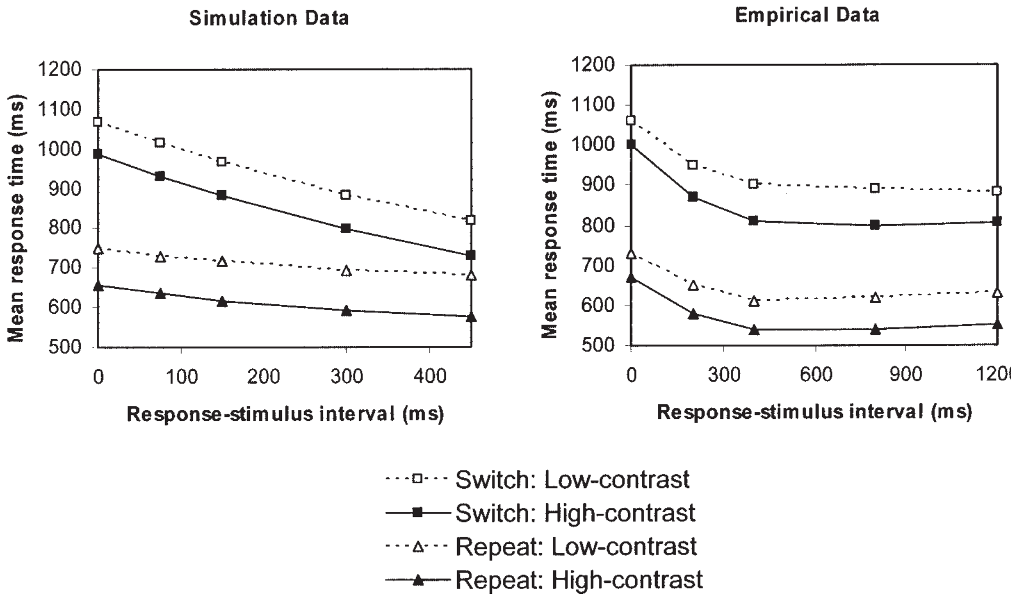

Figure 4. Simulated effects of perceptual contrast and response–stimulus interval on reaction time, on switch and repeat trials, along with equivalent empirical data from Oriet and Jolicœur's (2003) Experiment 1. From "Absence of Perceptual Processing During Reconfiguration of Task Set," by C. Oriet and P. Jolicœur, 2003, *Journal of Experimental Psychology: Human Perception and Performance*, *29*, p. 1040. Adapted with permission.

450 ms was chosen, because this led to a substantial reduction in switch costs.[5] In total, 1,000,000 simulated word-reading RTs were obtained, representing 50,000 simulated RTs in each condition. Error rates were extremely low (< 0.1%) and therefore only RTs are considered here. The results of these simulations and the comparable empirical data of Oriet and Jolicœur (Experiment 1) are presented in Figure 4.

Despite the fact that the model's parameters were originally selected to simulate different tasks to those investigated by Oriet and Jolicœur (2003, Experiment 1), over 90% of the variance in the empirical data plotted in Figure 4 was captured by the simulation (linear regression of simulated on empirical data: $r^2 = .91$). Crucially, the effect of perceptual contrast on switch RTs appears equal across the range of RSIs simulated. Oriet and Jolicœur (p. 1040) described three tests for whether there is more underadditivity between RSI and perceptual contrast on task-switch than task-repeat trials, each of which would yield a value of zero for perfect additivity. If anything, these tests revealed a slightly smaller underadditivity on switch than repeat trials, the size of this effect being very close to zero (below 7 ms). In the empirical data of Oriet and Jolicœur (Experiments 1–2), these tests yielded deviations from additivity of up to 18 ms, which were not significantly different from zero. Thus, the simulated data, from a model in which perceptual processing, task-set reconfiguration, and response selection take place as simultaneous interacting processes, is fully compatible with the empirical data reported by Oriet and Jolicœur. It is also of interest that the simulated effect of perceptual contrast was approximately equal on switch and repeat trials (87 ms and 98 ms, respectively). This is consistent with the finding of Rubinstein et al. (2001; Experiment 1) that a factor influencing perceptual processing had approximately equal effects in alternating-task and same-task blocks. It may seem surprising that the model was capable of producing this additivity between factors affecting simultaneous, interacting processes. However, it has been previously shown that similar overlapping-stage models frequently show approximately additive effects of factors affecting distinct (but simultaneous) processes (see McClelland, 1979; Miller, Van der Ham, & Sanders, 1995, for discussion).

An additional simulation was carried out in order to evaluate the extent to which the perceptual, task-set reconfiguration, and response-selection processes took place in parallel. The model was run without noise, at zero RSI, and the activity level in the input, task demand, and output layers was plotted over the course of a trial. These analyses were conducted separately for repeat and switch trials and with high- and low-contrast stimuli (Figure 5). This graph illustrates the activation level of the units in the input layer, the difference in activity between the task-demand unit favoring the current task and the unit favoring the previous task

[5] This is shorter than the maximum RSI of 1,200 ms investigated by Oriet and Jolicœur (2003, Experiment 1), because the model derives a greater benefit from preparation than subjects in typical empirical experiments (see Gilbert, 2002; Gilbert & Shallice, 2002, for discussion). However, the discrepancy between this aspect of the model's performance and the empirical data (including the data of Oriet and Jolicœur) is tangential to the evaluation of the present argument that a preparation interval sufficient to yield a large reduction in switch costs combines approximately additively with a simulated contrast manipulation on switch trials. Gilbert and Shallice (2002) suggested that one simple way in which their model could be extended to simulate the residual switch cost would be to engage the preparation mechanism probabilistically, to simulate an occasional failure of subjects to make full use of the preparation interval (cf. De Jong, 2000). This would not affect the simulated additivity between perceptual contrast and RSI.

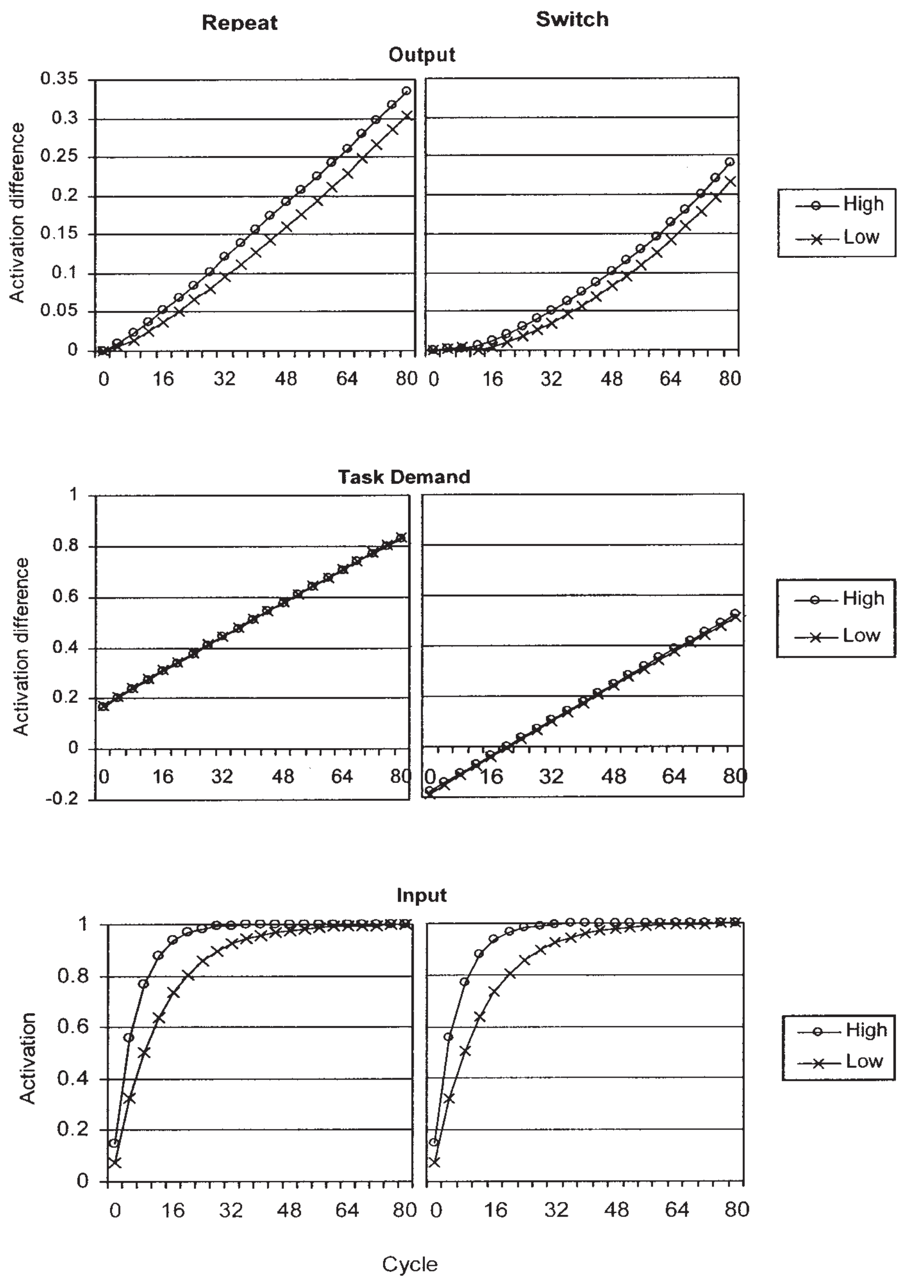

Figure 5. Activity in the input, task demand, and output layers over the course of a single trial, plotted separately for repeat and switch trials with high- and low-contrast stimuli.

(where a positive value represents greater activity in the unit favoring the current task), and the difference in activity in the output layer between the most active and the next most active unit. When this difference in output activity reaches 0.15, a response is produced; however, activity after this point (up to the 80th cycle) is presented in Figure 5 for illustrative purposes. Two features of Figure 5 are noteworthy. First, changes in activity in the three layers take place simultaneously rather than sequentially. Thus, the updating of the task-demand units on switch trials (so that the activation difference moves from a negative to a positive value) takes place at the same time as the accumulation of activity in the input units (representing perceptual processing) and the accumulation of evidence in the output units (representing response selection). Second, activity in the input layer does not differ between nonswitch and switch trials, and activity in the task-demand layer is essentially identical for trials with high- and low-contrast stimuli. Thus, perceptual processing (i.e., the building up of activity in the input layer) and task-set reconfiguration (i.e., the building up of an appropriate activation difference between the two task-demand units) do not block one another: The temporal dynamics of perceptual processing are equivalent between nonswitch and switch trials, and the temporal dynamics of task-set reconfiguration are equivalent between trials with high- and low-contrast stimuli. Both of these features are inconsistent with the model offered by Oriet and Jolicœur (2003), where "reconfiguration of task set [acts] as a hard functional bottleneck, preventing even very early processes from being carried out" (p. 1048).

Discussion

The present results extend the findings of Gilbert and Shallice (2002), demonstrating that a simple model incorporating multiple, simultaneous, interacting processes is able to account for a large body of data obtained in empirical studies of task switching, without needing to posit an additional stage that occurs on switch, but not repeat, trials. These results also cast doubt on Oriet and Jolicœur's (2003) use of the locus of slack logic. A problem of interpretation arises when only an additive relationship between a particular factor and SOA (or, in the present case, RSI) is obtained. In this case, it is not possible to distinguish between an account in terms of the factor affecting a postbottleneck stage and an alternative account where there is no bottleneck at all, and hence no period of cognitive slack to generate an underadditive interaction between the factor and decreasing SOA.

In studies investigating two factors, where one has an underadditive relationship with decreasing SOA and the other an additive relationship (e.g., Pashler, 1984; Pashler & Johnston, 1989), the locus of slack logic is more convincing. In this case, the most plausible explanation of the effects of a factor yielding an underadditive relationship may be in terms of its effects on a prebottleneck stage. Because the concept of a bottleneck is used to explain the effects of this factor (though see Navon & Miller, 2002; Tombu & Jolicœur, 2003, for capacity-sharing accounts), it then becomes necessary to explain the effects of another factor, which yields an additive relationship with SOA, in terms of its effects on a stage after this bottleneck. Thus, the present results do not necessarily challenge the findings of earlier studies using the locus of slack logic to obtain evidence for a response-selection bottleneck in the PRP paradigm (e.g., Pashler, 1984; Pashler & Johnston, 1989). It is of course possible that this response-selection bottleneck represents a genuine phenomenon in the PRP paradigm but not in the task-switching paradigm (especially if the bottleneck is strategic rather than structural; cf. Meyer & Kieras, 1997).

The results of Oriet and Jolicœur (2003) suggested a discrepancy between the PRP and task-switching paradigms, because perceptual contrast typically interacts underadditively with decreasing SOA in the PRP paradigm but interacted additively with RSI in the task-switching paradigm. As an explanation of this discrepancy, Oriet and Jolicœur suggested that the central process of task-set reconfiguration cannot take place in parallel with perceptual processes, whereas the central processes investigated in PRP paradigms can take place in parallel with perceptual processes. It is not clear why there should be this discrepancy between the central processes investigated in the two paradigms. However, an alternative explanation would be that, in the PRP paradigm, a bottleneck limits the simultaneous execution of central processes related to two separate tasks, whereas, in the task-switching paradigm, the processes of task switching and response selection (which contribute to the production of a single response) are not subject to a bottleneck. These processes could therefore take place simultaneously, along with perceptual processing. This account would be consistent with strategic bottleneck accounts of PRP phenomena (e.g., Meyer & Kieras, 1997), according to which subjects may impose a strategic response-selection bottleneck in order to ensure that they respond to the two stimuli in the correct order. In the task-switching paradigm, it may not be necessary to impose such a bottleneck on the various central processes (e.g., task-set reconfiguration and response selection) that are required to produce a single response.

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