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Reconfiguration of task-set: Is it easier to switch to the weaker task?

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Abstract Switching between two tasks afforded by the same stimuli results in slower reactions and more errors on the first stimulus after the task changes. This “switch cost” is reduced, but not usually eliminated, by the opportunity to prepare for a task switch. While there is agreement that this preparation effect indexes a control process performed before the stimulus, the “residual” cost has been attributed to several sources: to a control process essential for task-set reconfiguration that can be carried out only after the stimulus onset, to probabilistic failure to engage in preparation prior to the stimulus, and to two kinds of priming from previous trials: positive priming of the now-irrelevant task set and inhibition of the now-relevant task-set. The main evidence for the carry-over of inhibition is the observation that it is easier to switch from the stronger to the weaker of a pair of tasks afforded by the stimulus than vice versa. We survey available data on interactions between task switching and three manipulations of relative task strength: pre-experimental experience, stimulus-response compatibility, and intra-experimental practice. We conclude that it is far from universally true that it is easier to switch to the weaker task. Either inhibition of the stronger task-set is a strategy used only in the special case of extreme inequality in strength, or its consequences for later performance may be masked by slower post-stimulus control operations for more complex tasks. Inhibitory priming may also be stimulus specific.

Introduction

“Executive control”, the topic of this Special Issue, covers a multitude of specific control functions. Among those functions is the control of “task-set”: our ability to configure the processing resources available in the brain to perform one rather than another of the many cognitive tasks that an upcoming stimulus may afford. Here, we focus on the situation in which we must process a succession of stimuli of the same type, and examine the control processes that enable us, when we have been performing one task, to reconfigure the system to perform a different task in response to the next stimulus.

To study these task-set reconfiguration processes, we need experimental paradigms that exercise them and isolate their contribution to performance. A number of researchers have recently been exploring the consequences for performance (reaction time and errors) of switching tasks. Here are some of the paradigms that have been used:

1. Pure- versus mixed-task blocks: Blocks of trials in which subjects alternate between two tasks are compared to blocks in which they perform just one of the tasks (“pure blocks”). This is the method of Jersild (1927), revived and updated by Spector and Biederman (1976) and Allport, Styles, and Hsieh (1994). At least for “bivalent” stimuli (i.e. stimuli which afford responses in both tasks) reaction time (RT) is typically longer in alternating than in pure blocks.

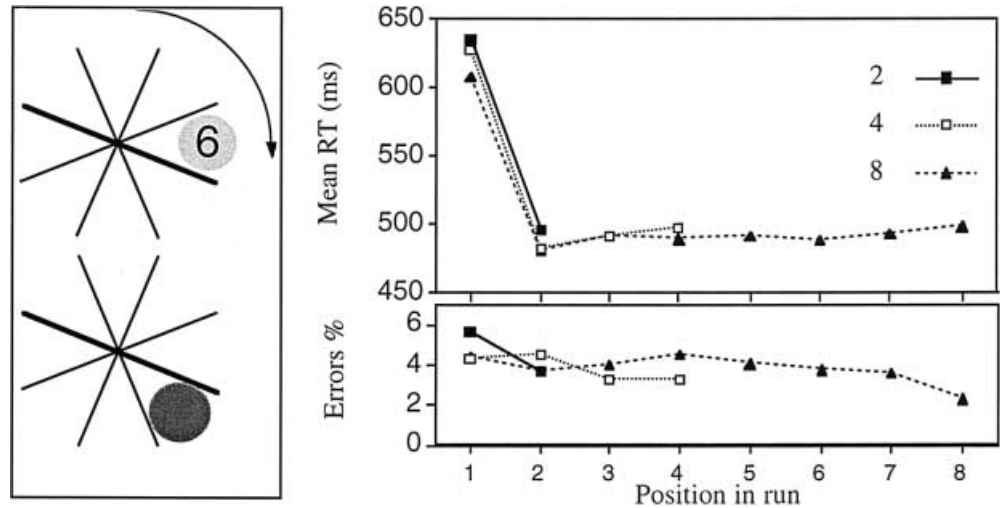
2. Pre-cued task sequences: On each trial there is a sequence of two (or more) stimuli; before the sequence, the subject is told which task to perform to each stimulus. Typically, the response is slower to the second stimulus when a change of tasks is required; moreover, although this measure of the “switch cost” reduces somewhat when more time is allowed for preparation between the response to the first stimulus and the onset to the second, a substantial switch cost remains at long intervals (Allport et al., 1994; Goschke, in press). [See

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Fig. 1 Examples of displays and data from an experiment (Monsell, Sumner, and Waters, in preparation) in which the task switched every two, four or eight trials (constant for a block of trials) between odd/even and high/low classification of a digit. After each response a red or green disk, depending on the task required, was displayed in the next locus clockwise, followed by the digit after 100, 600, or 1100 ms (constant for a block). Heavy radii indicated the loci of task switches (every four trials for the background shown)



Mayr and Keele (in press) for an extension of this paradigm to a sequence of more than two trials.]

3. Alternating runs: The task changes predictably every n th trial (Rogers & Monsell, 1995), with n remaining constant for a substantial block of trials. The subject is assisted to keep track of what the current task is, where they are in a run, and when a task switch is due, by cues such as position on the screen, background colour, or verbal cues. Figure 1 illustrates this paradigm with data from a recent experiment (S. Monsell, P. Sumner, & H. Waters; Task-set re-configuration after a predictable or unpredictable task switch: Is one trial enough?) in which the stimulus was one of the digits 1 to 9 (excluding 5); one task was to classify the digit as odd/even, and the other as greater or less than 5 (high/low). Each digit was displayed in the next segment clockwise around a permanent background display in the form of eight equally spaced radii, with heavy radii marking the point(s) at which the task changed (Fig. 1). Immediately after each response, a red or green disk, depending on the next task to be performed, was displayed in the location of the upcoming digit, and the digit was superimposed on the disk 100, 600 or 1100 ms after the previous response. This stimulus-response (S-R) interval remained constant for a block of trials. As can be seen, mean RT was about 130 ms longer on the trial on which the task changed than on the next trial, but there was no further improvement in performance. The difference between mean RT (and error rate) on the first and second trial of a run – the switch cost – did not interact with run length. The switch cost reduced from 150 to 120 ms as the preparation interval increased from 100 to 600 ms, but then reduced no further.

4. The task-cueing paradigm: Each stimulus can be preceded or accompanied by a cue informing the subject which of two or more tasks to perform, e.g. Meiran (1996), Shaffer (1965), Sudevan and Taylor (1987). Typically performance is improved by allowing more time to prepare between the cue and the stimulus, but

even with a long preparation interval performance is worse following a change of tasks.

5. The instructed switch paradigm: The subject is instructed to perform one task, processes a number of stimuli according to that instruction, then sees another instruction, which may specify the same or the other task, and then processes a number of stimuli according to that instruction. The first response following the instruction display is typically slow, but it is slower following a task switch than not (Allport & Wylie, in press; Gopher, 1996; and Gopher, Armony and Greenspan, in press, Kramer, Hahn, and Gopher, 1999).

In the first three paradigms, changes of task are entirely predictable, while in the other paradigms, they are not. However, data from all these paradigms indicate that changing tasks results in a substantial cost to performance on the trial on which the task changes, and each paradigm provides a measure of this cost in RT and error rate. Each paradigm also allows us to manipulate the time available for preparation for the upcoming stimulus. Results from the last four paradigms indicate that a person's ability endogenously to reconfigure task-set is limited: the opportunity for informed preparation reduces the switch cost somewhat, but (with one or two exceptions to be mentioned later), leaves a substantial "residual" cost – longer RT and often a higher error rate – on the first compared to later trials of a run.

One important contrast we shall need to refer to at various points is that between congruent, incongruent and neutral stimuli. In many task-switching experiments, the same small response set is used for both tasks (e.g. two or four key presses, a small set of colour names, or digit names). In such cases, a congruent stimulus is one for which the same response is appropriate, whichever task is being performed (e.g. the word BLUE displayed in blue in an experiment where subjects must switch between colour-naming and word-naming); an incongruent stimulus is one for which the two tasks specify different responses (e.g. the word RED in blue) and a neutral stimulus is one for which the currently

irrelevant task specifies no response (e.g. the character string “#” in blue, for colour naming). When the two tasks use different response sets, the contrast between congruent and incongruent stimuli is undefined, and there is only the contrast between bivalent stimuli (affording responses – necessarily different – in either task) and univalent (affording responses in only one task). Given Jersild’s (1927) discovery of cases of zero or even negative switch cost with sequences of univalent stimuli only, it is often assumed that there must be at least some incongruent or bivalent stimuli to produce switch costs. In fact this is not so, e.g. Rogers and Monsell (1995) Exp 4, and it remains an interesting question when and why a switch cost is sometimes obtained when subjects encounter only neutral or univalent stimuli. However, we shall restrict ourselves here to cases where there is competition because some or all of the stimuli are bivalent.

Even when subjects do not switch tasks, there is of course typically interference when subjects must perform the weaker of two tasks afforded by incongruent stimuli, as indicated by longer RTs for incongruent than for congruent stimuli, with RTs for neutral stimuli typically in between the two, but closer to those for congruent stimuli. The classic case is the Stroop task – naming the colour in which a colour word is printed – but many other Stroop-like cases have been studied (MacLeod, 1991). Indeed, the fact that a conflicting colour word interferes with colour-naming, while a conflicting colour does not interfere with word-reading, can be taken as a measure of the relative strength of the two task-sets. In this case, the difference in relative strength derives from the extensive practice that literate subjects have with reading as compared to colour-naming (MacLeod & Dunbar, 1988). Monsell, Taylor and Murphy (in press) report evidence from colour-naming experiments that suggests two levels of interference between word-reading and colour-naming: one at the level of the individual responses associated with a stimulus, and one at the level of the task-sets (reading, colour-naming) associated with the two stimuli.

We also see these two levels of interference in task-switching experiments. Typically, the difference between congruent, incongruent and neutral stimuli is enhanced on a task-switch trial. The increased difference between congruent and incongruent stimuli can be attributed to cross-talk between the tasks at the level of the individual responses associated with the stimulus. Interestingly, however, especially on switch trials, the performance on neutral stimuli can be as good as, and sometimes substantially better than, performance on congruent stimuli (e.g. Rogers & Monsell, 1995); this suggests that the presence of a stimulus-attribute value associated with the irrelevant task in *any* way causes interference that may oppose, and even outweigh, any benefit of the same response being activated by both attributes of the stimulus; this interference is clearly at the level of the whole task-set.

The main focus in this paper will be a survey of available evidence from our laboratory and elsewhere

on the interaction between the relative strength of two tasks and the costs of switching between them, to test an interesting general rule proposed by Allport et al. (1994): that larger switch costs are observed when switching from the weaker to the stronger of two tasks afforded by the stimuli than when switching in the opposite direction. As we shall explain, this implies inhibitory control of task-set and carry-over of such inhibition to the subsequent trial. To place this exercise in context, we begin with a review of current theories of the switch cost.

Theories of task-switching costs

Theoretical interpretations of switch costs fall into two broad classes. One treats the RT cost of a task switch as essentially a subtractive measure of the duration of a control process required for task-set reconfiguration, a process that happens on switch trials and not on non-switch trials. (The cost in errors of a switch must presumably be attributed to occasional failures to perform this process effectively or completely.) The other kind of theory, championed especially by Alan Allport and colleagues (Allport & Wylie, 1999, in press; Allport et al., 1994) attributes the additional difficulty observed on switch trials to interference with “normal” processing on the switch trial. The interference results from carry-over of positive priming of the now-irrelevant task-set (or S-R mapping) from its exercise on the previous trial(s), of inhibition of the now-relevant task-set (or S-R mapping) imposed during the previous trial(s), or both.

We will elaborate these ideas below. However, it is already abundantly clear that no simple theoretical dichotomy will be adequate to address the phenomena. For one thing, even for the apparently simple reactive tasks that most researchers have used – such as classifying, identifying, or matching symbols, shapes or colours, or arrays thereof – “task-set” must be a complex of numerous “settings”: which locus to attend to, which attribute of the stimulus to attend to, which response mode and values to get ready, what classification of the relevant stimulus attribute to perform, how to map those classes to response values, with what degree of caution to set one’s criterion for response, etc. Switching between a given pair of tasks may or may not require all these component settings to be changed. That is one sense in which switch costs may be multi-componential. What is involved in changing each component may also change radically with the pair of tasks considered. One cannot really have a theory of task-switching without also having at least the bare bones of a theory of how the tasks between which the person is switching are accomplished.

One major partitioning of the switch cost phenomenon that seems to have *prima facie* validity on the basis of data so far is the distinction between a component of the switch cost that a person can evade by adequate preparation before the stimulus, and a component is still manifest even after preparation – the “residual” cost.

We will discuss these in turn, and then the relation between them.

The preparation effect

As already noted, there is plenty of evidence that the switch cost is reduced, up to a point, by an increase in the time available to prepare for a change in task before the stimulus onset. Could this “preparation effect” be merely the result of a passive decay in the carry-over of persisting “task-set interference” (TSI) from the previous trial, as was suggested by Allport et al. (1994)? There are at least three reasons for thinking it is not:

1. The cueing paradigm allows one to vary the preparation interval while keeping constant the interval between the previous response and the stimulus onset. When this is done, there is still a marked reduction in the switch cost with preparation (Meiran, 1996).

2. Rogers and Monsell (1995) conducted two experiments in which response-stimulus interval (RSI) was varied over the range 150 to 1200 ms. In one (Exp 3), the interval was constant for a block of trials; the RT cost of a switch reduced by about a half as the interval increased from 150 to 600, and then reduced very little further, as the interval was increased to 1200 ms. The only difference in the other experiment (Exp 2) was that the interval varied randomly from trial to trial; there was now no reduction at all in switch cost with increasing interval. If the preparation effect seen with a constant interval were the result of a passive process, it should occur also with a varied interval. The effect must, therefore, be due to a voluntary preparatory process. It seems that under the particular conditions of our experiment, subjects were disinclined to engage in this process when it might be interrupted unpredictably by the stimulus onset. (However, note that a randomly varied interval has not generally discouraged subjects from preparing in cueing experiments, e.g. Sudevan & Taylor, 1987; Meiran, 1996.)

3. Goschke (in press) reports a study on switching between classifying the identity and colour of a letter, using a pre-cued sequence of two tasks. When subjects were required to articulate an irrelevant word (e.g. “Monday”) during the 1500 ms preparation interval, there was no reduction in switch cost relative to a group tested with a 14-ms interval, while subjects who articulated a word naming the task to be performed (i.e. “colour”, or “shape”) showed the same preparation effect as subjects who said nothing during the interval. It seems unlikely that passive decay would be *prevented* by articulating an irrelevant word, but wholly plausible that an active process would be facilitated, or at least not hindered, by verbalising the task to be prepared for.

Hence, at the time of writing, there seems to be general agreement that, as suggested by Rogers and Monsell (1995), the preparation effect indexes the occurrence of an active and endogenous control process during the preparation interval (see Allport & Wylie, in press-a).

The residual cost of a task switch

Allowing a second or more for preparation does not usually eliminate the cost of a task switch. What is the source of the “residual” cost that remains? Theories of the two broad types already mentioned have been applied to the residual cost as well.

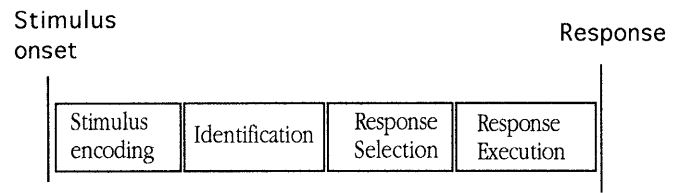
Task-set interference, or priming. As already noted, interference between tasks (and/or the responses specified by them) is a ubiquitous phenomenon even when there is no necessity to switch tasks. The necessity to switch tasks amplifies these interference effects, as described above. Even when not switching tasks, if the other task has been done recently (i.e. in the last few minutes) exaggerated interference effects are seen (Allport & Wylie, 1999, in press). Allport et al. (1994) proposed that in task-switching experiments the residual cost was due solely to interference with response-selection resulting from a carry-over from the pre-switch trial of activation or inhibition at the level of whole task-sets. That is, if a stimulus affords two tasks A and B, and the subject has just performed Task A, and must now switch to Task B, the task-set for A remains active – positively primed – and this makes it harder for the system to settle into the response state appropriate to Task B. For reasons we will elaborate below, they also argued for negative priming of task-set. If, to perform Task A on a previous trial, a strongly competing task-set B has to be inhibited, that suppression can carry over to a later trial and make it harder to activate task-set B on the switch trial. More recently, Allport and Wylie (in press) have proposed that, rather than merely lingering on from one trial to another in the form of transient activation (or inhibition), these priming effects are retrieved from memory by presentation of a stimulus recently associated with them, where “recently” means over the last few minutes. These authors have also obtained evidence that these carry-over effects may be to some extent stimulus-specific – a point to which we shall return below.

A post-stimulus control process. Rogers and Monsell (1995) attributed the residual cost to a control process, required to complete task-set reconfiguration, that could not be carried out until after the stimulus onset. They called this the “exogenous” component of the switch cost, with the notion that the trigger of the external stimulus was somehow needed to complete retrieval or reinstatement of the relevant task-set. They pointed to a number of phenomena that suggest that stimuli evoke task-sets: the smaller switch cost for neutral than for congruent stimulus observed by Rogers and Monsell (1995) and, more broadly, to instances of stimuli evoking habitually associated tasks in action errors and in the “utilisation behaviour” sometimes observed in frontal patients (see Monsell, 1996, for review).

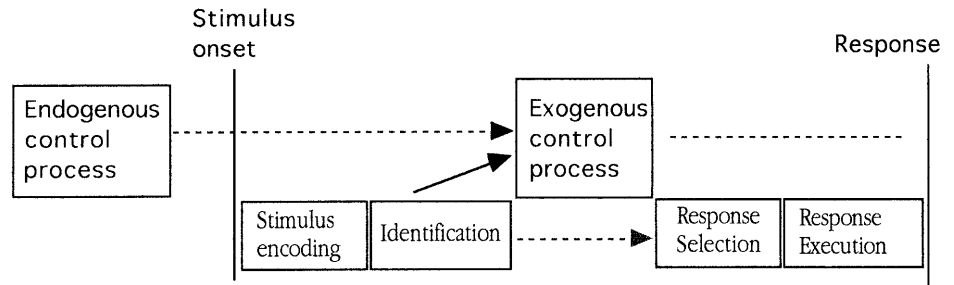
J. Rubinstein, D. E. Meyer and J. E. Evans (Executive control of cognitive processes in task switching, submitted) propose an especially strong variant of this kind of theory. Within the framework of the production-system model EPIC (executive production/interactive

Fig. 2A, B Two accounts of the “residual” switch cost. **A** The sequence of processes performed on non-switch trials is augmented, on switch trials, by a control process required for the completion of task-set re-configuration, which delays the onset of response selection. **B** The same sequence of processes is performed on switch as on non-switch trials, but at least one process (response selection) is prolonged by transient priming of the now-irrelevant task set, or inhibitory priming of the now-relevant task set

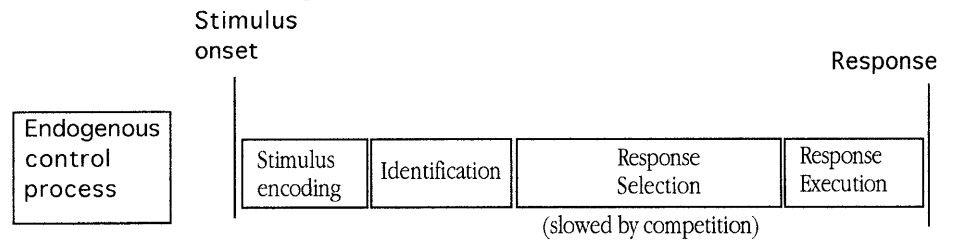
Non-switch trials



A. Switch trials, according to post-stimulus control process model:



B. Switch trials, according to task-set interference model:



control) of Meyer and Kieras (1997), they propose that changing tasks requires two stages of executive processing: “goal-shifting” (determining which productions are to be loaded into procedural working memory) and “rule-activation” (actually loading them). For reasons that are not entirely clear, goal-shifting can occur before the stimulus if time permits and a task change is expected, but rule-activation cannot; it requires the exogenous trigger of the stimulus. Further (and this does not appear to be logically required by EPIC’s architecture), the rule-activation processing stage is inserted into the sequence of task-specific processing stages, on switch trials, as a discrete Donderian stage; it cannot happen in parallel with task-specific processes.

Hence, two radically different views of the source of the residual switch cost are available (Fig. 2). One is that the subject goes through exactly the same set of processes on switch as on non-switch trials, but at least one such process – presumably response selection – is prolonged by carry-over of priming effects from previous trials; the positive priming component of this interference is essentially an amplification of interference effects, at both the S-R and the task-set level, that can be seen even in pure task blocks. The other view is that on switch trials an extra process is needed – presumably prior to response selection – and the duration of that process is directly or indirectly indexed by the switch cost.

It is important to note that, although these two theories can be stated in a mutually exclusive way, the two

sources of the residual cost they posit are not actually mutually exclusive (cf. Goschke, in press). Longer RTs on switch trials could result both from the duration of a control process needed to complete reconfiguration, and from the interference with task-specific processing that results from positive priming of the now-inappropriate task-set and negative priming of the now-appropriate set. Indeed, it is perfectly possible that an extra “control” process is required precisely to overcome that interference, once it arises as the result of the stimulus retrieving a recently activated task-set or the inhibition associated with a recently suppressed task-set.

Our own current position on the residual cost may be summarised as follows. We certainly accept that there are relatively long-term carry-over effects of the kind that Allport and colleagues have demonstrated. We shall provide further evidence for these below. Hence, in the case of data of the sort shown in Fig. 1, performance on the “non-switch trials” is certainly less efficient than it would be if the subject had not recently done the other task. Indeed, where we have made comparisons between performance in alternating-runs blocks and performance in pure blocks in the same experiments, all other things being equal, we have found that subjects are faster in the pure blocks than in the non-switch trials of the alternating runs (there are examples below), and we do not doubt that they would be faster still if they had never done the other task at all. However, we believe it remains moot whether, in data such as those in Fig. 1,

the dramatic improvement in performance from the first to the second trial of a run, and the stable performance thereafter, can be accounted for wholly, or even in part, by an additional short-term carry-over effect prolonging task-specific processes. We note that any such transient component of the carry-over effect would have to have the following properties:

- It does not decay with time when neither task is performed.
- It is eliminated by one performance of the changed task.
- It is not influenced by the length of the run since the same task was previously performed (see Fig. 1).

The relation between the preparation effect and the residual cost

According to Allport and Wylie (1999, in press), the preparation effect reflects the occurrence of a control process, but the residual cost does not. They favour the distinction of Fagot (1994) between “goal-setting” (which can be done before the stimulus) and “task-readiness” (which depends on factors such as task-set interference); a person may complete goal-setting but still be relatively unready to perform the task compared to their state of readiness when they have performed it once. According to some “extra process” theorists (Rogers & Monsell, 1995; and Rubinstein et al., submitted) the control process carried out after the stimulus (e.g. loading of S-R rules) must be of a different kind to the process that can, if time permits, be carried out before the stimulus arrives (e.g. goal-activation), though both are required to ready the system for the new task.

According to a recent variant of the “extra process” theory proposed by De Jong and colleagues (De Jong, in press; and R. De Jong, B. Emans, R. Eenshuistra, & E. -J. Wagenmakers, *Strategies and intrinsic limitations in intentional task control*, submitted), there is only one class of control process required for task-set reconfiguration (“intention-activation”), but the subject sometimes succeeds in carrying it out before the stimulus onset, and sometimes does not. De Jong’s central claim is that performance on switch trials with a long preparation interval results from a probabilistic mixture of trials on which the subject has completed this process and trials on which the process must be performed after the stimulus onset. De Jong finds that the distribution of RTs on switch trials with a long preparation interval is well fit by a mixture of RTs from two other conditions: non-switch trials with a long interval, and switch trials with a short interval (fully prepared, and largely unprepared trials, respectively, according to the hypothesis). S. Nieuwenhuis and S. Monsell (*Residual costs in task-switching: Testing the “failure to engage” hypothesis, in preparation*) found that de Jong’s mixture model fit the data of Rogers and Monsell (1995, Exp 3)

well, with a mean probability of completing preparation of about 0.49. According to De Jong, a subject might fail to engage their preparatory processes through lack of motivation, lack of understanding of the benefits of preparation, and because preparation requires effort. In an attempt to increase the incentives for preparation, Nieuwenhuis and Monsell replicated Exp 3 of Rogers and Monsell (1995) on subjects from the same population, but added monetary incentives and elaborate visual and auditory feedback on block-by-block improvements in performance, while giving full explanations of the benefits of preparation, and short blocks of only 16 trials. RTs were certainly substantially faster than those of Rogers and Monsell’s subjects, but, just as before, increasing RSI reduced the switch cost by only about half. In addition, although the mixture model continued to fit the data well, the mean estimated probability for preparation was still only 0.64.

De Jong’s probabilistic “failure to engage” version of the extra-process theory of residual costs gives a unified account of the preparation effect and the residual cost. It certainly merits further exploration. The puzzle it poses is why it is so hard to increase the estimated probability of “engaging” much beyond 0.5. True, there are at least two cases where the switch cost has been eliminated completely by a long preparation interval: De Jong et al. (submitted), Exp 3; and Meiran (1996), Exp 5, especially, in which the switch cost at the long preparation interval, for compatible stimuli, was 1 ms). It is interesting that, in both cases, the cue contained both the stimulus values to which the subject might have to respond (e.g. if the task was to classify a coloured shape as red or blue, the cue contained the colours red and blue). Perhaps this enabled the cue to trigger exogenously a “refractory” preparatory control process that would otherwise (on these trials) have needed the stimulus to spur it into action – much as suggested by Rogers and Monsell (1995)!

Certain other observations concerning the preparation effect will have to be accounted for by any model. First, it has been observed several times that the differences between congruent, incongruent and neutral stimuli (i.e. the response-congruence and task-cueing effects), although much larger on switch than on non-switch trials, do not reduce with increasing time for preparation, e.g. Rogers and Monsell (1995), Exp 3; but see Goschke (in press). Hence whatever else the “endogenous” process is doing that reduces RT, it does not defend the system against cross-talk from the other task on the switch trial; only after one actual performance of the task is the cross-talk reduced. Allport and Wylie (in press) note as a problem for a process account of the preparation effect that, although we may see a mean switch cost of 100–200 ms on unprepared trials, the switch cost does not typically reach its asymptotic minimum until the interval available for preparation reaches 500 or 600 ms. A process theorist would seem to have two possible answers. Either the control process takes longer if it is performed under endogenous activation only – because of the absence of exogenous driving – , or, in a similar

spirit to De Jong's proposal, we might suppose that even when the subject does succeed in engaging the control process prior to the stimulus, they often take some time to get the process under way.

Asymmetrical switch costs and negative priming of task-sets

The data shown in Fig. 1 were from an experiment in which the two tasks between which subjects switched were of roughly equal difficulty. Typically, switch costs are roughly symmetrical in such cases. However, in some cases of switching between tasks of unequal "strength", Allport and colleagues have observed an asymmetry of costs which is both counter-intuitive (at least if one's intuitions include the notion of some sort of reconfiguration process) and hard to explain except in terms of some sort of "carry-over" effect. Using incongruent Stroop stimuli, Allport et al. (1994), Exp 5, found, and Allport and Wylie (in press) replicated, a substantially larger cost of switching from colour-naming to word-naming than vice versa. Meuter and Allport (1999) had bilinguals switch unpredictably between naming digits in their dominant and subordinate languages. Naming in the dominant language was faster on the non-switch trials, but it was slower than naming in the subordinate language on switch trials. Thus, once again, it was easier to switch to the harder of two tasks.

If task-switching costs, and particularly the residual cost, arise as the result of the time taken by a reconfiguration-accomplishing control process, it is surely surprising that it takes longer to reconfigure oneself for a more practised task. While it is not obvious that a more-practised task-set should take less time to activate or engage than a less-practised one, it is baffling that it should take more. To Allport et al. (1994) this is clear evidence for the woeful inadequacy of the "extra process" account. Their explanation is that when task-set A is much stronger than task-set B, to perform task B requires task-set A to be actively inhibited. This inhibition carries over to the next trial. If this trial requires a switch to task A, the inhibition of task-set A must be overcome for response selection to settle into a stable end-state appropriate for Task A. To perform Task A trials, however, inhibition of task-set B is not required, and therefore does not carry-over to retard response selection when a switch to Task B occurs. Allport and Wylie (1999, in press) support this account further by demonstrating that the asymmetry of switch costs between word-naming and colour-naming occurs only if subjects have recently had to colour-name incongruent stimuli.

Two other kinds of evidence for carry-over of inhibition as a source of switch costs should be noted here. In experiments on both pre-cued and cued switching between classifying the colour and identity of letters, Goschke (in press) found that switch costs were somewhat greater when the stimulus on the pre-switch trials

was incongruent. He argued that to respond correctly to an incongruent stimulus requires (extra?) inhibition of the irrelevant task (or its perceptual dimension), and this carries over to the next trial, impairing performance if the next trial requires a switch to the inhibited task. Note that this account of the need for inhibition makes no mention of the relative strengths of the two tasks, unlike that of Allport et al. (1994).

Mayr and Keele (in press) had subjects detect the odd one out among four objects in three successive displays, using a different criterion for each display (e.g. colour, orientation, motion). With both cued and pre-cued switching, and with intervals for preparation, they found that when subjects had to use the same criterion as for two displays back (as in the sequence colour-motion-colour), they were slower than when three different criteria were used (e.g. orientation-motion-colour). They argue that to switch tasks, people must inhibit the task-set they have just been using (the colour set on the first display in the first example), and this inhibition must be then be overcome to re-engage that task set (on the third display). This is different from Allport's account in two ways. Again, there is no mention of the relative strength of the two tasks. More important, the relevant inhibition is applied on a switch trial to overcome activation of the now-irrelevant task, not on the previous trial to process the stimulus preceding the change in task. However, once this inhibition has been "attached" to a task-set, it persists over at least one intervening trial.

We note, further, that Allport and colleagues could be correct about the carry-over of inhibition, but wrong about its consequences. That is, rather than merely prolonging the same task-specific processes that happen on non-switch trials (e.g. response selection), inhibition may either prolong a control process that occurs only on the switch trial, or even evoke a control process, specific to overcoming inhibition, that would otherwise not be needed. [The same is true for the forms of inhibition proposed by Goschke (in press), and by Mayr and Keele (in press).] In short, the issue of carry-over of task-set inhibition is separable from the mechanism of its effect on switch cost.

A necessary preliminary to explaining Allport's counterintuitive asymmetry of switch costs is to establish its generality. In a number of recent experiments, including some conducted for other purposes, we have tested switching between tasks which clearly differ in "strength". We now review these here, giving only minimal details of each experiment (most will be published in full elsewhere). We review them under three headings, according to whether the difference in strength derives from pre-experimental experience, manipulations of S-R compatibility, or within-experimental practice. In every case the paradigm used is alternating runs of two trials, with an RSI of at least 600 ms (so that we can assume we are looking at residual cost), and with task and position in the run cued by position on the screen, in much the same manner as in Rogers and Monsell (1995), or by background colour or shape.

Strength through pre-experimental experience

One set of experiments has examined what happens to switching between the two Stroop tasks – the classic case of unequal strength – if we slightly handicap the stronger task, but not enough to remove the asymmetry of interference. In all cases we used only incongruent and neutral stimuli, the latter being false-font strings, and colour words in black. By “interference” we mean the difference in performance to incongruent and neutral stimuli. We tested colour-naming and word-naming in both pure blocks and in alternating-runs blocks.

Monsell, Williams and Wright (reported briefly in Monsell, 1996) examined switching, at an RSI of 800 ms, between colour-naming and word-naming of Stroop stimuli that were degraded to make them a little harder to read. The four colour words, or, for the neutral stimuli, false-font strings, were presented in mixed font styles and sizes, and with a superimposed dot pattern, such that word reading was slowed by about 100 ms. This manipulation did not remove the asymmetry of interference (incongruent versus neutral) in pure blocks, as shown in Table 1. However, the switch cost was essentially symmetrical.

N. Yeung and S. Monsell (Switching between tasks of unequal familiarity: the role of stimulus-attribute and response-set selection. in preparation-a) used a different form of handicap. Following Glaser and Glaser (1982), we displayed a black colour word (or matched false-font string) on a coloured (or outline black) rectangle, using an RSI of 1 s. When word and colour were presented simultaneously we replicated Allport’s observation of greater costs for switching from colour-naming to word-naming than vice versa. However, when the onset of the character string was delayed by 160 ms relative to the onset of the rectangle, the switch costs reversed, so that

it was now significantly harder to switch to the colour-naming than to the word-naming task. According to the interference effects observed in the pure blocks, the relative strength of the two tasks was scarcely changed by the delayed onset of the word.

Hence, even with Stroop stimuli, it is possible to find conditions under which the surprising asymmetry of switch costs can be removed or reversed by a handicapping of the word-naming task that is insufficient to attenuate, to any significant degree, the asymmetry of interference in the pure blocks that indexes the inequality of task strength. That might suggest that subjects resort to a strategy of active inhibition (and then suffer from its carry-over) only when the difference in strength is above a fairly high threshold.

Interestingly, though, in both our experiments and that of Allport and Wylie (1999, in press), the interference (incongruent minus neutral) observed in the alternating-runs blocks becomes more symmetrical on switch trials, and on non-switch trials is midway between the patterns for switch trials and in pure blocks. In other words, we might conclude that, on a switch trial, the two tasks become transiently more equal in strength, as a result of the recent exercise of the other task. However, if we were to take the interference observed in the switching blocks as the relevant measure of (current) relative task strength, it would become less clear why inhibition is required only for one task, and the rationale for the counterintuitive asymmetry of switch costs would be weakened.

For a different case of bivalent stimuli and unequal prior experience with the two tasks, we turn to data (Table 2) from three experiments in which subjects switched between naming a visually presented digit and a less familiar task. In the first two experiments the other task was classifying the digit as odd or even. As there is

Table 1 Mean correct RT (ms) and percent error (in parentheses) from experiments in which subjects colour-named or word-named Stroop incongruent and neutral stimuli either in “pure” blocks (one task only), or switching between the two tasks every two trials

	Pure blocks		Blocks of alternating runs			
	Incongruent stimuli	Interference	Incongruent stimuli		Interference	
			Non-switch trials	Switch Cost	On non-switch trials	On switch trials
Word degraded ^a						
Word-naming	575 (2.8)	-5 (1.3)	626 (3.1)	65 (0.3)	43 (0.4)	81 (1.9)
Colour-naming	625 (1.9)	77 (0.6)	649 (4.4)	61 (-0.1)	80 (3.1)	83 (2.8)
Simultaneous ^b						
Word-naming	465 (0.3)	2 (0.2)	565 (1.6)	99 (6.8)	41 (1.6)	87 (8.4)
Colour-naming	676 (3.6)	87 (2.4)	714 (5.9)	30 (0.8)	132 (4.1)	121 (6.3)
Word delayed ^b						
Word naming	492 (0)	12 (0)	557 (1.8)	51 (3.1)	66 (1.6)	79 (4.9)
Colour naming	641 (2.3)	78 (1.8)	665 (1.8)	106 (3.7)	81 (1.6)	138 (5.3)

(“alternating runs”) [*RT* reaction time, *Switch cost* increment in RT (% error) on switch relative to non-switch trials, *Interference* increment in RT (% error) on incongruent relative to neutral stimuli]

^a Coloured (or white) colour words (or false-font strings) degraded by mixed font and size, and by overlay of random dots, on black ground (Monsell, Williams and Wright, unpublished)

^b Black words (or false-font strings) on coloured (or outline)

rectangle. For one group of subjects the word and rectangle were simultaneous. For the other the word onset was delayed by 160 ms (Yeung and Monsell, in preparation-a, Exp 1)

Table 2 Mean correct RT (ms) and percent error (in parentheses) in experiments in which subjects saw digits on every trials and switched between naming the digit and a less familiar task [*Switch cost* increment in RT (% error) on switch relative to non-switch trials for that task]^a

	Non-switch trials	Switch cost
A		
Digit naming	388 (1.6)	21 (0.1)
Odd/even classification (keys)	471 (1.7)	67 (0.0)
B		
Digit-naming	471 (0.2)	51 (0.5)
Odd/even classification (vocal)	567 (2.4)	116 (2.8)
C		
Digit-naming	493 (0.4)	67 (2.9)
Tens-complement naming	615 (2.6)	26 (0.1)

^aData set A from experiments by S. Monsell, M. Eimer, M. Le Pelley, S. Strafford and N. Yeung (Is response activation postponed or prolonged by a task switch? A lateralized readiness potential study, in preparation), data sets B and C from experiments by N. Yeung and S. Monsell (in preparation-a)

no congruence effect to measure, we do not have a direct measure of “strength” here, but intuition, the low RT and error rate, and the very small Hick coefficient typically observed for digit-naming (Mowbray and Rhoades, 1959) suggest that digit learning is a paradigmatic case of a highly over-learned S-R mapping. In one experiment the classification response was a left or right key press, in the other a vocal response (“odd” or “even”). In both cases the cost of switching to the (more arbitrary, less familiar) classification task reliably exceeded the cost of switching to the naming task. In a third experiment, subjects switched between naming a digit and naming its tens-complement (e.g. saying “seven” in response to “3”). In this case we see Allport’s surprising asymmetry: a larger cost for switching to the easier task. Why the difference? Of the three, this is the only case using the same response set for the two tasks. This may be an important factor. But it certainly cannot be either necessary or sufficient, as further results to be reviewed below include cases of the counterintuitive asymmetry of costs without overlapping response sets, or even modalities, and the Stroop cases reported above include two cases where the response sets are identical, but the counterintuitive asymmetry is not observed. Hence our best guess at the moment is that only a marked discrepancy in task strength will yield the asymmetry: the differential weakness of the tens-complement task (relative to naming) appears to exceed this threshold; that of the odd/even task does not.¹

¹One suggestion – for which we are indebted to Ian McLaren – why switching between naming and odd/even classification does not conform to Allport’s rule is that to classify a digit one must first identify it; it is thus not possible to suppress the naming task by suppressing identification. However, the tens-complement task surely requires identification of the digit no less than the odd/even task, and probably more.

Strength through S-R compatibility

S-R compatibility is a broad concept, with a large research literature (e.g. Hommel & Prinz, 1997; Kornblum, Hasbroucq & Osman, 1990; Kornblum & Lee, 1995; Lu & Proctor, 1995). Compatibility can result from massive practice; for example, for highly literate people, reading a word aloud is said to be a compatible task. However, it can also arise through the availability of direct and efficient pathways in the brain between certain perceptual analyses of the stimuli and the control of motor output. The compatibility effects we have studied are, we believe, of this latter kind, and we have studied two types, which we call “mode-compatibility” and “value-compatibility” (cf. “set-level” and “element-level” compatibility of Kornblum et al., 1990). Mode compatibility refers to the naturalness of the relation between a stimulus attribute and a response mode (Wang & Proctor, 1996). Examples of high mode-compatibility are responding to speech input with speech output, or to a visual location with a spatially oriented manual response. In contrast, responding to speech with a finger extension, while perfectly easy, is not compatible in this sense. Value-compatibility refers to the fact that, for a given pairing of stimulus attribute and response mode, some mappings between stimulus value and specific response are more natural and easy than others; for example, given four visual positions in a row, and a row of keys under the finger of the right hand, it is easier to respond to a visual stimulus at one of those positions with the corresponding finger (index for the left-most, etc.) than with the reverse mapping (index, for the right-most, middle for the next one to the left, and so on), and that is easier in turn than an arbitrary rule (e.g. $1 \rightarrow 3$, $2 \rightarrow 2$, $3 \rightarrow 4$, $4 \rightarrow 1$). Value- and mode-compatibility are not independent (you cannot vary value compatibility if the mode compatibility is not great enough to afford a natural mapping of stimulus values to responses within that mode) but they can be manipulated separately.

Mode compatibility. R. Azuma and S. Monsell (Task switching and compatibility between stimulus attribute and response mode, in preparation-a) used a stimulus consisting of a horizontal rectangle containing a letter string (LEFT, RIGHT, or XXXX) on its left, on its right, or in its centre. The subject had to respond to the *location* of the letter string within the rectangle (left or right), regardless of its identity, or to the *word* (LEFT, RIGHT), ignoring its location. The other attribute could be congruent, incongruent or neutral. Moreover, subjects might respond to either attribute by saying the word “left” or “right” or by pressing a left or right key. This yields four possible tasks: location \rightarrow key, word \rightarrow say, location \rightarrow say, and word \rightarrow key. All seem equally value-compatible, but the first two tasks have higher mode-compatibility than the second two. How do we know this? First, when we run each of these tasks in pure task blocks and make appropriate comparisons within response mode, we see faster RTs and smaller interference effects in the first two tasks than in

the second two (see Table 3a). In addition, reading aloud is standardly considered a highly automated S-R mapping – hence the Stroop effect. There is also neuropsychological evidence for a “visuo-motor system” directly linking the perceptual analysis of visual location to motor areas, and specialised for the spatial guidance of manual actions (e.g. Milner & Goodale, 1995).

Having established that the location → key and word → say tasks are more compatible than the location → word and word → key tasks, we examined switching between compatible and less compatible tasks every second trial in two alternating-runs experiments, with an RSI of 1 s. In one experiment, subjects always switched between responding to the side and to the word. In one condition they switched between the side → key and word → key tasks. In another condition they switched between the side → say, and word → say tasks. Hence, in these two conditions, the relevant dimension alternated, but the response-set remained constant (as in the Stroop experiments reviewed above). Table 3b shows the switch costs obtained. Averaging over responses, the switch costs were 46 ms (1.5%) for switching to the compatible task, and 41 ms (2.9%) for

switching to the less compatible task. Only the contrast in error rate was reliable ($p < 0.05$). In a second experiment, subject switched response mode every second trial, but responded to the same attribute for a block of trials. (In this experiment the words “SAY” or “KEY” appeared permanently above the relevant display locations as a reminder of the response mode.) This can be seen as analogous to the language-switching experiment of Meuter and Allport (1999). Table 3c shows the switch costs. The mean cost for switching to the compatible task was 61 ms (2.0%), compared to 85 ms (1.9%) for switching to the less compatible task; the contrast in time costs was reliable, $p < 0.05$. Hence, if we are prepared to consider differences in mode-compatibility as constituting the sort of task strength inequality that is relevant to testing Allport et al.’s conjecture, these experiments provide no support for that conjecture: it was not detectably harder to switch to the demonstrably stronger task. It is perhaps significant, however, that none of these mappings is arbitrary: they are all value-compatible. This leaves open the possibility that the counter-intuitive asymmetry of costs may be limited to conditions where there is a more marked asymmetry of strength.

Value-compatibility. R. Azuma and S. Monsell (Task switching and compatibility between stimulus and response values, in preparation-b) manipulated value-compatibility as follows. The stimulus was a small 2×2 matrix of squares with a letter from the set A-D in one of the squares. For one task, subjects responded to the position of the letter within the matrix with the index finger and thumb of each hand, by pressing one of four keys arranged in a square. The S-R mapping could be either (spatially) compatible, in which case the key in the position corresponding to the position in the matrix was the correct response, or incompatible, in which case the correct key was specified by a memorised and pre-practised arbitrary mapping rule (NW → SE, NE → SW, SE → NE, SW → NW). For the other task, subjects responded to the letter with its name in the compatible condition, and in the incompatible condition with a letter name specified by a similar arbitrary rule (A → C, B → D, C → B, D → A). Table 4 (a, b) shows that there was a large compatibility effect. Once again we looked at switching between compatible and incompatible mappings in two ways.

In one experiment (12 subjects, 3 sessions²), the task switched between the two attributes every second trial. The response mappings for the two attributes differed in compatibility, and remained constant for a series of blocks. The task was indicated by the quadrant of a large background “X” in which the stimuli were displayed in a clockwise cycle; there was no additional cue for the task. As Table 4a shows, there were large (and highly significant) effects of compatibility, but switch

²But for half of each session, subjects switched between the two compatible or between the two incompatible tasks. Switch costs were much higher in the latter case.

Table 3 Data from experiments on stimulus-response mode-compatibility (Azuma & Monsell, in preparation-a)

(a) Mean correct RT (error rate) and interference from the irrelevant dimension (incongruent minus congruent) for the four tasks in pure blocks

	Mean RT (% error)	Interference
Key response:		
Side → Key	373 (2.0)	13 (2.2)
Word → Key	452 (3.9)	56 (7.8)
Vocal response		
Word → Say	466 (0.1)	20 (0.3)
Side → Say	536 (1.4)	48 (3.1)

(b) Switch costs from an experiment in which subject switched attribute every two trials, but used the same response mode for a block of trials

	Non-switch trials	Switch cost
Compatible		
Side → Key	464 (2.7)	58 (2.4)
Word → Say	543 (2.2)	34 (0.5)
Less compatible		
Word → Key	513 (5.0)	46 (3.8)
Side → Say	563 (2.3)	35 (2.8)

(c) Switch costs from an experiment in which subjects switched response mode every two trials, but responded to the same attribute for a block of trials

	Non-switch trials	Switch cost
Compatible		
Side → Key	427 (4.8)	77 (0.3)
Word → Say	483 (1.0)	45 (3.6)
Less compatible		
Word → Key	456 (8.6)	80 (1.2)
Side → Say	547 (1.3)	89 (2.6)

Table 4 Data from experiments on S-R value-compatibility (Azuma & Monsell, in preparation-b). Mean correct RT (ms and percent errors) on non-switch trials and switch cost (increment in RT and percent errors on a switch trial)

(a) When subjects switched attribute (letter, location) every two trials, but used the same S-R mapping for each attribute for a block of trials

	Non-switch trials	Switch cost
To compatible from incompatible		
Location	450 (1.6)	65 (0.7)
Letter	512 (0.2)	72 (0)
To incompatible from compatible		
Location	605 (4.4)	78 (0.8)
Letter	887 (2.7)	148 (0.7)

(b) When subjects responded to the same attribute (location or letter) for a block of trials, but switched every two trials between compatible and incompatible S-R mappings

	Non-switch trials	Switch cost
To compatible from incompatible		
Location	537 (1.3)	92 (2.4)
Letter	565 (0.2)	94 (0.9)
To incompatible from compatible		
Location	690 (4.6)	134 (1.2)
Letter	960 (2.6)	109 (1.8)

costs were no larger for switching to the stronger (compatible) task from the weaker (incompatible) than vice versa. If anything, it was easier to switch to the easier task (but not reliably so).

In the other experiment (16 subjects, 2 sessions), subjects responded to the same attribute (location or letter) for a series of blocks, but switched every two trials between compatible and incompatible responses to that attribute. Again the cost was not smaller but larger when switching to the incompatible mapping, and the increase in time cost was marginally reliable ($p = 0.06$).

We are aware of three other reports testing interactions between value-compatibility and task-switching in a similar way to the last experiment. Stoffels (1996a) had subjects respond with left or right middle fingers to a left or right pointing arrow in one colour, and with left or right index fingers to an arrow in a different colour. The colour changed randomly from trial to trial. Either response pair could be spatially compatible or incompatible, and in different blocks all four combinations were studied. If we compare colour alternation trials to colour repetition trials to get a measure of switch cost, the costs were roughly symmetrical for a compatible followed by an incompatible mapping and for an incompatible followed by a compatible mapping. Note that this is essentially a task-cueing experiment with no time for preparation so that it does not separate out the residual cost. In another study, with positions instead of arrows, and comparing alternating and pure blocks of trials with a 500-ms RSI, Stoffels (1996b), Exp 3, found greater costs for switching to the more compatible responses. Finally, in Experiment 1 of De Jong (1995), a

high or a low tone cued the subject to use a compatible or incompatible left/right S-R mapping to an arrow tilted left or right; the tone preceded the arrow by 100, 200 or 600 ms. At the shortest interval the switch cost (estimated as the difference between repeated and alternating mappings) was somewhat greater on compatible than on incompatible mapping trials; at longer intervals this asymmetry disappeared – but then so did the switch cost!

In summary, neither for compatibility between stimulus attribute and response mode, nor for compatibility between stimulus and response value, do manipulations of the relative “strength” of the two tasks between which the subject must switch provide much support for the claim of Allport et al. (1994) that it is harder to switch to the stronger of a pair of tasks. In the case of our mode-compatibility manipulations, it might be argued that the difference in relative strength was insufficient to promote active inhibition of the stronger task to enable the weaker. However, in the value-compatibility case, the compatibility effect was very large – large enough, one might think, for the difference in strengths to exceed any hypothesised threshold at which the stronger task must be inhibited to enable the weaker. Indeed an important class of models of spatial compatibility effects assumes that in some sense the person must always inhibit the automatic “direct” translation to enable the one specified by the more arbitrary rule to “win” (De Jong et al., 1994; De Jong, 1995, 1997; Shaffer 1965). Hence, we should entertain the possibility that there is indeed carry-over of such inhibition of the “automatic” translation to the switch trial, but the extra cost of overcoming this inhibition is counteracted – at least in Azuma and Monsell’s value-compatibility experiments – by an even larger effect: the extra time taken to activate the more complex rule set required for the incompatible task (cf. Rubinstein et al., submitted).

Strength through intra-experimental practice

The two manipulations of relative task strength discussed so far rely on the state of the subject’s brain when he or she begins the experiment. In a third set of experiments, we have, following the example of experiments on Stroop interference by MacLeod and Dunbar (1988), manipulated task strength by means of selective practice within the experiment. The initial intention was to take a pair of tasks, roughly equal in strength, measure the costs of switching between them, selectively practice one of them, measure switch costs again, selectively practice the other, and measure switch costs a third time. In an unpublished experiment using digit stimuli and the tasks of adding 3 and subtracting 2, Yeung found that having practised just one of the tasks reliably increased the cost of switching to it, and then practising the other task restored the symmetry of switch costs. However, further experiments in which we increased the amount of practice and the duration of the

switching blocks gave more equivocal results. We have come to believe that it is not the total amount of practice that is critical, but recency of practice during relatively early stages of practice, and this requires a different design, which we illustrate here with a brief account of Exps 2 and 3 from N. Yeung and S. Monsell (The effects of recent practice on the cost of task switching, in preparation-b).

The experiments used a pair of tasks chosen to show measurable improvements in performance with modest amounts of practice. The stimulus was a letter and a digit, displayed in the form: **B • 3**. One task was “alphabet arithmetic”: the correct response in this case is to say “E”, because E is 3 steps through the alphabet from B. Extensive study of the effects of practice in this task (Klapp, Boches, Trabert & Logan, 1991; Logan & Klapp, 1991) suggests a transition from an algorithm-based strategy (i.e. counting though the alphabet) to retrieval from memory of the learned answer, with little transfer to new problems. This makes it suitable for a study of acquired response “strength”. The other task was to decide whether the letter and digit matched on the perceptual feature of containing curvature. If both or neither contain a curve, the correct response was “Yes”, otherwise “No”. Though no literature exists on this task, it seemed also to afford the opportunity of instance-based learning coming to control performance.

In Exp 2 of Yeung and Monsell (in preparation-b), the initial stimulus set was composed of a pair of letters (e.g. E and P) each paired with four digits (1, 2, 3, and 4). Following 16 trials practice (two trials on each stimulus) with each task alone, and a practice switching block, 16 subjects cycled through two repetitions of the following sequence:

- Practice on one task (32 trials)
- Switch every two trials between the two tasks (32 trials)
- Practice on the other task (32 trials)
- Switch every two trials between the two tasks (32 trials).

The first task practised was balanced over subjects. Task was cued by display locations in quadrants of a background X, as in the compatibility experiments above. This whole sequence was then repeated with a different pair of letters (e.g. J and V), and then again with a third (e.g. S and M). The basic contrast is to look at performance on switch trials and non-switch trials in the switching blocks as a function of which task was more recently “strengthened” by practice in the immediately preceding practice block. Note that, as the experiment proceeds, both tasks on average receive the same amount of cumulative practice, both stimulus-specific and generic.

There were substantial switch costs for both tasks, and some differences in the effects of practice on the two tasks, but for clarity we average over tasks in Fig. 3. This shows that though performance on the more recently practised task was faster (by about 20 ms) on

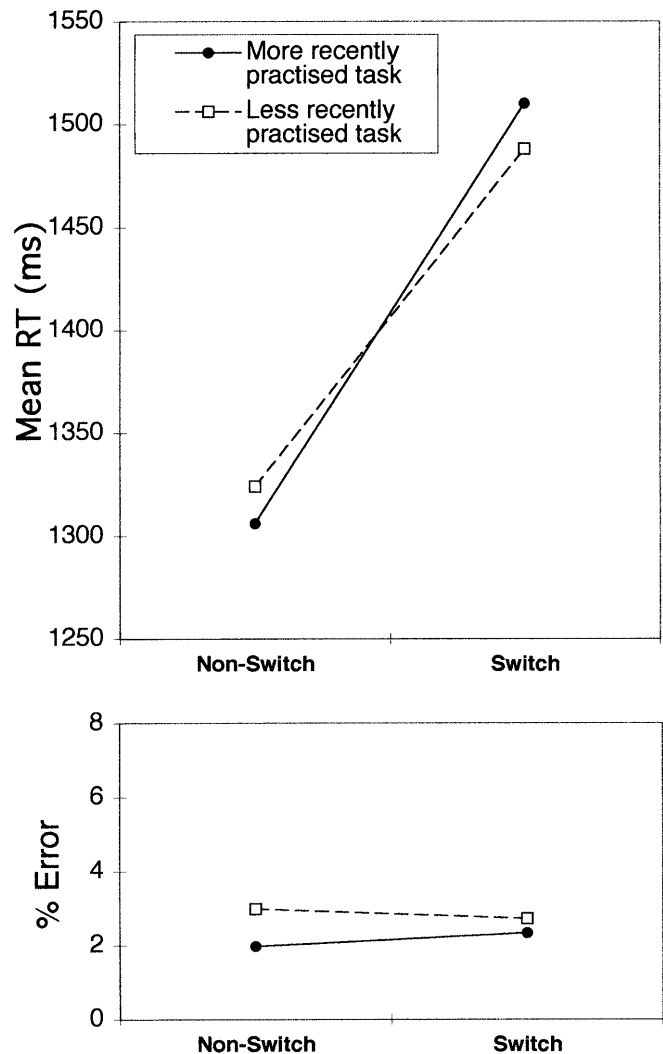
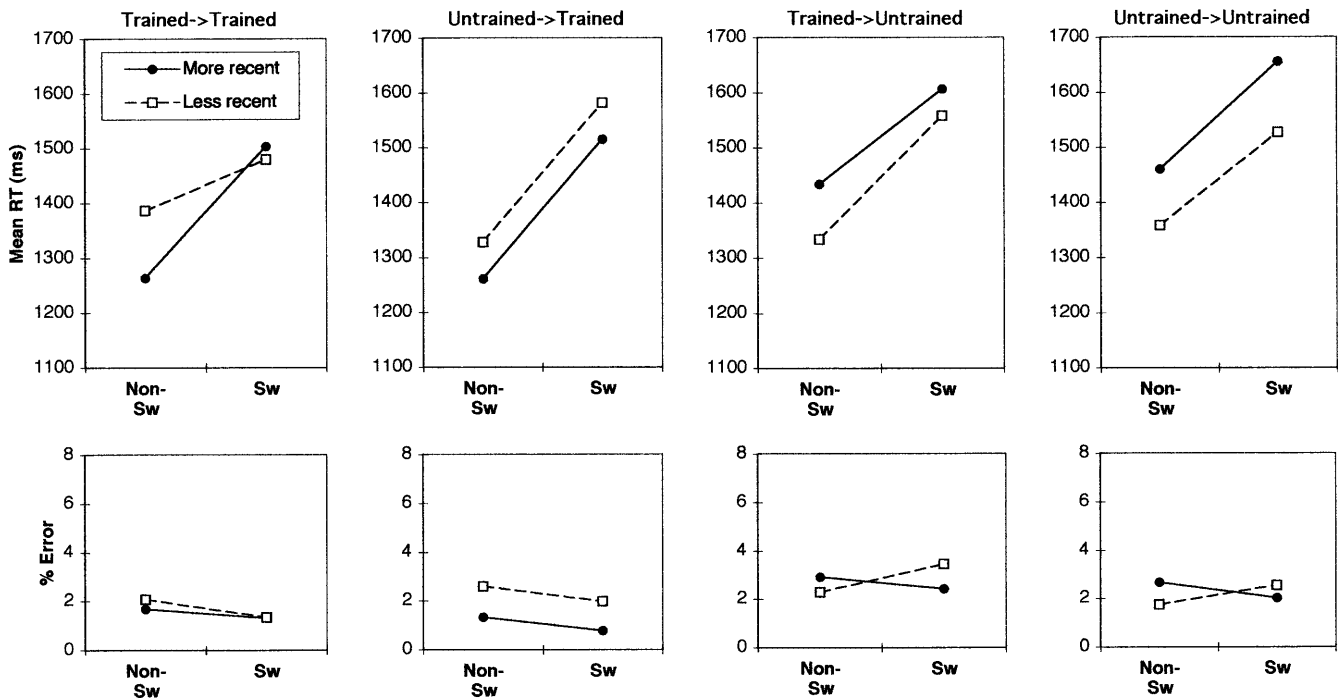


Fig. 3 Mean correct RT and error rate from switch and non-switch trials in Exp. 2 of Monsell and Yeung (in preparation-b), as a function of whether the task on the current trial was the more or less recently practised (i.e. in the immediately preceding single-task practice block or earlier) (RT reaction time)

non-switch trials, it was slower (by about 20 ms) on the switch trials. This interaction is reliable, $p < 0.05$, and the error rates, though showing better performance on the recently practised task on all trials, indicate a non-reliable interaction in the same direction as the RTs. This interaction constitutes a case strikingly in line with Allport et al.’s counterintuitive rule. Recent practice presumably strengthens the practised task, and, lo and behold, it becomes harder to switch to. This seems impressive support for the claim that when the irrelevant task-set is strong, inhibition required to suppress it is carried over to the next trial.

However, this experiment confounds the recency with which the subject had practised each task, and the recency with which the subject had practised that task *with the current stimulus*. To establish to what extent the effect of recent practice might be stimulus-specific, we ran a further very similar experiment in which only half



the stimuli (e.g. E•1, E•2, Q•3, Q•4) were practised in any one practice block. In the next practice block for that same task, the other half of the stimuli were practised. There were two complete sequences of blocks with different letters (rather than the three in the previous experiment); 48 subjects were tested.

Thus, in any switching block, we had a more and a less recently practised task, and within that factor we had “trained” stimuli (those practised in the most recent block of practice on that task) and “transfer” stimuli (the other half). Because the hypothesised source of the interaction between practice and switching is the strength of the irrelevant task on the previous trial, we must examine the data in four subsets: trained followed by trained, transfer followed by transfer, trained followed by transfer, and transfer followed by trained. As Fig. 4 demonstrates, it is instantly clear that the surprising asymmetry of switch costs observed in Exp 2 is still present, but limited to just one of these four subsets: the case of a trained stimulus followed by a trained stimulus. (The 4-way interaction was reliable, $p < 0.01$, as was the simple interaction in the trained-trained case, $p < 0.001$.) Hence it would appear that the need for inhibition is stimulus specific. Only if the previous stimulus has recently been practised in Task A does one get additional difficulty in switching to Task B. In this our results converge with the recent demonstration of Allport and Wylie (in press) that the difficulty of responding to the first word-naming trial after colour-naming is increased if the word was one ignored in an incongruent stimulus presented on a colour-naming trial. Less consonant with Allport’s interpretation, however, is the fact that our effect of recent practice is just as dependent on the present stimulus being one practised in the task to which the subject is switching.

Fig. 4 Mean correct RT and error rate from switch and non-switch trials in Exp. 3 of Monsell and Yeung (in preparation-b), as a function of whether the task on the current trial was the more or less recently practised (i.e. practised immediately preceding the current block or earlier), and whether the present and previous stimuli were among those in the most recent practice block for that task (*trained* stimuli) or not (*transfer* stimuli)

Inasmuch as an individual stimulus retrieves a task-set recently associated with it, one would expect practising Task B with a stimulus to assist in switching to Task B when that stimulus is presented shortly afterwards.

Conclusions on inhibitory priming and the residual cost

Allport et al. (1994) proposed that a major source of the residual cost of switching task was negative priming of task-set – a carry-over of inhibition of the now-relevant task-set from a previous trial. Their evidence was the surprising observation that, when two tasks differ in strength, it is easier to switch to the weaker task. To test the generality of this observation, we have surveyed the evidence available to us, from our own and others’ experiments, involving three different kinds of manipulation of the relative “strength” of a pair of tasks afforded by a stimulus, and the costs of switching between them. On the one hand there clearly are a number of cases where the surprising asymmetry is present. On the other hand it does not seem to be a general rule. A “box-score” is inappropriate, but we are certainly struck by the fact that it is only in a minority of our own experiments that we detected the pattern conforming to Allport’s conjecture. Moreover, in several cases it was evidently harder to switch to the weaker

task. Even the most gratifying of the cases conforming to Allport's rule – the effect of recent practice – turns out to be limited to a subset of trials in a way that suggests that both the need for inhibition, and the effect of its carry-over, are specific to particular stimuli, not to the task-set as a whole, as originally suggested by Allport et al. (1994). Nor can we tell whether, for these stimuli, it is merely the associated response that is inhibited, or the whole task-set. Further work with the recent practice design, and with Allport and Wylie's (in press) "before and after" design, will be needed to get a handle on the stimulus specificity of the effect.

There may be two reasons why the counterintuitive asymmetry of switch costs has this quality of "now you see it, now you don't". One is that active inhibition of the stronger task is a strategy needed only when the difference in relative strength of the two tasks is above some threshold. This would seem to receive some support from our Stroop experiments, in which we were able to reverse the asymmetry by modestly handicapping word-reading with degradation, or a delayed onset, while only slightly attenuating the asymmetry of interference. The second reason may be that even when there is carry-over of inhibition, there is also a countervailing effect: the greater time it takes to carry out post-stimulus onset control processes to enable a more complex task. This seems to us the likely account of our S-R value-compatibility experiments, where a marked asymmetry in task difficulty – naturally interpretable in terms of the number of condition-action rules required – resulted in, if anything, easier switching to the easier task. Finally, it should be noted that it is one thing to demonstrate a carry-over of inhibition, or negative priming, by means of its effect on the cost of switching tasks; it is another to understand the mechanism of that effect. Even when it is easier to switch to the weaker task, it does not follow that the effect of negative priming is merely to prolong task-specific processing (as proposed by Allport et al., 1994); the persisting (or retrieved) inhibition might instead prolong a control process responsible for task-set reconfiguration, or even evoke a control process needed to override inhibition.

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