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Task-switching and long-term priming: Role of episodic stimulus–task bindings in task-shift costs☆

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Abstract

When subjects switch between two tasks, performance is slower after a task switch than after a task repetition. We report five experiments showing that a large part of these "task-shift-costs" cannot be attributed to a control operation, needed to configure the cognitive system for the upcoming task (e.g., Rogers & Monsell, 1995). In all experiments subjects switched between picture-naming and word-reading. We presented different stimuli either in just one of the two tasks, or in both of them. Shift-costs were larger for stimuli presented in both tasks than for those presented in only one task, even after more than 100 intervening trials between prime and probe events. We suggest (as proposed by Allport & Wylie, 2000) that stimuli acquire associations with the tasks in which they occur. When the current task activation is weak, as on a switch of tasks, stimuli can trigger retrieval of the associated, competing task, provoking larger time costs.

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1. Introduction

While Cognitive Psychology has made substantial progress in recent years in analysing particular cognitive processes, much less progress has been made with regard to the mechanisms that guide or control these processes. The importance of such control mechanisms is especially obvious in cases where they malfunction. A prominent example of a pathological failure of control is "utilisation behaviour" (Lhermitte, 1983; Shallice, Burgess, Schon, & Baxter, 1989). It is characterized by a behavioural deficit showing some resemblance to the difficulties of our subjects in the experiments to be reported, viz. inability to inhibit actions from being triggered by the mere sight of an object with which the action is habitually associated. Utilisation behaviour and other failures of control (cf., Monsell, 1996) are typically related to frontal lobe damage (Duncan, 1986; Shallice, 1988; Shallice & Burgess, 1991).

Recently, the so-called task switching paradigm has been revived as a possible method for investigating some aspects of cognitive control (e.g., Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). The main feature of the task switching paradigm is that subjects have to alternate (in one way or another) between performing two different tasks—usually choice reaction-time (RT) tasks. The "switching" performance is compared with non-alternating control performance of the same tasks. The central finding is that shifts between intrinsically competing tasks produce substantial performance costs. RTs and error rates are considerably larger when a task shift occurs than when the same task is repeated across consecutive trials. It is widely assumed that shifting or switching task-set entails specific demands on cognitive control processes, demands which are reduced—or even absent—when the same task is repeated on successive trials; and this assumption has been the principal motivation for studying task switching.

The first to report data of this kind was Jersild (1927). In one of his experiments, he presented his subjects with lists of 2-digit numbers. In the alternating condition the subjects' tasks were to subtract 3 from the first number, to add 6 to the next number, and so on, alternately (ABABAB...) down the list. In the control conditions they had either to subtract 3 from every number or to add 6 to every number (AAAA or BBBB). Jersild computed the task switching cost (TSC) by subtracting the time taken by the subjects to work through the non-alternating lists from the time they needed for the alternating list. He found that the median time in the non-alternating lists was 84.5 ms, compared to 115.5 ms in the alternating lists. Some 50 years later Spector and Biedermann (1976) reported similar results, based on Jersild's experiments, using single-trial RT measurements. However, even though these TSC effects were large and apparently stable, the task switching paradigm has only recently received renewed attention.

2. Task switching: Results and theories

2.1. Top-down preparation of task-sets

Rogers and Monsell (1995) provided one of the recent landmark studies of task switching. To avoid certain confounds in Jersild's (1927) paradigm, they devised a new experimental method, the "alternating runs" paradigm, in which they measured the costs of task switching within blocks. In the alternating runs paradigm subjects alternated between runs of two (or more) trials of each task (AABBAABB...). Rogers and Monsell computed the TSC by subtracting RT on the non-alternating or repetition trials (A*A*, B*B*) from RT on the corresponding switch trials (B*A*, A*B*). Using this method, they still found substantial RT costs of task switching. They argued that these time costs, observed within the same block of mixed switch and repeat trials, reflect the need to shift tasks. In particular, they attributed the RT costs to (one or more) stage-like control operations, which are capable "of enabling and disabling connections between processing modules, and/or re-tuning the input-output mappings performed by these processes, so that the same type of input can be processed in the different way required by the new task" (Monsell, 1996, p. 135). They referred to this process as "task-set reconfiguration." Rogers and Monsell (1995) paraphrased the general idea in terms of a railway system; a control process "switches" the connections on the railroad network, ensuring that the stimulus-processing follows the correct lines. Accordingly, once a new task-set (railroad connection) is adopted, the reconfiguration process(es) do not need to be used again while that task remains in force.

In one experiment they varied the time between each response and the next stimulus (RSI, Response-Stimulus Interval) from 150 to 1200 ms, in separate blocks. They found that as the RSI increased up to 600 ms, the cost of task switching decreased, an effect that was also reported by several other authors (e.g., Allport et al., 1994; Fagot, 1994; Goschke, 2000; Meiran, 1996). Hence, the performance costs of task switching can be reduced by providing an appropriate preparation interval. As Rogers and Monsell (1995) argued, when subjects can anticipate a switch of task, they may make use of this interval by initiating the enabling and disabling of task-relevant vs. competing processing pathways prior to the presentation of the stimulus for the new task. Accordingly, Rogers and Monsell called this the "endogenous component" of task-set reconfiguration.

Interestingly, even with a preparation time of 1200 ms, a large asymptotic TSC remained, also a well replicable effect. Rogers and Monsell (1995) attributed these so-called "residual TSCs" to a second, exogenous component of control, which—they suggested—cannot take effect until it has been triggered by an appropriate task stimulus. Upon arrival of the target stimulus some further control process then somehow "completes" the task reconfiguration before the subject is ready to go, hence, residual TSCs represent the time demands of this hypothetical post-stimulus control process (see also De Jong, 2000; Rubinstein, Meyer, & Evans, 2001). However, Rogers and Monsell (1995) left it unclear both in what respect(s) the endogenous reconfiguration process was incomplete (or indeed what, specifically, it achieved), and how—or why—a stimulus-driven process was required to complete it (cf., Rubinstein et al., 2001, for some considerations about this theme).

2.2. Bottom-up priming of task sets

The general idea that task switching costs reflect some kind of reconfiguration of the cognitive system to perform the new task seems to offer an intuitively obvious interpretation, and the particular distinction between endogenous and exogenous control processes seems to be well covered by the findings available so far. And yet, we feel that (re)configurational accounts along the lines of Rogers and Monsell (1995), De Jong (2000), and Rubinstein et al. (2001) underestimate bottom-up, stimulus-driven contributions to TSCs and, as a consequence, tend to overestimate the role and meaning of (commonly not overly well specified) internal control operations. We think that this is particularly true with respect to "exogenous" control processes and the "residual" TSCs they are assumed to explain. Imperative stimuli, we will argue, carry their history with them and, hence, tend to evoke the task they have appeared in previously—an idea that Ach (1910) introduced into psychology (see Hommel, 2000). Accordingly, facing the same stimulus in different tasks produces cognitive costs, and it may be mainly these costs that are measured by residual TSC. Before working out this line of reasoning in more detail let us first turn to the empirical findings it was motivated by.

A first hint that the task history of a stimulus might affect its processing emerged from the observations of Allport et al. (1994). Their experiments were based on the early studies of task switching (Jersild, 1927; Spector & Biedermann, 1976), which had suggested that task switching costs arose only if the task-stimuli afforded both tasks. For example, in one experiment Jersild compared pure task repetition with regular alternation between the two tasks: task A was adding 3 to a digit, task B was giving the opposite of common adjectives (e.g., old, dark). With these two tasks (i.e., with completely non-overlapping stimulus and response sets) Jersild found essentially no costs of task switching at all. Thus, as Jersild and Spector & Biederman suggested, the non-ambiguity of the stimuli with respect to each of the two currently "valid" tasks apparently eliminated the costs of task switching.

In one of their experiments, Allport and colleagues (1994) used colour-word Stroop stimuli (colour names written in incongruent ink-colours) for task A, and number-numerosity Stroop stimuli (groups of from one to nine identical numerals, where the numeral value was incongruent with the numerosity of the group) for task B. There were two groups of participants. For the first group, task A was colour naming, i.e., subjects named the ink-colour and ignored the word (e.g., responded "red" to the word GREEN written in red ink). Task B was numerosity naming, i.e., subjects named the number of numerals and ignored the numeral value (e.g., responded "seven" to the a group of seven "5s"). Note that there was no overlap between either stimuli or responses in these two tasks. Accordingly, following Spector and Biederman's account (1976, see also Meiran, 2000), it should be possible for the subjects to switch between these two tasks (colour-naming, numerosity-naming) without any switching cost. This was indeed the case. A second group of subjects had to apply the complementary tasks to the same stimuli; i.e., they read the colour words in response to the colour-word Stroop stimuli and named the numerals in response to the number-numerosity Stroop stimuli. In this group too, participants did not show any costs of task switching.

So far, these results seemed to replicate the findings of the earlier studies (Jersild, 1927; Spector & Biedermann, 1976), viz. that the non-ambiguity of the stimuli (and non-overlap of responses) with respect to each of the two currently "valid" tasks is sufficient to eliminate the costs of task switching. However, in a second block of the experiment, participants were instructed to perform the respective complementary tasks. Thus, the group that had previously named colours and numerosities was instructed to read the colour words and to name the numerals, and vice versa. Both groups now showed large time-costs of task switching, of about 300 ms per item over the first few lists. The cost decreased over the course of the block, but was still highly significant at the end of it, after the subjects had performed the new (also non-overlapping) tasks on more than 150 trials. In the first block of the experiment the task-stimuli cued their respective tasks with virtually zero cost of task-switching. However, in the second block of the experiment, after the task instructions had been reversed, participants showed a large TSC. Hence, even pairs of tasks afforded by non-overlapping (or "univalent") stimulus- and response-sets can yield large alternation costs, viz. when the same stimuli have been involved previously in tasks that differ from the currently valid ones.

This latter observation prompted Allport and colleagues (1994) to attribute task-switching costs to what they called "task-set inertia" (TSI), "a kind of pro-active interference (PI) from competing S–R mappings with the same stimuli, persisting from the instruction set on preceding trials" (p. 436). They suggested that the persisting activation of a currently irrelevant task (and possibly the persisting inhibition of the previously irrelevant, but now relevant task) causes a time-demanding interference, due to a stimulus-cued conflict between the competing tasks. More recently, this task-set inertia account has been reformulated and extended (Allport & Wylie, 1999, 2000; Wylie & Allport, 2000; also Allport & Hsieh, 2001). In a series of experiments Allport and Wylie (2000) provided evidence for an additional mechanism contributing to TSC effects, besides TSI persisting from the immediately preceding trial. Two major findings are of special interest.

First, they demonstrated that the first trial in a run of RT trials, after a brief task-interrupt but no shift of task, showed a substantial RT cost compared to all later trials in the run. Other authors have also reported this "restart effect" (Altmann & Gray, 2002; Gopher, Armony, & Greenshpan, 2000), showing a striking behavioral similarity to the TSC effect, but with no actual switch between competing tasks. Allport and Wylie also found that the restart-effect (e.g., for Stroop word-reading) was greatly enhanced after exposure to a competing task (Stroop colour-naming). In other words, a restart of the same task as before, in a new run of trials, seemed to set off task-interference from a competing task recently executed in response to the same stimulus set.

Second, Allport and Wylie (2000) showed that this re-evocation of task interference was even more marked on switch trials, immediately following a run of trials of the competing task. Accordingly, Allport and Wylie (2000; Wylie & Allport, 2000) suggested that RT switch costs and restart costs may generally be due to the same kind of mechanism. Furthermore, they proposed that, in addition to inertial persistence (TSI) across immediately successive trials, the activation and/or inhibition associated with competing task-demands can also be retrieved from memory, cued by the presentation of stimuli previously associated with these demands. (Note that, to date, practically all task-switching experiments have used the same individual stimulus items in both tasks.)

A critical experimental question is thus: To what extent is the task-interference, observed on switch trials and restart trials, *item-specific*? That is, to what extent does the task-interference on these trials depend on an individual stimulus item having been primed by its prior presentation in the other—competing—task context? As Allport and Wylie (2000) have suggested, item-specific interference cannot readily be accounted for in terms of task-set re-configuration. The concept of "task-set" typically refers to the enabling, top-down, of certain, task-relevant cognitive operations or processing pathways, and the disabling or disconnecting of others, *independently of the individual stimulus-items to be processed*. Hence adoption of a given task-set, by definition, affects the processing of *all* task-relevant stimuli, whether previously encountered in a given task context or not. A representative statement of this traditional concept of task-set is provided by Monsell (1996): "Adopting a task-set involves, in part, getting the right set of processing modules from the available repertoire linked together (or better, enabling the existing links between them, and disabling the links to others). But that is not all. We must also 'tune' each processing module so that it performs the right mapping between its inputs and its outputs." (Monsell, 1996, pp. 123–124). Hence, implementing a task set prepares for processing a whole class of stimuli and responses in a particular way. If so, it is difficult to see why and how this preparation might depend on the history of the individual stimuli that are processed as a consequence of, and according to the rules embodied by, a given task set. To account for such historical effects seems to require some sort of bidirectional interplay between stimuli and task-sets and, in particular, the possibility that stimuli can activate and support the task-set they are (or have been) associated with.[1] Let us now turn to the question of how this may work in detail.

3. Perception–action integration, S–R-event bindings, and (long-term) priming

The basic idea we propose has two essential elements. The first is this. Selecting (and executing) a goal-directed action in response to a given stimulus creates a representation which integrates—or "binds"—information about the action-relevant

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[1] A related question which we will address at a later stage in this paper is whether (or to what extent) stimulus-driven priming affects task representations proper or individual stimulus–response mappings.

stimulus attributes and the corresponding action. In principle, we suppose that bindings are formed (or strengthened) between all the encoded constituents of the action-event: not only between the immediate stimulus and its response ("S–R bindings"), but also with the distal goal of the action, the task and task-specific processing operations, and possibly other relevant contextual features. For brevity, we shall refer to these postulated stimulus–task–action links, together, as "S–R-event bindings." Second, these S–R-event bindings can be long-lasting, and may later be re-activated or retrieved from memory, when cued by re-presentation of the same stimulus. Neither of these propositions is new. Related propositions have been discussed in a variety of different contexts, such as selection-for-action (Allport, 1987, 1989), automatization (Logan, 1988; Logan & Etherton, 1994), memory (e.g., Crowder, 1993), and action planning (Hommel, 1998a, 1998b; Stoet & Hommel, 1999).

A starting point from which to explain the general idea is the so-called "binding" problem. In the domain of perceptual processing, the binding problem refers to the question of how the perceptual system represents which of the currently activated perceptual features belong to one and the same object (Luck & Beach, 1998; Singer & Gray, 1995; Treisman, 1992). One of the most prominent theories addressing this issue is the feature integration theory of attention, put forward by Treisman and Gelade (1980). They suggested that when the "spotlight" of visuospatial attention is directed to a given location in space, all features registered in that location are integrated or "bound together," indicating that they belong to the same object. Kahneman, Treisman, and Gibbs (1992) extended the feature integration theory, by proposing a mechanism that preserves the result of this integration process after attention has been directed elsewhere. They suggested that the result of this integration process is temporarily stored in an "object file." As evidence to support this idea Kahneman et al. presented subjects with multi-letter prime and single-letter probe displays; they found that responses to the probes were faster when the probe matched one of the prime letters. More importantly, this "preview" effect was larger when the probe letter matched the prime with respect to both identity and location. Kahneman and colleagues called this the "object-specific preview benefit." They proposed that prime-letter identities and locations were integrated into object-specific representations, or "object files." If a prime object (a specific letter in a specific location) reappeared in the probe display, i.e., if the particular identity-location conjunction was repeated, the corresponding object file merely had to be updated. In contrast, if a novel object appeared in the probe display, a new object file had to be created in a new, time-consuming feature-integration process.

So far we have discussed the integration of perceptual information only. However, there is evidence that action information, too, can be integrated with sensory attributes. For example, Treisman (1992) trained subjects to perform certain tasks in response to a set of nonsense patterns. As expected, performance improved with practice. But when subjects were later asked to perform different actions in response to the same stimuli, she observed only minimal transfer. This might suggest that experience with the nonsense patterns led to the formation of bindings linking both perceptual and response- or action-related information. As in the "object-specific preview benefit" (Kahneman et al., 1992), the observed RT benefit may have resulted from repeating the whole integrated representation, i.e., both the perceptual and action-related components. Similarly, with coloured letters presented at different locations, Danzinger and Robertson (1994) found that a change of response reduced the beneficial effect of stimulus repetition.

These findings prompted Hommel (1998a) to investigate further the role of response-related information in feature integration. He used a task that required two successive responses, R1 and R2, to two successive stimuli, S1 and S2. (S1 and S2 varied randomly in form, colour, and location; R1 and R2 were a left or right keypress.) The identity of the first response, R1, was indicated by a precue. The subjects were to prepare R1, and to release it as soon as S1 was presented, regardless of the identity of S1. One second later S2 was presented; one feature of S2 (say, colour) indicated R2. Thus, R1 was released in response to the mere onset of S1, whereas R2 was made in response to the relevant feature of S2. Hommel found that R2 was fastest if both the task-relevant stimulus feature and the response were repeated between first and second S–R-event. In contrast, if the two S–R-events matched only partially (e.g., the same response, but a different task-relevant stimulus feature), R2 was delayed even compared to a complete mismatch of the two S–R-events. Hommel suggested that the S1-R1 co-occurrence resulted in the formation of an "event file" which integrated both stimulus and response features. Re-presenting the same action-relevant stimulus feature led to reactivation of the associated response. This was beneficial if the same response was to be executed, but detrimental if the repeated stimulus required a different response. Accordingly, Hommel suggested replacing the concept of "object file" with the more general concept of an "event file," linking action-relevant stimulus features with codes characterising the action to be performed.

Certain findings concerning the modality shift effect (Sutton, Hakerem, Zubin, & Portnoy, 1961) accord well with these ideas. In modality shift experiments, subjects are required to make the same motor response to each of the stimuli in a random series of, say, lights and tones. The common finding in such experiments is that RTs are longer when the imperative stimulus switched modality (i.e., has a different modality than the preceding stimulus) than when the stimulus was repeated. Sutton et al. put forward a "trace" theory to explain the modality shift effect (MSE), suggesting that some residue of neural activity in the sensory pathways or in short-term memory predisposes the organism to be better prepared to respond to stimuli in the same modality. Intriguingly, various findings suggest that preceding stimulation elicits an MSE *only* if it required a response (e.g., Rist & Thurm, 1984; but see Hanewinkel & Ferstl, 1996). This prompted Cohen and Rist (1992) to suggest that the effect is due to neural traces not in sensory pathways per se, but in entire S–R "cycles." These considerations are especially interesting in the present context, because modality shift experiments can be considered as a very simple variant of task switching, with subjects switching between responding to tones and lights. If one accepts this analogy, the "trace" theory proposed for the MSE and the suggestions we put forward below are in essence the same: a preceding S–R-event interferes with a subsequent S–R event because their integrated features (stimulus–task–action properties "bound together") are incompatible.

Most of the experiments described above demonstrated trial-to-trial effects, i.e., effects of the immediately preceding trial. However, there is reason to believe that these S–R-event bindings can serve to guide performance on later occasions too (cf., Allport, 1987). A possible link between the short-term "event file" idea and long-term guidance of performance is the instance theory of automatization (cf., Barsalou, 1990; Hintzman, 1976, 1986; Jacoby, Baker, & Brooks, 1989; Jacoby & Brooks, 1984; Logan, 1988; Logan & Etherton, 1994). Logan (1988) suggested that stimulus–response combinations may be stored in so-called instances which, of course, could be considered as the residues of "event files" (for further discussion, see Hommel, 2003). Logan proposed that later presentation of the same stimuli may retrieve these instances, and thus may facilitate the response. Grant and Logan (1993) investigated the buildup and decline of repetition priming in a lexical decision task over the course of two months. They found significant priming effects even at the end of this interval. Such a mechanism is useful, since, outside the laboratory, many objects afford the same type of motor response time and again.[2] In a task-switching experiment, however, the storage of such instances may be counterproductive. We will argue that a large part of the task shift costs, in the experiments described here, is due to the retrieval of incompatible stimulus–response, and/or stimulus–task bindings, created in prior S–R episodes in which the same stimuli occurred in the competing task context.

The main assumptions of instance theory (Logan, 1988; Logan & Compton, 1998; Logan & Etherton, 1994) are as follows: First, it assumes that the consequence of attending to a stimulus is the obligatory encoding of that stimulus into memory. The memory traces, or instances, left behind represent whole processing episodes, which "consist of the goal the subject was trying to attain, the stimuli encountered in pursuit of that goal, the interpretation given to the stimuli with respect to the goal and the response made to the stimulus" (Logan, 1988, p. 495). Second, "attending to a stimulus is sufficient to retrieve from memory whatever has been associated with it in the past" (Logan, 1988, p. 493). Logan argued in his formulation of the theory that only attended information is stored in an instance (Logan & Etherton, 1994). However, the episodic retrieval account of negative priming, by Neill and his colleagues (Neill, 1997; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) assumes that actively ignoring a distractor can create episodic memories which include the information that the distractor items are "to-be-ignored." Together, these two models comprise two kinds of item-specific priming that could affect switching between mutually competing tasks, cued by the same bivalent stimuli: (a) positive priming of the previously relevant but now irrelevant, competing task ('competitor priming'); and (b) negative priming of the currently intended task, e.g., by stimulus-attributes which appeared previously (in the competing task) as distractors, but which are now task-relevant.

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[2] For example, a computer mouse is slid across a 2-D pad; a screwdriver is grasped by its handle in the palm of the hand; etc., etc. Of course, these basic motor routines can be embedded hierarchically in a miriad different, higher-order, goal-directed plans.

4. The paradigm and a look ahead

In most task switching experiments to date, the same small set of stimulus items has been used for both tasks: i.e., the stimulus sets for the two tasks overlap completely. However, task-switching experiments confounding task and stimuli in this way are not able to separate effects of switching between different processing pathways (task-set effects) from the conceptually quite different effects of stimulus overlap and item-specific S–R-event priming. The reason why so few studies have addressed this important issue hitherto probably stems from the difficulty of manipulating the "factors" of task and stimuli independently, with a small stimulus set. This is why we chose picture-word (Stroop) stimuli as the experimental material. The number of available words and pictures makes it possible to create a large item-pool; this, in turn, allows us to unconfound tasks and stimuli in a systematic way.

We unconfounded tasks and stimuli by probing subjects' performance: (1) on stimuli that were presented in both competing tasks, as in most previous experiments, and (2) on stimuli that occurred solely in one or the other of the competing tasks. The central idea is that any effect attributable to top-down task-set variables should result in equivalent performance costs in response to all stimuli, regardless of whether they had been presented previously in the competing task or not. On the other hand, item-specific effects should apply solely to the item set presented in both tasks.

We used a variant of the "Before and After" paradigm (Allport & Wylie, 1999; Allport & Wylie, 2000), recently also referred to as the "instructed switch paradigm" (Monsell, Yeung, & Azuma, 2000). In the original "Before and After" paradigm, subjects are first instructed about one task (task A), which they perform for a good number of trials (the "baseline" phase). They next receive instructions about a second task (task B), which they then perform for a further number of trials before returning to task A. In the variant used here, subjects then continue to switch, in successive short runs, between tasks A and B ("alternating phase").

The original motivation for this paradigm was the observation that performance on task-repeat trials, e.g., in the alternating runs paradigm (Rogers & Monsell, 1995), can be considerably slower than performance of the same task in non-alternating "pure task" blocks (Allport & Wylie, 1999; Allport & Wylie, 2000). Thus, task-repeat trials in switching blocks may not represent a condition of full or "optimum reconfiguration" for the current task. Instead, we suggest that the best possible control for this purpose is a sample of performance, under pure, non-alternating task conditions, prior to any exposure to the competing task, B. Hitherto, the main argument for measuring switch and repeat trials within the same switching block (Meiran, 1996; Rogers & Monsell, 1995) was that comparing performance in alternating and pure blocks confounded the need to shift tasks and the need to hold two tasks in working memory. To avoid this confound, in the experiments reported here we measured the subjects' switch performance (specifically, shifts from task B to task A) in a situation in which they knew that no further trials of the competing task, B, would be required, unless and until they initiated these task B trials self-paced. Thus, during performance of task A, in both the pure blocks and the alternating blocks, only one task needed to be held in current working memory. Thus, for task A, subjects' performance in switch trials could be contrasted with two other conditions: first, with their performance in the "baseline" phase (the "restart" trials), and second, with their performance in the following repeat trials within the alternating phase. For the sake of simplicity, however (and because there was no "baseline" phase in Experiments 3 and 4), we shall focus on the latter, more common contrast.

In our experiments, the subjects' tasks were either to name the picture or to read the word in response to a picture-word Stroop stimulus. We focused primarily on the effects of a shift from picture-naming to word-reading, for two reasons. First, we wanted to explore the larger time costs occurring on a switch from picture-naming to word-reading than from word-reading to picture-naming (cf., Allport et al., 1994); second, we wished to relate our experiments to previous experiments addressing the same issue (Allport & Wylie, 2000; Wylie & Allport, 2000).

In summary, the basic structure of all five experiments is as follows. Subjects switch between picture-naming and word-reading. Picture-naming is designed as the priming task, and word-reading as the probe task. Subjects encounter only a certain subset of items for picture-naming. It is assumed that S–R-event bindings are created in the course of these trials, linking each stimulus-item to the *picture-naming process*. In word-reading, subjects encounter: (a) the same items which had previously been presented for picture-naming ("Picture and Word," PW items), and also (b) items which have not been presented for picture-naming ("Word Only," WO items). We hypothesised that presentation of the PW items can trigger retrieval of the previously created—now competing—S–R-event-bindings formed in the picture-naming task, thus delaying response because these will conflict with the word-reading task. Stimuli not previously presented for picture-naming may also tend to elicit retrieval of the competing task, but only through some form of "stimulus generalisation," i.e., in so far as their perceptual and/or semantic encoding overlaps with the primed items. Hence, presentation of new items should lead to (at most) much weaker interference costs on a switch trial.

To anticipate the results: As predicted, switching costs for word-reading were much greater for stimuli that had previously been presented in the picture-naming task, than for (otherwise matched) stimuli that had never been presented for picture-naming. Moreover, this item-specific effect appears to be long-term, taking effect even when more than 100 trials intervene between the presentation of a given stimulus for picture-naming and the occurrence of the same item in word-reading. We will refer to this item-specific interference effect, due to the retrieval of incompatible S–R-event bindings, as "competing S–R event priming."

Before proceeding to the experiments, we should note an obvious but important proviso. Like the other, previously published studies of stimulus-priming and task switching (Allport & Wylie, 2000; Wylie & Allport, 2000), the experiments described here used Stroop-like tasks. It might be conjectured, therefore, that our pattern of results could be confined to task pairings of this kind, in which there is a marked asymmetry in relative task 'strength' (as there clearly is between word reading and picture naming). Using task pairings like these may impose special processing demands, including active suppression of the dominant task (e.g., word reading) whenever the non-dominant task (e.g., picture naming) is to be performed. This is no doubt part of these tasks' enduring fascination, motivating one of the largest research literatures in human performance (MacLeod, 1991). The fact remains (this is the proviso) that our results may turn out to be more or less specific to asymmetrical task pairings. As against this possibility, however, Koch and Allport (2003) also obtained very large stimulus-priming effects, much larger on switch trials than on task repeat trials, with a highly symmetrical pairing of (non-Stroop) tasks (viz. number judgments of magnitude vs. parity).

5. Experiment 1

The two tasks were word-reading and picture-naming, in response to incongruent picture-word Stroop stimuli, as described below. Responses were oral, and response latency was recorded by means of a voice key. The experiment was run in two successive phases. In the first *baseline* phase, pure word-reading performance was probed. In the second *alternating* phase, subjects switched between picture-naming and word-reading. In this alternating phase, subjects' word-reading performance was probed: (1) in response to stimuli which had been presented previously in the competing picture-naming task, and (2) in response to stimuli which subjects had never encountered in the picture-naming task. In so far as the RT costs of a switch of task from picture-naming to word-reading are *item-specific*, depending on the past history of the subject's encounters with individual stimuli, these costs should arise only in response to the subset of items previously encountered during picture-naming. In contrast, in so far as the TSC is related to top-down reconfiguration of the task-set (as a whole), costs of task switching should be equivalent for all items, regardless of whether they had been presented previously during the picture-naming or not.

5.1. Method

5.1.1. Participants

Twelve subjects, 5 male and 7 female, participated in a single-session experiment; their mean age was 23 years. All the experiments lasted about one hour, and participants received DM 15,- (about 7.5 €) for attendance. In all the experiments subjects were native German speakers, and none had ever participated in a similar experiment.

5.1.2. Apparatus and stimuli

The experimental material consisted of 108 line drawings presented with a superimposed German word (picture-word Stroop-stimuli) on a 17-inch EIZO Flexscan 9080i-M Monitor. They were presented in black on a white background at the centre of the screen. The mean extension of the stimuli was approximately 1.9° in the vertical and 1.9° in the horizontal dimension. The words were placed in the centre of the line drawings. Example stimuli are shown in Figs. 1 and 2.

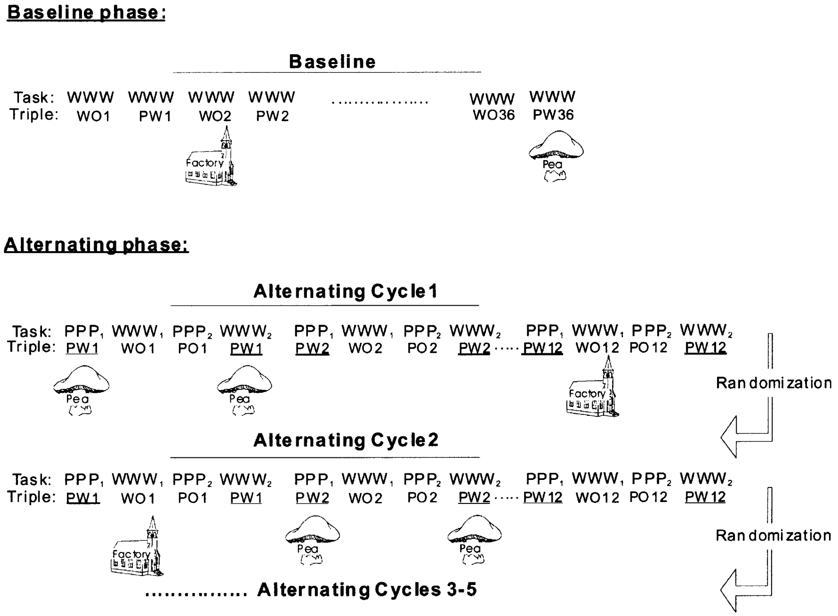

Fig. 1. Design of Experiment 1. The items illustrate when subjects might encounter a stimulus-item from set WO or set PW.

The line drawings and corresponding norm data were obtained from the Snodgrass-Vanderwart Set of Standardized Pictures (Snodgrass & Vanderwart, 1980). The words and norm data were drawn from the CELEX Lexical Database of the Dutch Centre for Lexical Information (see Burnage, 1990).

In all experiments the following constraints applied to the selection of stimulus items, and the pairing of line drawings and word elements: (1) no picture was also presented as a word and vice versa, (2) the pictures' names and the written words were all of one or two syllables, (3) the pictures were linguistically and conceptually as unambiguous and familiar as possible, (4) the imageability and frequency of the words should be as high as possible, (5) the individual pairings of picture and word elements should have the largest possible semantic overlap, and minimal orthographic and phonetic overlap. Rules (4) and (5) were included because they are known to maximise picture-word Stroop-interference (e.g., La Heij, 1988; Lupker, 1979).

The 108 picture-word stimuli were subdivided into three sets of 36 items each. The three subsets were matched as strictly as possible for syllable-length, name agreement, image agreement, familiarity and complexity with regard to the picture elements, syllable-length and word-frequency with regard to the word elements, and semantic overlap between picture and word elements with regard to the pairing of the elements. Finally, in order to reduce possible semantic priming between the different stimulus sets, we tried to minimize the semantic overlap between the items of the three subsets. The item-sets are shown in Appendix A.

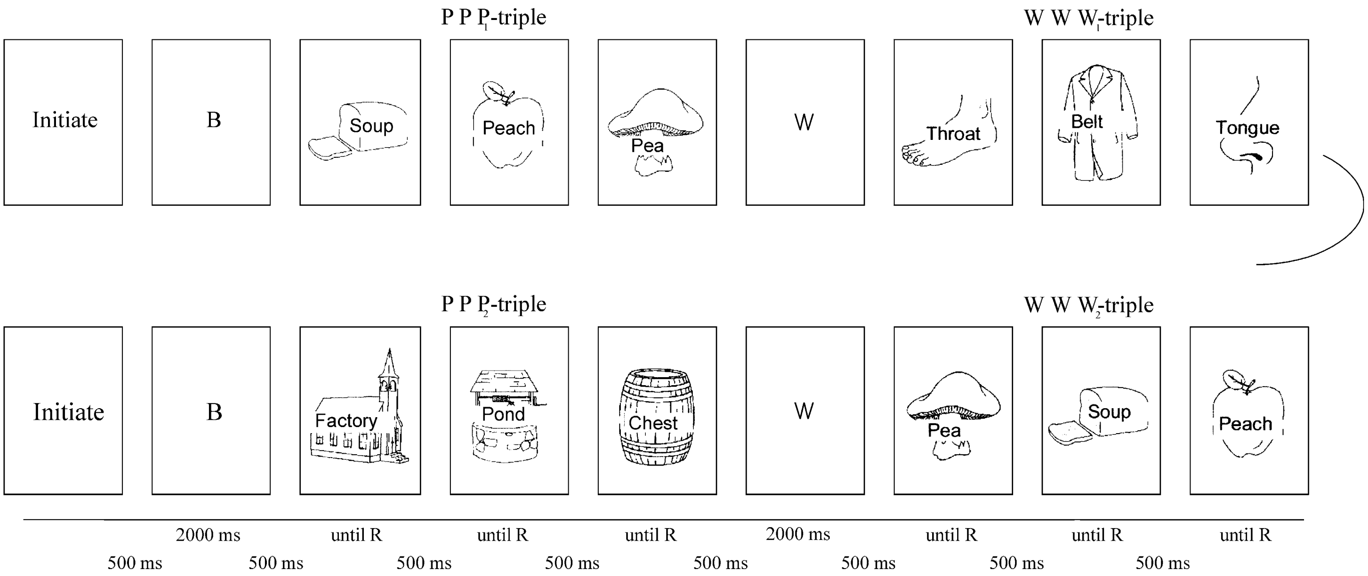

Fig. 2. Procedure for the alternating phase in Experiment 1.

5.1.3. Design

The three stimulus subsets were assigned, counterbalanced across subjects, to three different experimental sets: PW (stimuli presented in *Picture naming and Word reading*), PO (stimuli presented in *Picture naming Only*), and WO (stimuli presented in *Word reading Only*). Thus, with regard to word-reading, which is the principal focus of this paper, PW items were *primed* by prior presentation in picture-naming. By contrast, WO items were *unprimed*, because they were not presented in the competing picture-naming task. Similarly, but of minor importance, with regard to picture-naming, PW items were primed by prior presentation in word-reading, whereas PO items were unprimed. The design of the experiment is depicted in Fig. 1.

5.1.3.1. Baseline phase. The experiment began with the baseline phase. Participants performed word-reading in runs of three trials, as a pure task, that is without any intervening picture-naming, but with a brief interruption between each three-trial run (triple). This enabled us to observe a well practised sample of performance at word-reading in short runs of word-reading trials, prior to any exposure to the competing picture-naming, and thus to measure the pure task 'restart' effect. In order to provide a stable baseline, this phase included three complete iterations of all stimulus-items which were later presented for word-reading in the alternating phase (sets PW and WO). Thus, subjects performed 216 word-reading trials, in 72 triples (36 PW and 36 WO triples).

5.1.3.2. Alternating phase. Subjects alternated between picture naming and word reading, in runs of three trials at each task (PPP, WWW). The sequence of trials was based on successive 12-trial "units": PPP_1, WWW_1; PPP_2, WWW_2. (Twelve such units constituted one complete "cycle" of the experiment.)

Stimuli were selected and ordered as follows. First, for each subject, the 36 stimulus-items of each set (PW, PO, and WO) were randomly subdivided into 12 item-triples (PW1…PW12; PO1…PO12; WO1…WO12). For the first 12-trial unit, stimulus-triples were arranged in the sequence, PW1, WO1; PO1, PW1. (That is, the first item-triple of set PW (PW1) served as PPP_1, the three stimulus-items of WO1 served as WWW_1, the three stimulus-items of PO1 served as task-triple PPP_2, and finally the three items of PW1 were presented again for a second time, as task-triple WWW_2.) The same procedure was repeated for each 12-trial unit, but with a new set of stimuli. Thus, in the course of a complete cycle (144 trials) items of sets PO and WO were all presented once each; items of set PW were presented twice each, once at the beginning of a 12-trial unit, for *picture-naming* (PPP_1), and a second time, for *word-reading*, as the last triple of the of the 12-trial unit (WWW_2). Thus, the WWW_2 items were primed during PPP_1, whereas the WWW_1 items were never presented during picture-naming.

Note that there were no external cues to indicate this structure. The three stimulus-items of set PW (PW1) were pseudorandomly re-sequenced (orthogonalized) between their presentation in the PPP_1-triple and their presentation in the WWW_2-triple. Thus, even if the participants had noticed the repetition of the PW-items, they would not have been able to predict the order of the WWW_2-stimuli trial by trial.

At the end of a cycle, the 36 items *within* each set were re-randomised into 12 new triples, and the whole procedure was repeated. We conducted five cycles.

Given this structure, the cumulative number of priming trials (in which the items of set PW were presented during picture-naming) incremented by one each cycle, although the ratio of trials in which these items appeared for picture-naming and word-reading remained 1:1. With regard to the priming from picture-naming to word-reading, the mean lag between priming trials (PPP_1) and probe trials (WWW_2) was eight trials. In contrast, any possible priming from word-reading to picture-naming occurred with a mean lag of one cycle (144 trials). This is because the items of set PW, presented in one of the WWW_2-triples during cycle 1, were next presented in one of the PPP1-triples of cycle 2, and so on.

5.1.4. Procedure

At the beginning of the session, participants were familiarized with the word-reading task, using twelve stimulus items not used in the main experiment. During the practice, subjects were encouraged to respond loudly, to ensure that their vocal responses triggered the voice-key reliably on every trial. They were also instructed to respond as fast and as accurately as possible.

The 216 *baseline word-reading* trials were presented in blocks of 36 trials (12 triples). At the beginning of each block a display saying "Initiate" appeared on the screen. The subject's keypress started the block. Stimuli were presented in runs of three trials each (triples) as follows. For a 500 ms interval the screen remained blank. Then the task cue, the letter "W" (word-reading) which extended 1.4° vertically and 1.3° horizontally, appeared for 2000 ms. There was then another blank interval of 500 ms before the onset of the first stimulus. The stimulus remained on the screen until the subject's response, which triggered a blank interval of 500 ms followed by the presentation of the second stimulus of the triple. The same held for the presentation of the third and last stimulus of the triple. After the subject responded to the third stimulus the screen was blank for 500 ms and the procedure then repeated, commencing with the presentation of the task cue. After each block of 36 trials a display indicating the end of the block ("xxx") appeared on the screen. The subject's keypress started the next block, again beginning with the "Initiate" display.

After the baseline phase, the subjects received practice at naming all the pictures of stimulus sets PW and PO, to establish name-agreement. The practice was carried out with the picture elements only, without superimposed words. Subjects were then instructed for the alternating phase. They were familiarized with the alternating task procedure in four alternating runs of picture-naming and word-reading, performed on practice items not used in the main experiment.

The subjects initiated the first cycle of the *alternating phase* by a keypress. Each 144-trial cycle was presented in the form of 24 successive, 6-trial "mini-blocks": three picture-naming trials followed by three word-reading trials. Each mini-block started with an "Initiate"-display (see Fig. 2). The subjects had to press a key to initiate the mini-block. The screen remained blank for 500 ms. Then the task cue for the first triple of the mini-block, the letter "B" (for "Bilder benennen" = picture-naming) which extended 1.4° vertically and 0.9° horizontally, appeared for 2000 ms on the screen.

After another blank interval of 500 ms the first stimulus was presented. The stimulus remained on the screen until the subject's response, which triggered a blank interval of 500 ms followed by the presentation of the second stimulus of the PPP-triple. After the subject's response to the third stimulus of the PPP-triple, the screen was blanked for 500 ms. The procedure then repeated, commencing with the presentation of the task cue, except that the cue for word-reading was presented, indicating the start of the WWW-triple. Thus, the RSI between PPP and WWW task-triples was 3000 ms. Participants were encouraged to use this interval to prepare for the upcoming task. Hence, any resulting RT costs of the task switch can be considered to be residual. After the subject finished the WWW-triple, the "Initiate"-display was presented and the subjects had to press a key to initiate the repetition of this procedure for the next mini-block. Fig. 2 shows the procedure for one 12-trial series (two mini-blocks), which was repeated, with different items, through the 144-trial cycle. At the end of the cycle a display ("xxx") indicated a rest pause. The subject's keypress started the next cycle.

5.2. *Results and discussion*

Only RTs of correct trials were retained for further analysis. Overall, accuracy was very high ($M = 98.5\%$, $SD = 0.8\%$). Therefore, errors were too few to be statistically analysed. However, in none of the experiments did the error pattern counteract the RT pattern, thus, a speed-accuracy trade-off cannot account for the results. RTs triggered prematurely by the subject's breath or by involuntary vocalisations were also excluded from the analysis ($M = 2.7\%$, $SD = 2.0\%$).

The main results are illustrated in Fig. 3. The figure denotes RTs and errors for: (1) baseline word-reading, excluding the first item iteration, (2) alternating picture-naming, and (3) alternating word-reading.

5.2.1. *Word-reading baseline phase*

Data for the first baseline cycle was not included in the analysis. The first presentation of the stimulus items was designed to familiarize subjects with the stimulus material. As predicted, the baseline showed a reliable 1st-trial RT cost of about 30 ms for both item subsets. An ANOVA was performed on the baseline phase with the factors Cycle (2 vs. 3), Stimulus Subset (WO vs. PW), and Trial Position (1 vs. 2 vs. 3). Trial position was the only significant effect: $F(1.58, 17.38) = 5.682$, $MSe = 2774.07$, $p < .02$. There was, as expected, no difference between the two stimulus subsets.

5.2.2. *Word-reading alternating phase*[3]

The appropriate ANOVA included the factors Cycle (1–5), Stimulus Subset (WO vs. PW), and Trial Position (1 vs. 2 vs. 3). Two highly significant main effects,

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[3] Note that it would be possible to contrast the word-reading alternating performance directly with the word-reading baseline performance, and thus to avoid any confound of switch/repeat and RSI. The results would be essentially the same.

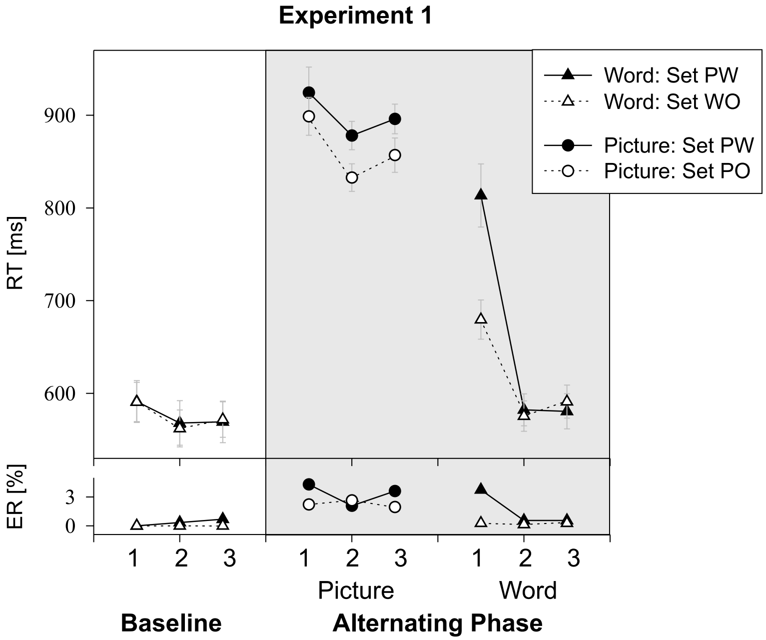

Fig. 3. Experiment 1: mean RTs (and error rates) for the word baseline (left panel) and the picture-word alternating phase (shaded area). Data are shown as a function of trial (1st, 2nd, and 3rd) and stimulus set (set PW, set WO, and set PO). In word reading, PW items were primed from the preceding picture-naming task. WO items were unprimed.

Stimulus Subset, $F(1,11) = 16.52$, $MSe = 10736.34$, $p < .01$, and Trial Position, $F(1.13, 12.47) = 43.04$, $MSe = 46522.21$, $p < .001$, were accompanied by a highly significant interaction of Stimulus Subset × Trial Position, $F(1.11, 12.18) = 24.06$, $MSe = 14872.91$, $p < .001$. Fig. 3 clearly shows that these effects were due to 1st-trial RT costs of about 100 ms for the unprimed items (set WO), and 230 ms for the primed items (set PW). Thus, the experiment revealed a robust item-specific component of TSC which more than doubled the 1st trial switch cost for unprimed stimuli. There was no main effect of Cycle nor any interaction: the word-reading RT pattern was virtually the same for all five cycles. A priori *t* tests confirmed the 1st-trial RT-costs to be significant for both item-sets (*p*s < .001 in all five cycles). The difference between RTs to primed and unprimed stimuli, on the 1st-trial, was also highly reliable (*p*s < .001 in all five cycles).

By contrast, on repeat trials (trials 2 and 3) within the alternating phase no differences between word-reading in response to primed vs. unprimed items (PW vs. WO) could be observed. Furthermore, repeat trial RTs showed no reliable difference between the baseline and the alternating phase.

A feature of the data that is not shown in Fig. 3 is whether a primed stimulus-item had been presented for picture-naming, in the preceding mini-block, as the 1st, 2nd, or 3rd trial of the PPP trial-sequence. This variable had no effect on RTs of the following word-reading trials, in response to the same items. In an ANOVA including Word-reading Trial Position (1 vs. 2 vs. 3) and Previous Picture-naming Trial Position (1 vs. 2 vs. 3) neither the main effect of the factor Previous picture-naming trial, $F(2,22) = 1.301$, $MSe = 1236.32$, $p < .3$, nor the interaction was significant, $F(3.5, 38.5) = 0.325$, $MSe = 1465.42$, $p < .9$. We refer again to this result in Section 10.

5.2.3. Picture-naming alternating phase

The appropriate ANOVA included the factors Cycle (1–5), Stimulus Subset (PO vs. PW), and Trial Position (1 vs. 2 vs. 3). Three main effects were significant: Cycle, $F(3.20, 35.18) = 4.87$, $MSe = 14631.23$, $p < .01$, Stimulus Subset, $F(1, 11) = 4.78$, $MSe = 26268.96$, $p = .05$, and Trial Position, $F(1.55, 17.04) = 6.00$, $MSe = 23264.65$, $p < .02$. The main effects were accompanied by a significant Cycle × Stimulus Subset interaction, $F(3.04, 33.46) = 3.09$, $MSe = 4760.49$, $p < .05$. *T* tests revealed that there was a solid 1st-trial overall effect for both item subsets (*p*s $< .01$ in both cases). RTs also tended to increase in the 3rd-trial (see Fig. 3). It might be suggested that this RT increase on trial 3 reflects an anticipation of the forthcoming task switch. However, sequences of picture-naming triples without a shift of task (PPP PPP PPP...), in Experiment 2, showed a similar RT increase on trial 3. Thus, it appears unlikely that the RT increase on trial 3 depends on anticipating the switch of tasks. See Altmann and Gray (2002) for discussion of a similar phenomenon.

The main effect of Stimulus Subset in *picture naming* reflects long-term item-specific priming from word-reading to picture-naming. There were increased RTs for the items of set PW compared to items of set PO. However, Fig. 3 shows clearly that, in contrast to word-reading, the priming effect in picture-naming was not restricted to 1st trials—if anything, the effect was larger in 2nd and 3rd trials. The significant interaction with cycle reflects the fact that (given the basic structure of the 12-trial series) in cycle 1 there could be no possible item-specific priming of set PW stimuli from word-reading to picture-naming. Indeed, analysis of cycle 1 picture-naming RTs showed no significant difference between stimulus subsets PW and WO.

The core results of this first experiment can be summarised as follows:

(1) Alternating word-reading RTs to primed items (set PW) compared to unprimed items (set WO) showed a massive performance cost, on switch trials only. The results demonstrate a massive item-specific effect, accounting for more than half of the first trial switch cost.

(2) Alternating picture-naming RTs to primed items (set PW) also showed performance costs. However, in sharp contrast to word-reading, the priming was not limited to 1st trials, but arose on repeat trials also. The discussion of this difference between word-reading and picture-naming will be deferred until Section 10.

(3) The competing S–R event priming is evidently long lasting. In Experiment 1 there was a mean lag of eight trials between the picture-naming priming event and the next word-reading trial using the same stimulus-item. It is important to note also that, during the intervening lag between prime and probe events, there were other word-reading trials that showed apparently complete task readiness (on trials 2 and 3). For a word-reading switch trial, the lag between prime and probe varied

between 6, 7, or 8 intervening trials. A post hoc analysis showed no reliable effect of this variable. Clearly, however, we cannot rule out that larger variations of lag might have an effect on the item-specific interference. Experiments 3 and 4 address this issue.

The item-specific interference from word-reading to picture-naming (which was not the focus of this experiment) occurred after a mean lag of a whole cycle (144 trials) between prime and subsequent probe trial.

(4) All alternating cycles, including the first one, showed approximately the same size of item-specific interference from picture-naming to word-reading. This demonstrates that a single picture-naming presentation is sufficient to result in a large priming effect. The effect showed no cumulative increase, as a function of repeated presentation of the primed item in the competing task context, over successive cycles, i.e., there was no effect of the absolute number of picture-naming presentations. Note that, in the alternating phase, the ratio between picture-naming and word-reading trials remained constant at 1:1. Nevertheless, it is possible that the ratio of picture-naming and word-reading trials with a given item may affect the size of the interference effect. Presenting an item, say, four times in picture-naming and only once in word-reading might yield a larger interference than presenting the item only once in picture-naming and once in word-reading, as in Experiment 1. We explored this question in Experiments 2 and 3.

(5) Replicating the results from Allport and Wylie (2000), in the baseline phase, we found an RT increment of about 30 ms on the first trial of each triple, simply after a task interruption of 3 s in the series of speeded response trials, without any explicit switch of task ('restart' effect).

These results have some important implications for the three principal accounts of (residual) switching costs, reviewed in Section 1. If the residual switch cost reflected the time cost of an extra control process during the course of the switch trial (as proposed by Rogers & Monsell, 1995; Rubinstein et al., 2001; and others), it is difficult to explain why stimulus-items presented previously for the competing task (i.e., primed items) should show any larger switch costs than unprimed items. A control operation, which sets up the correct processing pathways should presumably establish the same degree of task-readiness for all task-relevant stimuli. Thus, at least the *item-specific* component of the residual switch cost could not be due to a general resetting of processing pathways.

The item-specific priming effects, similarly, cannot be accounted for by the initial conception of task set inertia (Allport et al., 1994), viz. simply as persisting facilitation of previously task-relevant pathways and persisting inhibition of previously competing pathways. As noted in result (3), above, the item-specific interference effect occurred across an interval between prime and probe in which word-reading was performed with full task-readiness. Hence, this effect could not result from activation or suppression of competing pathways simply persisting over this interval.

In contrast, the item priming effects in word reading are in perfect accordance with the retrieval account of task switching costs proposed by Allport and Wylie (2000). Whether the much smaller RT switch costs found with unprimed items are due to some kind of task-set reconfiguration, or to task-set inertia, or whether they, too, should be attributed to the retrieval of S–R associations triggered by stimulus generalisation to related stimuli, is considered further in Section 10, below. Consideration of the task-switching performance in the Picture naming task, and the strikingly different pattern of item-specific priming effects, is also deferred to Section 10.

6. Experiment 2

As noted in Section 1, the retrieval account of task switching costs is related to other theories that model human processing, and skill acquisition, in terms of instances (e.g., Logan, 1988; Logan & Etherton, 1994) or strengthening of connections (e.g., Cohen, Dunbar, & McClelland, 1990).[4] An integral prediction of these theories is that the "stronger" the connections, or the more instances accumulated in memory, the more efficient are the processes based on these connections or instances. Thus, if a similar associative learning mechanism accounts for the item-specific interference in task switching, reported in Experiment 1, then increasing the number of instances in which a given stimulus-item is associated with the competing task (e.g., picture-naming), should yield increasingly impaired performance in later word-reading, in response to the same item. Indeed, Lowe (1998) has already reported an effect of the number of prime trials on negative priming.

Hence, Experiment 2 was designed to find out whether RTs on a switch trial from picture-naming to word-reading increase as a function of the number of prior presentations of that stimulus-item in the picture-naming context. The design was very similar to that of Experiment 1, with a baseline pure task word-reading phase followed by an alternating phase, in which subjects switched between picture-naming and word-reading. In the alternating phase subjects' word-reading performance was again probed on items which previously occurred in picture-naming (PW items, primed items), and on items which were never presented for picture-naming (WO items, unprimed items). In Experiment 2, however, there were two subsets of primed items. The items of one subset (PW1) were each presented for picture-naming once per cycle, whereas the items of the other subset (PW4) were presented for picture-naming four times per cycle. Items from subset PW1 and PW4 were each presented once per cycle for word-reading, after their occurrence in the picture-naming trials. Thus, for items of PW1 the picture:word item-ratio (p:w item-ratio) was 1:1 (as in Experiment 1 for PW), whereas items of subset PW4 had a p:w item-ratio of 4:1.

To summarize, we assumed that the size of the competing S–R event priming, as observed in Experiment 1, is a function of the number of picture-naming presentations prior to the word-reading probe. If so, it should be larger for items of subset PW4 than for items of subset PW1.

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[4] Note that we do not take a specific position on this issue.

6.1. Method

6.1.1. Participants, apparatus, and stimuli

Eighteen subjects, 6 male and 12 female, participated in this experiment; their mean age was 24 years. The apparatus was the same as in Experiment 1. The experimental material consisted of 96 picture-word Stroop stimuli (four sets of 24 items each, see Appendix A).

6.1.2. Design

Four stimulus subsets were assigned counterbalanced across subjects to four different sets: PW4, PW1, WO, and F. Sets PW4 and PW1 were presented in both picture-naming and word-reading, set WO items in word-reading only. To hold constant the mean lag between each word-reading presentation and the most recent of the previous picture-naming presentations for both item groups, PW1 and PW4, it was necessary to use a fourth item-set that occurred in picture-naming only. Set F ("filler" items) was used for this sole purpose.

6.1.2.1. Baseline phase. The baseline was similar to Experiment 1. Participants performed word-reading in runs of three trials as a pure task. Again, this phase included three iterations (cycles) of all items later presented for word-reading in the alternating phase (sets PW4, PW1, and WO).

6.1.2.2. Alternating phase. The 24 items of each set (PW4, PW1, WO, and F) were randomly subdivided for each subject into 8 item-triples. Thus, the experimental material consisted of four item-sets of eight item-triples (PW1-1...PW1-8; PW4-1...PW4-8; WO1...WO8; and F1...F8).

In the alternating phase, subjects switched between a series of nine picture-naming trials (in three triples) and three word-reading trials (PPP PPP PPP WWW....). This increased ratio of picture-naming to word-reading trials resulted from presenting set PW4 items four times.

The three word-reading trials were either an item triple of set PW4, PW1, or set WO. Thus, all three items within a triple were from the same set; their order within a triple was randomized.

Prior to their word-reading presentation, the item-triples of set PW4 had each been presented four times in picture-naming: two times within the last but one run of nine picture-naming trials, and another two times within the last but two runs of nine picture-naming trials. The items were presented pseudorandomly, in such a manner that the mean lag between the last occurrence of a set PW4 item in picture-naming and the occurrence of this item in word-reading was 14 trials. Similarly, prior to their word-reading presentation, the item-triples of set PW1 were presented in the last but one run of nine picture-naming trials, in such a manner that the mean lag between the picture-naming and the word-reading occurrence was also 14 trials. Thus, the minimum lag was the same for both groups of primed items, PW4 and PW1. The remaining picture-naming trials were performed on set F item-triples. As already mentioned, these items served solely as filler items in order to obtain the constant picture-word lag in the way described. After all items of the subsets PW4, PW1, and WO had been presented once in word-reading, the items within each set were newly re-randomised into triples, and the whole procedure was repeated in two further cycles.

6.1.3. Procedure

The procedure was identical to Experiment 1 (see Fig. 2), except for the following modifications: (1) A subject-paced mini-block consisted of three picture-naming triples followed by one word-reading triple (PPP PPP PPP WWW); (2) the task pre-cue for picture-naming, presented before each picture-naming triple, was a non-alphanumeric symbol (a circle with a dot in the middle; the circle was approximately the same size as the word-reading cue). Furthermore, all task cues were presented for 1000 ms only. Nevertheless, since the word-reading preparation interval was 2000 ms, it is reasonable to assume that all task switching costs were residual ones.

6.2. Results and discussion

RTs of incorrect trials and RTs resulting from subject's breath or involuntary vocalisations ($M = 1.2\%$, $SD = 0.6\%$) were excluded from the analysis. Again, overall accuracy was very high ($M = 97.6\%$, $SD = 1.0\%$), and the error pattern did not counteract the RT results.

Fig. 4 shows RTs and errors for respectively (1) baseline word-reading, (2) alternating picture-naming (set F omitted), and (3) alternating word-reading.

6.2.1. Word-reading baseline

The data are for the second and third baseline cycles (as in Experiment 1). The appropriate ANOVA included the factors Cycle (2 vs. 3), Stimulus Subset (WO vs. PW1 vs. PW4), and Trial Position (1 vs. 2 vs. 3). Two main effects were highly significant: Cycle, $F(1.56, 26.25) = 60.549$, $MSe = 1238.319$, $p < .001$, and Trial Position, $F(1.85, 31.38) = 6.886$, $MSe = 1686.223$, $p < .01$. As expected, there was no difference between the three stimulus subsets. The main effect of cycle was due to a general reduction of RTs in the third baseline cycle. However, in contrast to Experiment 1, Fig. 4 shows that the baseline did not show clearcut 1st-trial RT costs (relative to trials 2 and 3), because all three item-sets also showed increased RTs in trial 3.

6.2.1.1. Word-reading in the alternating phase. We conducted an ANOVA including the factors Cycle (1–3), Stimulus Subset (PW4 vs. PW1 vs. WO), and Trial Position (1 vs. 2 vs. 3). Two main effects were significant or approached significance: Trial Position, $F(1.19, 20.17) = 43.033$, $MSe = 13917.35$, $p < .001$, and Stimulus Subset, $F(1.49, 25.38) = 3.324$, $MSe = 5404.29$, $p < .07$. These main effects were accompanied by a significant Stimulus Subset × Trial Position interaction, $F(1.93, 32.83) = 7.047$, $MSe = 5564.71$, $p < .01$. Fig. 4 clearly indicates that this interaction is once more due to larger 1st-trial RT costs for primed (set PW4 and PW1) than for

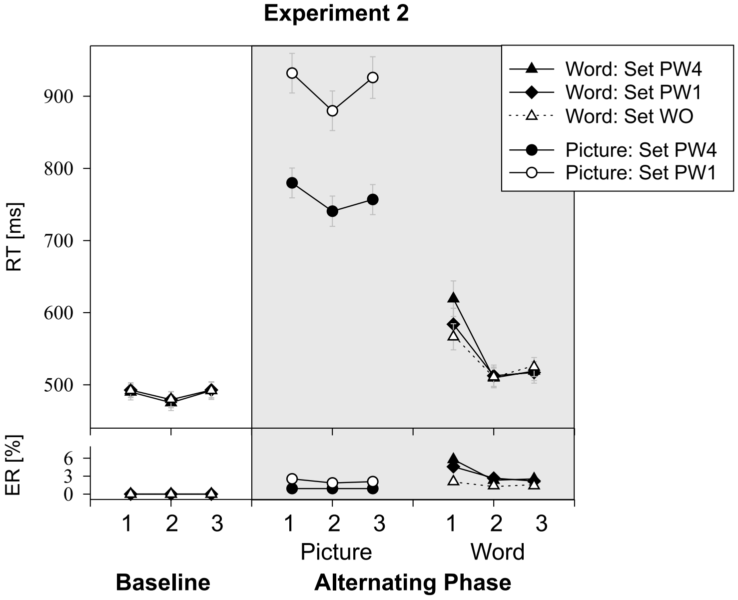

Fig. 4. Experiment 2: mean RTs (and error rates) for the word baseline (left panel) and the picture-word alternating phase (shaded area). Data are shown as a function of trial (1st, 2nd, and 3rd) and stimulus set (set PW1, set PW4, and set WO).

unprimed (set WO) items. 1st-trial RT costs were about 55 ms for unprimed items (WO), about 70 ms for the items of set PW1, and about 110 ms for items of set PW4. On repeat trials, as in Experiment 1, there were no differences between word-reading in response to primed (PW1 or PW4) and unprimed items (WO). A priori *t* tests confirmed the 1st-trial RT-costs to be significant for all three item-sets (*p*s $< .001$ in all cases). Furthermore, *t* tests comparing 1st-trial RTs reached significance for all three contrasts (PW1 vs. WO, PW4 vs. WO, and PW4 vs. PW1; $p < .05$ in all cases).

In general, these results replicate the item-specific component of the costs of task-switching found in Experiment 1. What is more, the competing S–R event priming, as predicted, was significantly larger for items of set PW4 than for items of set PW1. That is, items which had been presented four times per cycle in the competing task context yielded larger costs of task switching than items which had been presented only once.

6.2.1.2. Picture-naming in the alternating phase. Although picture-naming was not the focus of this experiment, we report the main results here for the sake of completeness. An ANOVA comparing overall picture-naming RTs included the factors Stimulus Subset (PW1 vs. PW4; we omitted set F), and Trial Position(1 vs. 2 vs. 3). Both main effects reached significance: Stimulus Subset, $F(1,17) = 49.330$, $MSe = 12895.824$, $p < .001$, and Trial Position, $F(2,34) = 6.414$, $MSe = 3053.020$, $p < .01$. For both item-sets (PW4 and PW1), *t* tests confirmed the main trial position effect to be due to 1st-trial RT costs (ps $< .05$ for both item subsets).[5] However, both item sets also showed a significant tendency to increased RTs in 3rd-trials. Not surprisingly, the main effect of Stimulus Subset is due to faster RTs for set PW4 items than for set PW1 items, because the former have been presented for picture-naming four times more often than the latter.

The principal results of this experiment can be summarised as follows.

(1) As in Experiment 1, switching to word-reading was harder when the items to be responded to had been previously presented in picture-naming than when they had not. Furthermore, as in Experiment 1, the item-specific interference was present only on switch trials. The effect was observed even though a minimum of 12 trials intervened between the presentation of the same stimulus-items in picture-naming and subsequently in word-reading. Thus, Experiment 2 replicates the main features of Experiment 1.

(2) Experiment 2 also supported the hypothesis that the item-specific interference from picture-naming to word-reading increases with the number of presentations of an item in the picture-naming context. This strengthens the assumption that the effect is memory based. Some record of processing each item in picture-naming is evidently encoded in memory, and retrieved when the item is presented again on a word-reading switch trial. With repeated presentations of the same items during picture-naming, the same S–R-event bindings were apparently strengthened (or more numerous instances accumulated in memory), generating increased interference with word reading. Hence, Experiment 2 supports the idea of competing S–R event priming as described above.

(3) In contrast to Experiment 1, we failed to find baseline 1st-trial RT costs for word-reading. It is not clear what procedural or other difference accounts for the smaller restart costs in this experiment. Allport and Wylie (2000; Wylie & Allport, 2000) found robust baseline 1st trial RT costs, approaching 100 ms, when subjects read colour-word Stroop stimuli. Switch costs for unprimed items were also much smaller than in Experiment 1: approximately halved, from 100 ms in Experiment 1 to 55 ms in Experiment 2. As noted in Section 1, it is possible that both phenomena, restart costs and switch trial costs, are affected by the same or overlapping variables.

(4) A further, unexpected feature of Experiment 2 was the relatively small magnitude of the item-specific interference effects, on switching from Picture to Word, compared to Experiment 1. For set PW4, the item-priming effectively doubled the size of the first-trial switch cost (from 55 to 110 ms). However, for set PW1 the priming effect was only about 15 ms, which (though significant) was far smaller than the equivalent effect in Experiment 1.

The co-occurrence, in Experiment 2, of greatly reduced first trial effects of all three kinds (the restart effect in baseline word reading; the unprimed switch costs; and the

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[5] Note that in this case the 1st-trial RT costs for picture-naming do not correspond to "costs of task switching," but refer to 1st-trial RT costs across the picture-naming triples of the runs of nine picture-naming trials in the alternating phase.

additional, item-specific interference effect on word reading) would be consistent with (but does not require) a common causal origin for all three types of effect. We have no explanation to offer for the small absolute magnitude of these effects in Experiment 2. Happily, however, both switch costs and item-specific interference costs increased again in the following three experiments.

7. Experiment 3

The finding that negative priming may persist across many trials, or a long span of time, has been considered to be a strong argument for an episodic retrieval account of negative priming (e.g., DeSchepper & Treisman, 1996; Lowe, 1998; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991). If negative priming resulted only from persisting inhibition or blocking of distractor representations (Houghton & Tipper, 1994; Neill, 1977; Neumann & DeSchepper, 1991, 1992; Tipper, 1985; Tipper & Cranston, 1985), it is implausible that the representations would be rendered unavailable for such an extended duration. Indeed, most authors agree that at least some part of the negative-priming phenomenon is retrieval-based (e.g., Fox, 1995; May, Kane, & Hasher, 1995; Milliken, Tipper, & Weaver, 1994).

The same arguments apply to the findings from Experiments 1 and 2: Observing effects of S–R event priming across a mean lag of at least eight to 14 intervening trials strongly suggests a memory-based explanation. However, it would be interesting to know whether the effect survives even longer lags, which is why we conducted Experiment 3. The subjects' tasks were again word-reading and picture-naming, and the experiment was run in two successive phases This time, however, the first phase was one of intensive picture-naming (“priming phase”). In the second, alternating phase, subjects once more either named pictures, or read words, shifting task every third trial.

For picture-naming in the alternating phase we used, exclusively, items that never appeared as word-reading targets, i.e., subjects performed picture-naming and word-reading on completely non-overlapping item-sets. The item-overlap occurred only between word-reading in the alternating phase and the picture-naming in the initial priming phase. In this priming phase, one set of items was presented for picture-naming sixteen times (PW16), another set four times (PW4), and a third set was not presented (WO). All three sets (PW16, PW4, and WO) were later used as word-reading targets in the alternating phase. Thus, in the alternating phase subjects' word-reading performance was again probed on items that had been presented previously in the competing picture-naming task, during the priming phase (PW16, PW4, and primed items), and on items that subjects had never encountered in the picture-naming task (WO, unprimed items). The design was thus similar to Experiment 1, except that the priming from picture-naming to word-reading occurred with a much larger—and steadily increasing—lag between the priming and the alternating phase, and that some items were primed more often than other items.

7.1. Method

7.1.1. Participants, apparatus, and stimuli

Sixteen subjects, 7 male and 9 female (mean age 23 years), participated. The apparatus was the same as in Experiment 1 and stimuli were as in Experiment 2 (see Appendix A).

7.1.2. Design

The four stimulus subsets (24 items each) were assigned, counterbalanced across subjects, to the four different experimental sets: PW16, PW4, WO, and PO. The priming phase consisted of four priming blocks, each of which began with a series of pure word-reading, without any intervening picture-naming, followed by a series of pure picture-naming without any intervening word-reading. During the initial series of word-reading in each priming block, all items of the sets PW16, PW4, and WO were presented once each in word-reading triples. During the following (much longer) series of picture-naming, items of set PW16 were each presented four times and items of set PW4 were each presented once in each priming block. Thus, over the course of the four priming blocks, PW16 items were presented a total of 16 times, and PW4 items were presented a total of four times each. In order to avoid a confounding of the recency of the item-presentation (during the picture-naming) with the number of presentations, in each block, the items of PW16 were presented first, in three complete iterations, and thereafter the items of PW16 and PW4 were presented once each, intermixed. Stimulus-items were assigned randomly to triples, for each subject. This procedure was repeated in four successive priming blocks. This ensured that the most recent presentations of both stimulus subsets in each of the four priming blocks had the same mean lag to the alternating phase.

For the subsequent alternating phase, the 24 items of each set (PW16, PW4, WO, and PO) were randomly subdivided for each subject into 8 item-triples (PW16-1.... PW16-8; etc.). The structure of this phase was again based on alternately performed picture-naming and word-reading triples. This time, the basic unit consisted of eighteen trials (PPP, WWW_1; PPP, WWW_2; PPP, WWW_3). All picture-naming triples used items of set PO. In the first basic unit of a cycle, task-triple WWW_1 used the items of triple PW16-1. Task-triple WWW_2 used item-triple WO1 and task-triple WWW_3 used item-triple PW4-1. For half the subjects this order was reversed. After all triples of the sets PW16, PW4, and WO had been presented once (i.e., after eight units or one complete cycle) the 24 items within each set were re-randomised into triples, and the whole alternating procedure repeated. The items of set PO had to be presented three times per cycle in picture-naming. We conducted two alternating cycles.

The main features of this design are, thus, the different, cumulative number of priming trials in the priming phase (PW16 vs. PW4 vs. WO) and, the increasing lag between priming and alternating phase over the two successive alternating cycles. In the first alternating cycle, the mean lag between the last picture-naming presentation of a given item, in the priming phase, and its word-reading presentation was 96 trials; in the second alternating cycle, the mean lag was 168 trials.

7.1.3. Procedure

At the beginning of the session, participants were familiarized with the tasks and the pictures. The priming phase started with a display indicating the beginning of the experiment. Word-reading and picture-naming in the priming blocks was done in subject-paced mini-blocks of two triples (WWW WWW then PPP PPP). The timing of these mini-blocks was the same as for the PPPWWW-mini-blocks in Experiment 1, except that task cues before each triple indicated a word-reading or picture-naming triple. After the priming phase subjects were instructed for the alternating phase and were familiarized with the alternating procedure, which was the same as in Experiment 1.

7.2. Results and discussion

Again, accuracy was very high ($M = 97.6\%$, $SD = 1.0\%$), and error rates did not counteract the RT pattern. RTs resulting from erroneous trials and subject's breath or involuntary vocalisations were excluded from the analysis ($M = 2.1\%$, $SD = 1.5\%$).

The results of the alternating phase are illustrated in Fig. 5, which shows RTs and errors for picture-naming (collapsed over the two cycles) and word-reading separated for the two cycles.

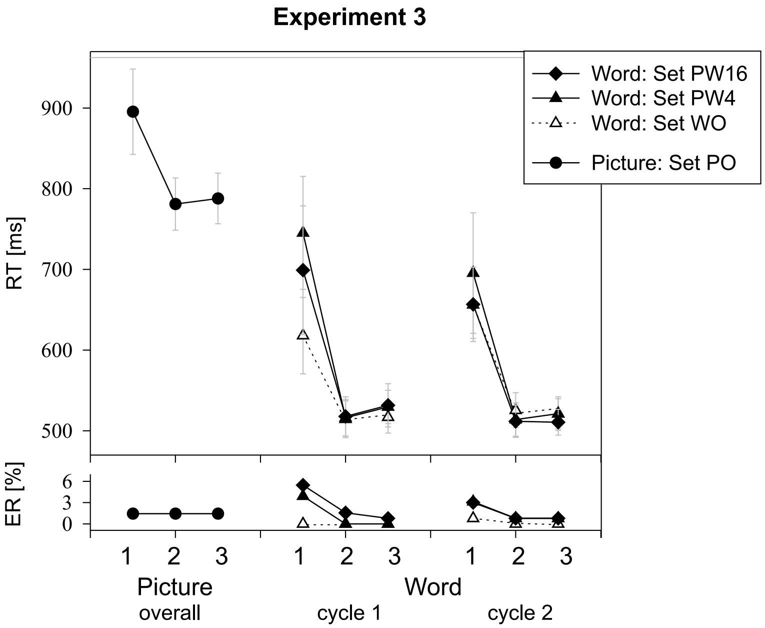

Fig. 5. Experiment 3: mean RTs (and error rates) for the picture-word alternating phase. Data are shown as a function of trial (1st, 2nd, and 3rd) and stimulus set (sets PW16, PW4, WO, and PO). Picture-naming RTs are shown collapsed across the two alternating cycles. Word-reading RTs are shown separately for the two alternating cycles.

7.2.1. Picture-naming in the alternating phase

The picture-naming in the alternating phase showed a marked 1st-trial RT cost (*p*s $< .01$ in both cycles).

7.2.2. Word-reading in the alternating phase

The appropriate ANOVA included the factors Cycle (1–2), Stimulus Subset (WO vs. PW4 vs. PW16), and Trial Position (1 vs. 2 vs. 3). Two main effects were significant: Trial Position, $F(1.02, 15.30) = 17.347$, $MSe = 91812.97$, $p < .001$, and Stimulus Subset, $F(2, 30) = 3.287$, $MSe = 5853.716$, $p = .05$. These main effects were qualified by a significant Stimulus Subset × Trial Position interaction, $F(2.09, 31.27) = 4.413$, $MSe = 8021.53$, $p < .02$.

Fig. 5 clearly shows that this interaction is due to larger 1st-trial RT costs for primed stimuli (PW16 and PW4) than for unprimed stimuli (WO). However, the data pattern is different for the two alternating cycles.

7.2.3. Word-reading: Alternating cycle 1

First-trial RT costs, on the switch from picture-naming to word-reading, were about 100 ms for the unprimed items (WO), about 180 ms for the items of set P16, and about 230 ms for the items of set P4. Thus, the results in cycle 1 were similar to Experiment 1. Again, 2nd- and 3rd-trials did not show any differences between word-reading in response to primed vs. unprimed items. A priori *t* tests confirmed the 1st-trial RT-costs to be significant for all three item-sets (*p*s $< .01$ in all cases). Moreover, the difference between RT to primed and unprimed stimuli on the 1st-trial was reliable (*p*s $< .03$ for PW16 vs. WO and for PW4 vs. WO), thus replicating the substantial item-specific component of the RT task-switching cost found in Experiment 1, at the much longer mean lag of 96 trials. In contrast, the difference between sets PW4 and PW16 was nowhere near significance ($t = -0.83$, $p > .4$).

Clearly, S–R event priming can survive a very large number of intervening events. Note that between the priming and the alternating phase the subjects also received a new set of instructions. The mean time that elapsed between the last presentation of an item of set PW16 or PW4 in the priming phase and that item's presentation for word-reading in the first alternating cycle was about 8 min.

7.2.4. Word-reading: Alternating cycle 2

In contrast to cycle 1, the only significant effects in cycle 2 were the 1st-trial RT costs for all three stimulus subsets (*p*s $< .01$ in all cases). The difference between set PW4 and the other two stimulus sets was not significant ($t = 0.87$, $p > .4$ with respect to PW4 vs. WO).

Thus, the item-specific interference was essentially absent in the second cycle of the alternating phase. Two possible explanations for this difference between cycles 1 and 2 might be suggested. First, the reduced item-specific interference might be due simply to the increased lag: that is, either the number of intervening trials, and/or the total time elapsed between the priming phase and the second alternating cycle, might have simply been too great. Second, it is possible that just one intervening trial of word-reading, in response to an item previously primed in picture-naming, is sufficient to "overwrite" the previous S–R event representation. Tipper et al. (1991) demonstrated that negative priming can survive intervening events unless either the intervening event is a novel one (i.e., has a low probability) or, more important, the ignored stimulus itself appears as a target item between the prime and probe trial. If this holds for the competing S–R event priming too, we should not expect to find any difference between primed and unprimed items in cycle 2 of the alternating phase, because all primed items (PW16 and PW4) were presented for word-reading in cycle 1, and received no further priming in the picture-naming task, thereafter. Experiment 4 addresses this issue.

With regard to the effect of the number of presentations in picture-naming, the results are clear: There was no evidence for a difference between items that had been primed 16 times and items that had been primed only four times. If anything, set PW4 items yielded a numerically larger interference than set PW16 items but this difference was far from significant. Experiments 2 and 3 thus have divergent results concerning the dependency of the priming effect on the number of previous picture-naming presentations: More frequently presented items clearly showed larger 1st trial RT costs in Experiment 2 but not in Experiment 3. The most obvious difference between the two experiments that might account for this discrepancy is the much smaller mean lag between the presentation of the primed items in picture-naming and in word-reading in Experiment 2 (14 trials) than in Experiment 3 (96 trials in cycle 1, 168 trials in cycle 2). If this difference was responsible, this would suggest that the difference between more and less frequently primed items disappears at very long lags. In other words, in the long run a few instances are as effective as a large number of instances.

8. Experiment 4

Experiment 4 investigated whether the reduction of interference between cycles 1 and 2, found in Experiment 3, can be ascribed to the increased lag between the priming and alternating phase, or to the "overwriting" of S–R event bindings as a result of presenting the items for word-reading in cycle 1. The key features of the design were as in Experiment 3, with an initial priming phase (an extensive block of picture-naming with interspersed word-reading) and an alternating phase (picture-naming, word-reading). Again, in the alternating phase picture-naming and word-reading were performed on non-overlapping item-sets, whereas the picture-naming items of the priming phase and the word-reading items of the alternating phase partially overlapped, thus enabling possible long-term priming from picture-naming to word-reading.

The two major differences from Experiment 3 were that, first, Experiment 4 included four (shorter) alternating cycles and, second, word-reading in alternating cycles 1 and 2 was performed on different stimulus subsets from those presented in cycles 3 and 4. That is, subjects performed cycles 1 and 2 in response to one stimulus subset (item-lot 1, including both primed and unprimed items), and cycles 3 and 4 in response to a different, novel stimulus subset (item-lot 2, also including primed and unprimed items).

The experiment addressed two complementary questions: first, the extent to which the apparent decline of long-term S–R event priming, found in Experiment 3, can be interpreted as the passive decay of priming with increasing lag between prime and probe trials; and second, the extent to which the decline is due to the resetting or overwriting of stimulus–action associations in the course of cycle 1. Insofar as the decline is simply a function of lag, the item-specific interference should decrease smoothly across the four alternating cycles. Insofar as it is a consequence of overwriting the previously established stimulus–action associations, appropriate for picture-naming, by performing word-reading on these items, then only cycles 2 and 4 should be affected. This is because the associations affecting item-lot 1 would be overwritten in the course of cycle 1 and those affecting item-lot 2 would be overwritten in the course of cycle 3. Of course, it is possible that both factors co-act.

8.1. Method

8.1.1. Participants, apparatus, and stimuli

Fourteen subjects, 4 male and 10 female, participated in this experiment, their mean age was 24 years. The apparatus was the same as in the previous experiments. The experimental material consisted of the same set of 108 picture-word Stroop-stimuli, in three matched sets of 36 items each, as used in Experiment 1 (see Appendix A).

8.1.2. Design

The three matched stimulus sets were assigned—counterbalanced across subjects—to three different experimental sets: PW (Picture and Word, primed items), WO (Word Only, unprimed items), and PO (Picture Only). As in Experiment 3, the priming phase comprised four priming blocks. Again, each of these blocks began with a series of pure word-reading followed by a series of pure picture-naming. The design of the priming phase was identical to Experiment 3 except for three changes. First, there was only one set of primed items (set PW); second, each item of set PW was presented twice in each of the four priming blocks; third, both the priming phase and the alternating phase were run in trial pairs instead of triples. For the subsequent alternating phase set PW and set WO were first subdivided into two subsets (PW1, PW2; WO1, WO2) randomly for each subject. Subsets PW1 and WO1 composed item-lot 1, and subsets PW2 and WO2 composed item-lot 2.

As in previous experiments, subjects read words and named pictures, but this time they shifted task every second trial. In cycle 1 all picture-naming was done on the 36 items of set PO, and all word-reading was done on the 18 items of set PW1 and the 18 items of set WO1. For cycle 2, the items within each set were re-randomised, and the whole procedure repeated. The same procedure was applied for cycles 3 and 4, except that, for word-reading, item-lot 2 (PW2 and WO2) was used.

8.1.3. Procedure

The procedure was the same as in Experiment 3, except that the subjects performed runs of two trials instead of triples.

8.2. Results and discussion

Again, incorrect trials (overall accuracy: $M = 97.7\%$, $SD = 1.1\%$) and RTs triggered by the subject's breath or involuntary vocalisations were excluded from the analysis ($M = 1.6\%$, $SD = 0.8\%$). Again the error pattern corresponded with the RT pattern (see Fig. 6). Fig. 6 illustrates the core results. The Figure represents RTs and errors for alternating picture-naming collapsed over the four cycles and alternating word-reading separated for each cycle.

8.2.1. Picture-naming alternating

As expected, the picture-naming RTs in the alternating phase showed a marked 1st-trial effect (ps < .01 in all cycles).

8.2.2. Word-reading in the alternating phase

We ran an ANOVA including the factors item-Lot (L1 vs. L2), Cycle (1 vs. 2), Stimulus Subset (WO vs. PW), and Trial Position (1 vs. 2). The only significant main

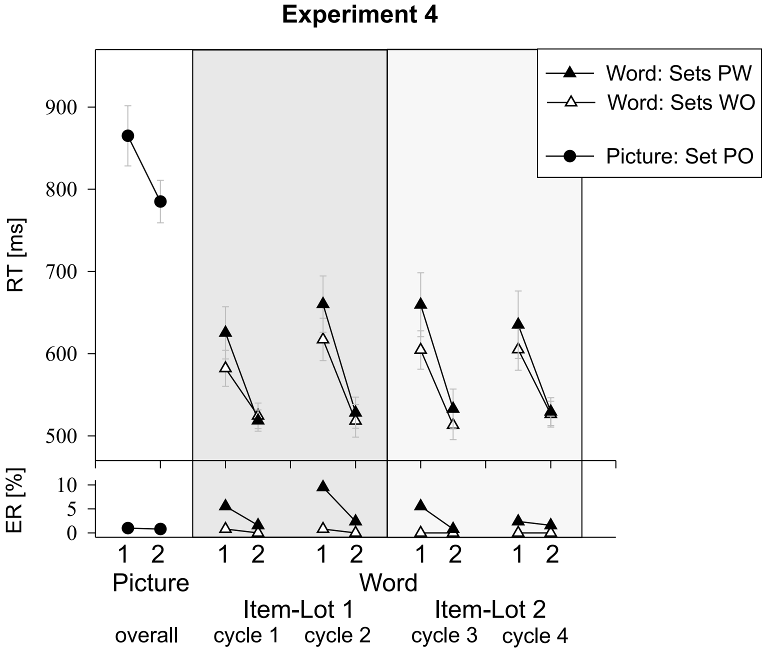

Fig. 6. Experiment 4: mean RTs (and error rates) for the picture-word alternating phase. Data are shown as a function of trial (1st and 2nd), stimulus set (sets PW, WO, and PO), and item-lot (1 vs. 2). Picture-naming RTs are shown collapsed across the four alternating cycles. Word-reading RTs are shown separated for the four alternating cycles.

effects, viz. of the factors Trial Position, $F(1,13) = 53.473$, $MSe = 10435.265$, $p < .001$, and Stimulus Subset, $F(1,13) = 9.760$, $MSe = 3520.659$, $p = .01$, were accompanied by a significant Trial Position × Stimulus Subset interaction, $F(1,13) = 5.830$, $MSe = 3134.488$, $p < .05$.

As shown in Fig. 6, the interaction is again due to larger 1st-trial RT costs for primed items (sets PW1 and PW2) than for unprimed items (sets WO1 and WO2). The 1st-trial RT costs were significantly larger for primed than for unprimed items (*p*s $< .05$ for the first three cycles, $p < .15$ for the fourth). On 2nd trials there were no RT differences between primed and unprimed items observable, as in previous experiments.

Importantly, there was no influence of either Lot or Cycle, i.e., there was no sign of an overwriting effect. Furthermore, the results suggest that any possible reduction in priming as a function of lag is very small, over the observed range of four alternating cycles of 72 trials each (i.e., a total of 288 trials). This experiment thus confirmed that the item-specific component of the task-switching costs was long-lasting; that the magnitude of the item-specific interference did not decay substantially, at least up to lags of more than 200 trials; and that performing intervening trials of word-reading on the primed items did not counteract the interference.

9. Experiment 5

Thus far, we have left open one important question about the basis of the item-specific priming effects, observed consistently in our experiments on a switch from picture naming to word reading tasks. In Section 1, we proposed a mechanism of S–R-event bindings, linking *all* the encoded constituents of an action-event, including the task, the goal of the action, and other relevant contextual features, as well as the stimulus and the overt response. However, in all of the preceding four experiments, the observed item-specific interference might be explained, in principle, solely in terms of direct stimulus–*response* (S–R) associations. That is, the stimuli previously presented for picture naming interfered with word reading, on the switch of tasks, because they elicited the conflicting *response* associated with the picture naming task, rather than because of higher-order associations of these stimuli with the competing *task*.

On the one hand, even pure stimulus–response effects would be in line with our general argument: that stimulus-triggered conflicts, not control processes, account for a considerable portion if not all of residual TSC. On the other hand, in order to model the emergence of residual TSC in any detail, we need to know whether these stimulus-triggered conflicts are conflicts between competing responses or between more comprehensive *task* representations (of which responses may well be a part). To assess the possible contribution of competing stimulus–*task* bindings, we need to study item-specific priming in the absence of any possible, direct, stimulus–*response* priming. This is what we did in Experiment 5.

As is well known, residual switch costs are obtained even when the competing tasks lead to the *same* response, i.e., with response congruency (e.g., Rogers & Monsell, 1995; Meiran, 1996). Clearly, switch costs that occur under those circumstances cannot be explained in terms of the retrieval of incompatible stimulus–*response* bindings. Hence it seems all the more important to establish whether competing S–R event priming still affects switch-costs, when the stimuli presented for word reading are response-congruent. If primed stimuli generated larger switch costs, even though there was no direct competition at the response level, then this would strongly support the notion of bottom-up (stimulus-triggered) competition at the level of task-specific processing or task-set, as a factor in the emergence of residual switch-costs.

Experiment 5 investigated this issue. In essence, it is a replication of the earlier experiments: subjects named pictures and read words, switching task every second trial (PPWW...). As before, subjects were presented with primed and unprimed items for word-reading. However, in contrast to the previous experiments, the majority of word-reading trials were performed on *congruent* picture-word stimuli. (All picture-naming trials were performed on incongruent Stroop stimuli, as in previous experiments.)

9.1. Method

9.1.1. Participants and apparatus

Sixteen subjects, 4 male and 12 female (mean age about 26 years), participated. All were native German speakers, and none had participated before in a similar experiment. The apparatus was the same as in the previous experiments.

9.1.2. Stimuli

The experimental material consisted of four stimulus sets: three experimental sets, each containing 24 line drawings and the *corresponding* 24 German object names (i.e., in these sets, in contrast to the previous experiments, each picture was also represented as a word); and one additional set for control purposes (see below) containing 16 line drawings and 16 *non*-corresponding German words (i.e., as in the previous experiments, none of these pictures was also represented as a word). The first three, experimental sets were used to assess the contrast between primed and unprimed word-reading performance. The fourth set was used for catch trials only, as described below. Most of the items were drawn from the stimulus sets used in the previous experiments, but some were new (see Appendix A).

9.1.3. Design

The three main stimulus subsets were assigned, counterbalanced across subjects, to three different experimental sets: PW (Picture *and* Word), WO (Word *Only*), and PO (Picture *Only*). As in the previous experiments, items assigned to set WO were presented for word-reading only, items assigned to set PO were presented for picture-naming only, and items assigned to set PW were presented for both tasks, picture naming and word-reading. In contrast to the previous experiments, in the word-reading trials, all items were presented as *congruent* picture-word stimuli (except the catch trials, see below). Participants switched task every second trial.

For the picture-naming trials, a picture from set PW was always randomly combined with a word from set PO, and pictures from set PO were randomly combined with words from set PW. Hence all picture-naming trials were performed on *incongruent* picture-word conjunctions. (As a further consequence, the *corresponding* pictures and words of set PW were primed in different picture-naming trials.) For the word-reading trials, words and pictures both from set WO (unprimed) were paired together, and words and pictures both from set PW (primed) were paired together, in such a way as always to produce *congruent* picture-word conjunctions.

The experiment consisted of four cycles. Within each cycle the stimulus items were selected and paired as follows. First, the 24 pictures and the 24 words of each experimental set (PW, WO, and PO) were randomly subdivided, for each subject, into 12 "bins," with each bin being comprised of two words and the two corresponding pictures. One bin from each set was used to construct one "unit" of eight picture-word conjunctions each (that is, one bin from each of the three experimental sets was used with the PW bin being used twice). Four picture-word conjunctions in each unit were to be used for picture-naming trials, and the other four were to be used for word-reading trials. For the four picture-naming trials, the two words of the PW bin were combined with the two pictures of the PO bin, and vice versa, to produce incongruent Stroop stimuli (see above). For the four word-reading trials of a unit, the items from the same bin of set PW and from one bin of set WO were used. Importantly, these items were combined to form picture-word conjunctions. Thus, the four word-reading stimuli in a unit consisted of two congruent picture-word conjunctions from set PW, and two congruent picture-word conjunctions from set WO.

For a complete cycle of the experiment, this procedure was repeated for each of the twelve bins (i.e., a cycle consisted of $12 \times 8 = 96$ trials, plus the 16 catch trials described below). As a consequence, the items from set PO and WO were presented only once per cycle (items from set PO once for picture-naming, items from set WO once for word-reading); however, items from set PW appeared twice per cycle, because each bin of set PW was presented once in the picture-naming trials of a given unit, and once in the word-reading trials of the same unit.

Successive units were presented in a "nested" way, as follows, such that participants switched tasks after every second trial. After every second picture-naming trial of a unit x, we presented two word-reading trials of the previous unit $x-1$. Since unit x represents unit $x-1$ with respect to the unit that follows unit x (unit $x+1$), the succession of trials can be illustrated as follows. If $\{\mathrm{P}x, \mathrm{P}x\}$, $\{\mathrm{P}x, \mathrm{P}x\}$, $\{\mathrm{W}x, \mathrm{W}x\}$, $\{\mathrm{W}x, \mathrm{W}x\}$ represent the eight trials of a given unit, they were interleaved with the previous and the following unit in this order: $\{\mathrm{P}x, \mathrm{P}x\}$, $\{\mathrm{W}x-1, \mathrm{W}x-1\}$, $\{\mathrm{P}x, \mathrm{P}x\}$, $\{\mathrm{W}x-1, \mathrm{W}x-1\}$, $\{\mathrm{P}x+1, \mathrm{P}x+1\}$, $\{\mathrm{W}x, \mathrm{W}x\}$, $\{\mathrm{P}x+1, \mathrm{P}x+1\}$, $\{\mathrm{W}x, \mathrm{W}x\}$. Given this structure, the priming from picture-naming to (congruent) word-reading occurred with a mean lag of nine trials between prime and probe events.

Presenting congruent picture-word conjunctions for all word-reading trials would permit the subject, at least in principle, not to switch tasks, but simply to name the pictures on all trials. To provide a check on this strategy, we presented without warning a set of 16 incongruent trials (PPWW...) at the end of each cycle. Stimuli for these trials were drawn from the 16 line drawings and the 16 words of the 'catch trial' stimulus subset (see above). All stimuli occurred as incongruent picture-word pairs, for both the picture-naming *and* word-reading tasks. Any subject who failed to switch tasks from picture-naming to word-reading would thus respond incorrectly on these incongruent word-reading catch-trials. Note that there were no external cues to indicate the beginning of the catch-trial sequence.

9.1.4. Procedure

The procedure was identical to the alternating phase of Experiment 4. That is, subjects performed self-initiated mini-blocks of two picture-naming trials followed by two word-reading trials. The timing of the stimuli was the same as before.

9.2. Results and discussion

Two participants made more than 10 catch-trial errors and were therefore excluded. On the 32 critical word-reading trials, the remaining subjects made hardly any errors: eight subjects made none; four subjects made a single error, and two subjects made two errors. Thus, we can be confident that these subjects reliably switched between picture-naming and word-reading, the more so as their RTs were considerably shorter for word-reading than for picture-naming. Overall accuracy was very high ($M = 99.0\%$, $SD = 0.8\%$), and error rates did not counteract the RT pattern. Erroneous trials and trials triggered by the subject's breath or involuntary vocalisations were also excluded from the analysis ($M = 1.2\%$, $SD = 0.9\%$). Fig. 7 shows RTs and errors for picture-naming and word-reading.

9.2.1. Picture-naming

The picture-naming in the alternating phase showed only a small 1st-trial effect, which was statistically not reliable ($p < 0.2$).

9.2.2. Word-reading

We ran an ANOVA with the factors Trial Position (1 vs. 2) and Stimulus Subset (WO vs. PW). The main effect of Trial Position was highly significant: $\mathrm{F}(1,13) = 89.78$, $MSe = 1403.64$, $p < .001$. The main effect of Stimulus Subset approached significance: $F(1,13) = 4.33$, $MSe = 1210.60$, $p < .06$. However, these main effects were qualified by a significant Trial Position × Stimulus Subset interaction, $F(1,13) = 9.69$, $MSe = 430.44$, $p < .01$.

Fig. 7 shows that this interaction effect was due to a robust item-specific component of TSC; unprimed items (set WO) showed a 1st-trial RT cost of about 77 ms, whereas primed items (set PW) showed a much larger 1st-trial RT cost of 112 ms. A priori *t* tests confirmed the 1st-trial RT-costs to be significant for both item-sets (*p*s $< .001$ in both cases). The difference between primed and unprimed stimuli on the 1st-trial was also reliable ($p < .01$).

Experiment 5 thus revealed essentially the same effect as observed in the previous experiments. That is, even though, in Experiment 5, word reading was done in response to *congruent* picture-word stimuli (i.e., with the identical naming-response

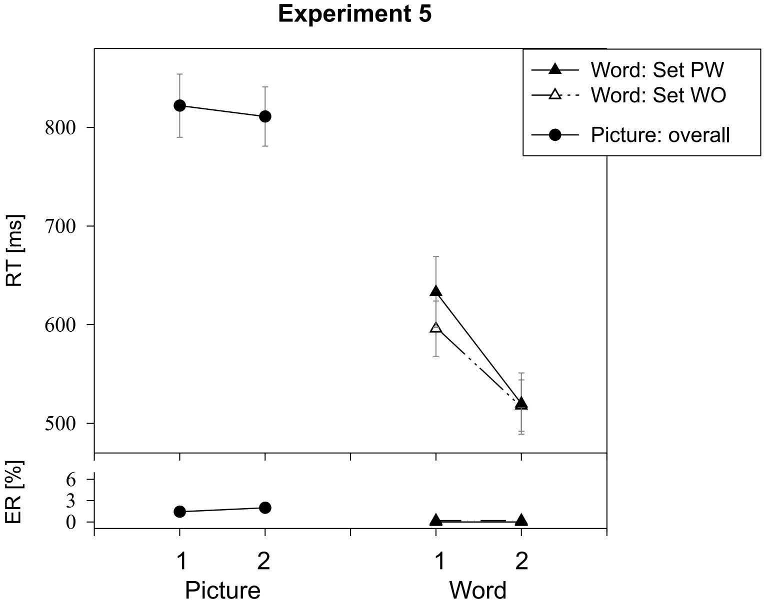

Fig. 7. Experiment 5: mean RTs and error rates for picture-naming and word-reading. Data are shown as a function of trial (1st and 2nd), and stimulus set (sets PW and WO). Word reading is in response to congruent picture-word stimuli.

for both tasks), priming of these items in an earlier picture-naming trial resulted in substantially increased 1st-trial RT costs, on a switch to word reading.

Before we can conclude that Experiment 5 has demonstrated stimulus-specific priming of *tasks*, there is one issue that merits further attention. Note that in this experiment, and in the four previous ones, there are two possible sources of stimulus-specific interference: positive or 'competitor' priming (CP) of the previously executed but now irrelevant task, cued by the (now irrelevant) stimulus-attributes; and negative priming (NP) of the intended task, by stimulus-attributes which appeared previously as distractors, in the competing task, but are now task-relevant.

In so far as the item-specific priming here is *competitor* priming (i.e., in this case, positive priming of the picture-naming task), the argument is straightforward. Stimulus-driven priming of the competitor task (picture-naming) could not be simply at the level of competing responses, because target (word) and competitor (picture) both have the *same* response. Thus, with regard to competitor priming, any item-specific priming effect must reflect stimulus-priming of higher-order task features (tasks).

However, in so far as the item-specific priming is negative priming, the resulting interference could, in principle, be operating either at the task level (viz. the stimulus inhibits the word-reading process—or *task*—as a whole) or at the level of responses (viz. if the primed—word—stimulus comes to elicit a 'suppress response' or 'do-not-respond' code); or it could operate at both levels. Fortunately, however, we have independent evidence suggesting that the item-specific effect in Experiment 5 (and in the other experiments reported) depends on competitor priming only. This evidence comes from another series of experiments (Waszak, Hommel, & Allport, 2003), which addressed the question whether negative priming, competitor priming, or both, were responsible for the stimulus-specific, first-trial interference effects reported here. In order to discriminate between negative and competitor priming, subjects' word-reading performance (on a switch from picture naming) was probed in four conditions. All trials used incongruent picture-word conjunctions. The conditions differed only in the way the stimulus-items had been primed in prior picture-naming trials, as follows: condition U (unprimed), in which neither the word nor the picture had been presented during picture naming; condition NP, in which only the word was (negatively) primed, but not the picture; condition CP, in which only the picture was (competitor) primed, but not the word; and condition NP + CP, in which both the word and the picture were primed from the picture naming task.

The first experiment of this series was run with a large stimulus set (72 pictures and 72 words), as in the present study. Other aspects of the design were also the same as in Experiment 5. The experiment revealed a large 1st-trial priming effect in the condition NP + CP (about 40 ms), an equally large 1st-trial priming effect in the condition CP (also about 40 ms), and no 1st-trial priming effect at all in condition NP (a non-significant, 5 ms 'positive' priming effect). This pattern of results shows unambiguously that the 1st trial interference effect was caused solely by competitor priming. Other experiments in the series showed that NP can be observed, but only if the stimulus set is small (e.g., just twelve pictures and words) and hence items are frequently repeated. The different results with large and small stimulus sets can be explained following Malley and Strayer (1995). In a series of standard, trial-to-trial, negative priming experiments, Malley and Strayer showed that negative priming depends on stimulus repetition. They proposed that, as the activation levels of the items increase with repeated presentation, selection difficulty also increases; only under these circumstances—viz. when the system must determine which of two highly activated prime-trial elements is the target item—is negative priming observed. Since in Experiment 5, as in the experiment outlined above, there was minimal stimulus repetition, negative priming mechanisms do not come into operation.

We can thus safely conclude that, in Experiment 5, negative priming was very unlikely to contribute to the priming effect, hence, the whole effect was due to competitor priming. Since, with congruent stimuli, competitor priming cannot generate interference at the response level—because both tasks would elicit the same response—it follows that the RT interference must be attributed to stimulus-driven priming of higher-order task elements. Stimuli can prime tasks.

10. General discussion

It is commonly accepted that a substantial component of the RT cost of a task shift (TSC) is "exogenous," that is, that it depends on triggering by an external task-stimulus (e.g., Allport et al., 1994; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995). However, there is disagreement concerning the origin of this exogenous RT cost. As outlined in Section 1, two principal types of account have been proposed. The first type assumes that the residual TSC results from additional processing demands on executive functions, to configure the cognitive system for the new task. That is, the residual TSC is assumed to reflect the time needed for an additional control operation, which takes place only on switch trials and which completes the task-set reconfiguration needed for that trial (e.g., Rogers & Monsell, 1995; Rubinstein et al., 2001). In contrast, the second type of account assumes that the exogenous switch costs result from long-term and short-term priming, arising from prior execution of the competing task: competitor priming of the now-irrelevant task, and (in certain conditions) negative priming of the now-relevant task (Allport & Wylie, 1999, 2000; Wylie & Allport, 2000). We note that, *a priori*, these two contrasting accounts of 'switching costs' are by no means mutually exclusive.

The experiments reported here document that stimulus-elicited priming from a prior, competing task can indeed have very large interference effects on the speed of response to the same stimuli, following a shift of task, and that these effects can be very long-lasting. We demonstrated that a large part of the residual switch cost, associated specifically with a shift from picture-naming to word-reading, is item-specific, depending on the prior priming history of that individual stimulus-item. Item-specific interference was also found following the reverse shift—from word-reading to picture-naming; however, in this case the interference affected all trials, both switch and non-switch, equally.

10.1. Word-reading: Item-specific priming and shift costs

We consider first the effects of a shift from picture-naming to word-reading, which is the principal focus of this paper. The item-specific interference, observed on the switch trial from picture-naming to word-reading, was replicated across all experiments. Experiment 1 showed that: (1) TSC for word-reading was much greater in response to stimuli previously presented for picture-naming (*primed* items), than for stimuli not previously presented for picture-naming (*unprimed* items);[6] (2) furthermore, this item-specific negative transfer from picture-naming to word-reading can result from a single prior trial of picture-naming in response to that item; and (3) it can take effect even after several intervening events (i.e., after further picture-naming and—more importantly—further word-reading trials). Experiment 2 showed that (4) the interference effect increased cumulatively with the number of times that an item had been presented in the competing picture-naming context.

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[6] As mentioned in the introduction, we do not know, as yet, to what extent the results reported in this study may be a feature, principally, of asymmetrical, Stroop-like task-pairs. However, as already noted, an experiment by Koch and Allport (2003) found very similar, item-specific stimulus–task priming effects—which contributed massively to switch costs—in non-Stroop tasks. These effects were observed also on response-congruent trials.

Experiments 3 and 4 showed that (3a) the interference effect remains very robust, even when subjects have performed more than 100–200 intervening trials between the priming event of picture-naming and the word-reading probe, and (5) even when the intervening trials include word-reading of the items previously primed by picture-naming. Experiment 5 confirmed that (6) interference takes place even under response-congruent conditions, suggesting that the effect is due to stimulus–task bindings rather than stimulus–response bindings. Finally, Experiment 1 replicated the finding (7) that the first trial in a run of word-reading RT trials, after a mere task interrupt, shows a substantial RT restart cost, compared to subsequent trials (cf., Allport & Wylie, 2000; Altmann & Gray, 2002; Gopher et al., 2000; Wylie & Allport, 2000).

The main points to be made here rest upon these major findings. Costs of task switching which are affected by whether or not the stimulus-item, presented on the switch trial, has previously occurred in the competing task-context suggest a rather different model of task-set, and its control, than the conventional metaphor of switching railroad tracks—or of resetting functional connections between processing modules. Suppose that task-set-reconfiguration conformed to the railroad-switching analogy: suppose, that is to say, that top-down control processes determined stimulus access to task-relevant and -irrelevant processing (and response) pathways *as a whole* (“re-tuning the input-output mappings…, so that the same type of input can be processed in the different way required by the new task “[Monsell, 1996, p. 135]). Any such global shift of connections should affect processing of *all* stimuli, regardless of whether those stimuli had occurred previously in the competing task or not. Clearly this was not the case in our experiments, even after ample time for anticipatory preparation. The railroad metaphor suggests a system that is memory-less, that is, essentially unchanged by which trains have recently passed, and how often, on which routes. It also suggests a fundamental separation between “control” (what is done by the signalman) and “processing” (the progress of the trains). Both features of the metaphor, we believe, are profoundly misleading, at least with respect to the residual TSCs our study focuses on. Current models of task-set, in general, fail to accommodate the influence of bottom-up, or stimulus-driven, constraints; and they fail to accommodate the contribution of *learning and memory*, as a major determinant of performance in attentional tasks. Indeed, most current models of attention and action control are essentially a-historical: their operations are unaffected by prior processing events. The role of item-specific cueing and priming, for example, is seldom included in models of selective attention, and equally seldom controlled for, experimentally.

The principal contribution of this paper is thus to emphasise the substantial impact that previous processing-events can have, on performance measures conventionally attributed to a-historical, memoryless control processes. Our proposals about S–R event-based learning and retrieval were outlined in Section 1. Briefly, we proposed that, in the course of each S–R event, an event file (Hommel, 1998a) is compiled, linking or binding the selected, action-relevant stimulus features with codes characterising the action that is performed. These bindings may also include the information that a distractor item is “to-be-ignored” (Neill, 1997; Neill & Valdes, 1992; Neill et al., 1992) and/or "not-to-be-reacted-upon" (Fuentes, Vivas, & Humphreys, 1999a, 1999b; Hommel, 1998a). We suppose this binding operation to be an integral process of selection-for-action. The residue of the S–R-event binding process is a memory trace, which maintains these object-task-action associations over time. Reactivation of the same stimulus-codes (or indeed the same response- or the same context-codes) can trigger involuntary retrieval of the associated components of that event, including higher-order representations (tasks). This mechanism is useful in our daily interaction with the environment, because in many cases action-relevant objects habitually require the same action-routine. In the task shifting context, however, the retrieved instances may conflict with the currently intended action. The time demand to resolve this conflict is reflected in the additional RT cost of task switching for primed items. Even if one were to call the process that resolves the conflict a "control process" (which would mean a considerable inflation of the term), its characteristics and function would be unlikely to be specific to task-switching situations.

Note that we do not deny the existence of some control operation, determining which task to perform. We only question the idea that the RT cost of task switching, and of residual TSC in particular, directly reflects an additional, on-line task-set reconfiguration process, which programs the processing system from one configuration of task readiness to another. Attention and task-set, we suggest, are more appropriately modelled in terms of partially modular, constraint-satisfaction networks (Allport, 1989; Duncan, 1999; Duncan, Humphreys, & Ward, 1997; Ward, 1999). Performance ("task readiness") in systems of this kind can be massively affected by stimulus-driven (and, of course, learning-dependent) processes, as well as by "top-down" constraints. Moreover, both types of control, we suggest, are implemented primarily by activation (and/or inhibition) of task-related structures ("schemata"?), rather than by any direct modification of their functional connections. Learning in the course of prior processing events, e.g., intentional perceptual-motor actions, is what determines functional connections.

Consistent with these suggestions is a theory put forward by Fagot (1994). The most important feature of this theory consists in a distinction between "goal-setting" and "task-readiness"—a distinction that is also emphasized in motivational approaches to human action control (e.g., Gollwitzer, 1999; Heckhausen & Gollwitzer, 1987). Goal-setting can be done in advance of an imperative task-stimulus (during the preparation interval). However, "setting the goal" merely determines which task will be performed. Goal setting need not affect the subject's behavioural readiness to perform that task, i.e., *the time the system takes* to settle to a task-relevant response. This distinction is readily captured in a distributed, constraint-satisfaction network. That is, "goal-setting" (in Fagot's terminology) corresponds to setting up a set of task-relevant contextual constraints, which bias the possible stable states to which the system is able to settle. Thus, even though these contextual task-constraints may be sufficient to determine which task will be executed, e.g., on a switch of tasks, the system can still be prone to stimulus-driven interference effects from prior, competing tasks. Hence, on word-reading switch trials, the system is constrained to perform word-reading next, but is not yet fully "ready" to do so. Accordingly, subjects suffer from interference effects, as described above, but do finally perform the correct task.

We have described these ideas, above, in terms of relatively "discrete" event files, or instances, stored in memory (cf. Hommel, 1998a; Logan, 1988). However, our account is by no means tied to discrete representations. The phenomena that we have described are equally consistent with the cumulative strengthening of S–R bindings, by means of Hebbian (or related forms of) associative learning, linking together stimulus-, task-, and action-features within a connectionist network.[7] Current constraint-satisfaction (or "integrated competition") models of attention and task-set (cf. Duncan et al., 1997; Ward, 1999), we believe, would provide a suitable framework within which to model these associative learning processes. Along these lines, Gilbert and Shallice (2002) have developed a parallel distributed processing model of task switching (taking up ideas of Cohen et al., 1990) that is able to simulate both effects of task-set inertia (Allport et al., 1994) and stimulus-specific priming of tasks (Allport & Wylie, 2000).

10.2. Picture-naming: Priming and shift costs

We now consider in more detail the effects of a task shift in the opposite direction, from word-reading to picture-naming (Word → Picture). There were at least two differences from the effects of Picture → Word shifts. First, as noted above, RT task-shift costs were consistently smaller for Word → Picture than they were for Picture → Word shifts, in all experiments. That is, a shift to the intrinsically stronger or dominant task (word-reading) incurred a larger RT cost than a shift to the weaker or non-dominant task (Stroop picture-naming). This "paradoxical" asymmetry in TSC has been found, also, for a number of other task pairings, including shifts between naming in a dominant first language and a weaker, second language (Meuter & Allport, 1999), shifts between recently practised vs. unpractised tasks (Allport & Wylie, 1999; Yeung, 1999), as well as in colour-word and picture-word Stroop tasks. However, this pattern is not always found. Monsell et al. (2000) report a number of studies of task-switching, between pairs of tasks with relatively high and low S–R compatibility, showing the opposite pattern: a larger TSC for a shift to the less compatible task. Gilbert and Shallice (2002) discuss the issue in some detail. They show that, in their model, the "paradoxical" asymmetry of TSC is obtained when the two tasks demand large differences in top-down control inputs, as in the classic Stroop tasks, to prevent catastrophic interference or capture by the dominant task, whereas the reverse pattern is obtained when the tasks differ principally in the strength of their respective S–R mappings, as with typical S–R compatibility effects.

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[7] Learning algorithms would presumably need to include "fast" weight changes, in order to accommodate one-trial learning of S–R event bindings.

Table 1
Asymmetry of switching costs for Experiments 1–4

Experiment	Primed word-reading	Unprimed word-reading
1	165**	38*
2	72*(PW4); 34(PW1)	18
3	87*(PW16); 135**(PW4)	10
4	37*	2

The table shows mean RT differences in task switching cost (switch minus repeat-trial RT) between unprimed picture-naming (PO) compared, respectively, to primed (PW) versus unprimed (WO) word-reading. The data from Experiment 3 refers to alternating cycle 1 only. In Experiment 2, task switching costs for unprimed picture-naming are in response to set F, which is comparable to sets PO in the other experiments.

* *p* value of *t* test <.05.

** *p* value of *t* test <.01.

In all the experiments, however, the asymmetry of TSC between Word and Picture tasks is largely a product of the primed stimuli. Table 1 shows this asymmetry (i.e., the difference in first trial RT costs for word-naming versus picture-naming) respectively for primed and unprimed trials. (We omitted Experiment 5, since in this experiment picture-naming was performed on incongruent stimuli, whereas word-reading was performed on congruent stimuli). Admittedly, since the present study focused on shifts from picture-naming to word-reading, the two tasks differed in several ways in all reported experiments. Thus, they are not designed to allow the comparison between picture-naming and word-reading switch costs. Nonetheless, we believe that the results summarised in Table 1 are of interest, and point to an hypothesis to be addressed in future experiments, with more appropriate designs. In all experiments, the asymmetry of TSC was greatly reduced, or even eliminated, when the responses to unprimed stimuli alone are compared. Thus, the asymmetry appears to be due—primarily, if not entirely—to the item-specific component of the task-switching costs.

Experiment 1 illustrates a second, rather striking contrast between the Picture and Word tasks. In the word-reading task, item-specific priming was confined entirely to switch trials, and hence contributes a large component of the so-called switch cost. In contrast, in the picture-naming task, primed stimulus items showed an RT cost on repeat trials as well as switch trials, with no hint of any reduction in the priming effect over trials 2 and 3 (see Fig. 3). Hence, for picture-naming, item-specific priming does not appear to contribute to the estimated switch cost. The other experiments reported here did not include item priming from Word to Picture tasks, so that this pattern could not be observed. However, we have replicated this finding in a number of further, unpublished studies: item-specific priming effects were consistently present on non-switch trials, as well as on the switch trial, when shifting from Stroop word-reading to picture-naming. How is this difference between the Stroop word and picture tasks to be explained?

The answer, we suggest, is intimately connected with the contrasting characteristics of these two tasks. In the case of the related, and more widely studied, Colour-Word version of the Stroop tasks, (Stroop, 1935), an extensive literature supports the idea that the Word task (Stroop word-reading) is the stronger task—its underlying S–R pathway is stronger—than the complementary Colour task (Stroop colour-naming). This claim is based on three main findings (see MacLeod, 1991, for a review). First, the Word task is typically much faster than the Colour task. Second, colour-naming shows interference from an incongruent word stimulus, but—in normal conditions—word-reading shows no interference from an incongruent ink-colour (MacLeod, 1991). Glaser and Duengelhoff (1984), and Lupker and Katz (1981), demonstrated that similar RT differences, and the same strong asymmetry of interference, are found also in the Picture-Word version of the Stroop naming tasks, as used here. Third, MacLeod and Dunbar (1988) showed that the dominance relations between two tasks is strongly affected by the amount of practice subjects receive on the respective tasks. They inferred that differences in the relative strengths of competing S–R pathways (arising, in their experiment, as a result of differential amounts of practice) were sufficient to account for the effective dominance of one or other task, and the resulting asymmetry of interference, as in the classic Colour-Word and Picture-Word Stroop tasks.[8]

However, a major asymmetry in the relative strength of the two tasks means that, in order for the weaker task (here, picture-naming) to be successfully executed at all, in response to incongruent (Stroop) stimuli, a strong top-down bias is needed, favouring the weaker task. For the Picture task, this bias will be needed on non-switch trials as well as on switch trials (and also in pure task performance). However, even in pure task conditions, the top-down bias in favour of the picture-naming task is insufficient to prevent interference (response conflict) by an incongruent word. The interference will be even stronger if the stimulus has been primed in the competing task context. Thus, in Stroop picture-naming, item-specific priming effects will be found on non-switch as well as on switch trials, as we have observed. Gilbert and Shallice's model also simulates this pattern of results (Gilbert, personal communication). In contrast, the dominant (Word) task can be executed, even in response to incongruent stimuli, with little or no top-down bias, although its speed of performance (in response to both neutral and incongruent stimuli) can be affected (cf. Cohen et al., 1990, Simulation 6). The Word task is liable to interference from the presence of an incongruent picture only on a switch trial—and even more strongly if the stimulus has been

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[8] This by no means implies that the Colour and Word tasks—or indeed the Picture and Word tasks—differ only in their relative degree of practice, having, in all other respects, equivalent architectures (see, e.g., Cohen, Usher, & McClelland, 1998; Glaser & Glaser, 1989; Kanne, Balota, Spieler, & Faust, 1998; Schriefers, Meyer, & Levelt, 1990, for discussion.) The "strength" of a given S–R pathway can depend on differences in functional architecture, in the systematicity or arbitrariness of the mappings, etc., as well as in amount of practice.

primed in the competing picture-naming task. According to the TSI model, this is because, on a switch from picture-naming to word-reading, the persisting trial-to-trial TSI keeps the picture-naming task-set activated, and the word-reading task-set inhibited. In this respect, on word-reading switch trials, when task activation is weak, subjects are more or less in the same state as in all picture-naming trials, viz. in a state in which they suffer Stroop interference—or, in the case of word-reading, "reverse" Stroop interference.

10.3. Open issues

Two questions not yet addressed should be emphasised here. First, we suppose that the remaining RT switching cost in word-reading, in response to *unprimed* stimuli, can also be attributed—in part, at least—to stimulus-driven interference from previously established processing demands. Note that, in the experiments reported here, subjects did not merely "name pictures"; they did so in response to a specific type of stimulus (picture-word Stroop stimuli), all of which shared a range of very similar attributes. The stimuli all appeared in the same location on the same monitor screen; they were all approximately the same size, with the same line-thickness, colour, and general appearance; and all represented (or were the names of) familiar objects. As stated in Section 1, we suppose that associative bindings are formed between all the encoded constituents of the given action-event, including perceptual, semantic, and contextual features. Thus, stimuli not previously presented for picture-naming may also elicit retrieval of the competing task, to the extent that their perceptual, semantic, and/or contextual encoding overlaps with other stimulus items presented in the competing task context, through basic "stimulus generalisation." Moreover, we assume that task-set inertia from the immediately preceding trial, independent of any item-specific effects, also contributes to the "unprimed" switch costs. The origin of the switch costs, observed with unprimed stimuli, will be discussed in more detail elsewhere (Waszak, Hommel, & Allport, in preparation).

Another possible mechanism contributing to the residual shift costs is "backward inhibition" (Mayr & Keele, 2000). Backward inhibition refers to the idea that disengaging from a given task-set results in that task-set being inhibited (another kind of long-term "task-set inertia"). When subjects have to shift back again to a task from which they recently disengaged (as is typically the case in task-switching experiments), the task suffers residual inhibition, and RTs are prolonged. We note, however, that the item-specific interference, reported above, could not be interpreted in terms of "long-term backward inhibition." Experiment 1 showed that the item-specific priming effect was independent of whether the primed item had been presented previously on a 1st, 2nd, or 3rd trial of picture-naming. If backward inhibition was responsible for the item-specific interference effect, only items occurring at the end of a run of picture-naming, and thus associated with disengagement from picture-naming, (i.e., 3rd trial items) should yield the effect.

Second, as outlined in Section 1, several authors have reported a "restart effect" in a run of RT trials, after a brief task-interrupt but no shift of task (Allport & Wylie, 2000; Gopher et al., 2000). We replicated this "restart" effect in Experiment 1, but failed to find it reliably in Experiment 2. Stressing the behavioural similarity to the TSC effect, Allport and Wylie (2000) suggested that RT switch costs and restart costs may generally be due to the same kind of mechanism, i.e., that costs on a "switch" trial may be a special case of a much more general phenomenon triggered by the onset of a new run of trials. Clearly, "restart" effects are an interesting and potentially important phenomenon; however, they were not the focus of this paper, and it remains to be clarified how "restart" and "switch" costs are related.

Many open questions remain, also, regarding the detailed mechanisms of S–R event-based priming. We have evidence, so far, only that some attributes of an S–R processing episode can be maintained—over remarkably long intervals—bound together in something like an event file or instance, including highly specific stimulus information and also *task*- or process-dependent operations. We do not know to what extent these S–R event-based memory traces should be thought of as wholly procedural, rather than 'declarative'; whether they can encompass much larger-scale action-episodes; nor whether they include representation of other, purely contextual information (cf., Hommel, 2003). More sophisticated experiments are needed to elucidate these questions. It is possible, however, that task-switching paradigms may offer particularly favourable conditions in which these questions can be investigated.

10.4. Conclusions

The central finding of this study is that subjects' performance in task switching was impaired, in response to stimuli which previously occurred in the competing task context, even when the delay between the two occurrences was very long. On a switch from Stroop picture-naming to word-reading, such item-specific interference resulted in hugely increased "switching costs." This finding challenges the widespread assumption that RT differences between "switch" and "repeat" trials, in general, reflect control operations to alter "task readiness" (e.g., De Jong, 2000; Rogers & Monsell, 1995; Rubinstein et al., 2001). We suggested, instead, that this large component of the observed RT switching costs was due to retrieval-based interference from previously acquired, event-based learning in the competing task context. We note two important qualifications. While re-presentation of the same items in both tasks had effects on both word-reading and picture-naming, only word-reading "switching costs" were increased. By contrast, in picture-naming, both switch and repeat trials were affected equally. Second, as already noted, an important question to be explored is the extent to which the results reported in this study are found predominantly in asymmetrical, Stroop-like tasks, and which of these two patterns of results, above, will be found most often with other pairs of tasks.

Appendix A

Stimulus-sets (English translations of German terms) in Experiments 1–5. The entries denote to which stimulus subset the given picture-word conjunction belonged (Experiments 1–4). With respect to Experiment 5, the entries refer to the picture, which—in this experiment—were also represented as words. "C" refers to the catch stimuli used in Experiment 5.

Picture	Word	Experiment			Picture	Word	Experiment			Picture	Word	Experiment		
		1, 4	2, 3	5			1, 4	2, 3	5			1, 4	2, 3	5
cap	scarf	1	1	1	bear	bull	2	2	2	arm	knee	3		1
coat	belt	1	1	1	cat	monkey	2	2	2	ear	mouth	3	1	1
dress	tailcoat	1	1	1	cow	elk	2	2	2	eye	chin	3	1	1
hat	umbrella	1	1	1	dog	goat	2	2	2	finger	tooth	3	1	1
pants	boot	1	1	1	donkey	deer	2	2	2	foot	throat	3	1	1
shirt	tie	1	1	1	fox	panther	2	2	2	hand	heel	3	1	1
shoe	helmet	1	1	1	horse	llama	2	2	2	nose	tongue	3	1	1
skirt	blouse	1	1	1	lion	wolf	2	2	2	leg	thumb	3	1	1
vest	sock	1		1	mouse	toad	2	2	2	barrel	chest	3	3	
airplane	boat	1	4	3	rabbit	rat	2	2	2	bottle	tube	3	3	
bicycle	coach	1	4	3	sheep	camel	2	2	2	bowl	trough	3	3	c
wheel	axle	1	4		tiger	pig	2	2	2	cup	tin	3	3	
bus	tank	1	4	3	zebra	bison	2	2	2	glass	pot	3	3	
car	dredger	1	4	3	apple	peach	2	1		pitcher	bucket	3	3	
train	tractor	1	4	3	cherry	plum	2	1		suitcase	bag	3	3	
barn	castle	1	4	3	pear	grapes	2	1		vase	mug	3	3	
church	factory	1	4	3	bee	midge	2	2	2	bed	locker	3	4	3
house	palace	1	4	3	beetle	worm	2	2	2	chair	divan	3	4	3
door	wall	1	4	3	fly	caterpillar	2			couch	coffer	3	4	3
window	balcony	1	4	3	spider	flea	2	2	2	stool	armchair	3	4	3
axe	spade	1			chicken	dove	2		2	table	shelf	3	4	3
hammer	pliers	1	3		duck	gull	2	2	2	pencil	pen	3	3	
nail	rasp	1			ostrich	blackbird	2	2	2	crown	sceptre	3	4	c
brush	spatula	1			owl	raven	2	2	2	harp	piano	3	3	c
saw	plane	1	3		rooster	woodpecker	2	2		violin	cello	3		
screw	drill	1	3		swan	goose	2	2	2	bell	bracket	3	3	
button	twine	1	3		peacock	titmouse	2	2		fork	plate	3	3	

Appendix A (*continued*)

Picture	Word	Experiment			Picture	Word	Experiment			Picture	Word	Experiment		
		1, 4	2, 3	5			1, 4	2, 3	5			1, 4	2, 3	5
needle	scissors	1			mountain	cliff	2	2		frying pan	oven	3	3	
candle	torch	1	4		sun	moon	2	1		spoon	scoop	3	3	
lamp	traffic light	1			asparagus	bonk	2			toaster	mixer	3	3	
fence	lattice	1	4	c	mushroom	peach	2	1		bread	soup	3	3	
glasses	loop	1		c	onion	bean	2	1		cake	cracker	3	3	
ring	bracelet	1	3	c	flower	grass	2	1	c	basket	backpack	3	4	
well	pond	1	4		tree	cactus	2	1		clock	balance	3	4	
book	journal	1	3		lobster	cancer	2	2		ladder	stair	3	4	
chain	rope	1	4		leaf	thorns	2	1		broom	shovel	3	3	
glove				1	belt				1	apple	pepper			c
bone				1	tie				1	pear	date			c
tooth				1	sock				1	violin	drums			c
eagle				2	umbrella				1	cherry	bean			c
iglu				3	monkey				2	sun	cloud			c
tent				3	caterpillar				2	lamp	shelf			c
carpet				3	boat				3	mountain	sea			c
canoe				3	tractor				3	bottle	cup			c
mill				3	locker				3	flute	tube			c
					oven				3					

References

Ach, N. (1910). *Über den Willensakt und das Temperament* (*On temperament and the act of will*). Leipzig: Quelle & Meyer.

Allport, A. (1989). Visual attention. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 631–682). Cambridge, MA: MIT Press.

Allport, A. (1987). Selection for action: Some behaviorial and neurophysiological considerations of attention and action. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 395–419). Hillsdale, NJ: Lawrence Erlbaum.

Allport, A., & Hsieh, S. (2001). Task-Switching: Using RSVP methods to study an experimenter-cued shift of set. In K. Shapiro (Ed.), *The limits of attention: Temporal constraints on human information processing*. Oxford: Oxford University Press.

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Attention and performance 15: Conscious and nonconscious information processing* (pp. 421–452). Cambridge, MA: MIT Press.

Allport, A., & Wylie, G. (1999). Task-switching: Positive and negative priming of task-set. In G. W. Humphreys, J. Duncan, & A. M. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 273–296). Oxford: Oxford University Press.

Allport, A., & Wylie, G. (2000). 'Task-switching', stimulus–response bindings and negative priming. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 35–70). Cambridge, MA: MIT Press.

Altmann, E. M., & Gray, W. D. (2002). Forgetting to remember: The functional relationship of decay and interference. *Psychological Science, 13*, 27–33.

Barsalou, L. W. (1990). On the indistinguishability of exemplar memory and abstraction in category representation. In T. K. Srull, & R. S. Wyer (Eds.), *Advances in social cognition*: Vol. 3. *Content and process specificity in the effects of prior experiences* (pp. 61–88). Hillsdale, NJ: Lawrence Erlbaum.

Burnage, G. (1990). *Celex: A guide for users*. Nijmegen, the Netherlands: SSN.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97*, 332–361.

Cohen, J. D., Usher, M., & McClelland, J. L. (1998). A PDP approach to set size effects within the Stroop task: Reply to Kanne, Balota, Spieler, and Faust. *Psychological Review, 105*, 188–194.

Cohen, R., & Rist, F. (1992). The Modality Shift Effect: Further explorations at the crossroads. In D. Friedman & G. E. Bruder (Eds.), *Annals of the New York Academy of Sciences*: Vol. 658. *Psychophysiology and experimental psychopathology: A tribute to Samuel Sutton* (pp. 163–181). New York: New York Academy of Sciences.

Crowder, R. G. (1993). Systems and principles in memory theory: Another critique of pure memory. In A. F. Collins & S. E. Gathercole (Eds.), *Theories of memory* (pp. 139–161). Hove, UK: Lawrence Erlbaum.

Danzinger, S., & Robertson, L. C. (1994). *Repetition effects of response irrelevant features*. Paper presented at the 35th annual meeting of the Psychonomic Society, St. Louis.

De Jong, R. (2000). An intention-activation account of residual switch costs. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 357–376). Cambridge, MA: MIT Press.

DeSchepper, B., & Treisman, A. (1996). Visual memory for novel shapes: Implicit coding without attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 27–47.

Duncan, J. (1986). Disorganisation of behaviour after frontal lobe damage. *Cognitive Neuropsychology, 3*, 271–290.

Duncan, J. (1999). Converging levels of analysis in the cognitive neuroscience of visual attention. In G. W. Humphreys, J. Duncan, & A. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 112–129). Oxford: Oxford University Press.

Duncan, J., Humphreys, G., & Ward, R. (1997). Competitive brain activity in visual attention. *Current Opinion in Neurobiology, 7*, 255–261.

Fagot, C. (1994). *Chronometric investigation of task switching*. Unpublished doctoral thesis, University of California, San Diego.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review, 2*, 145–173.

Fuentes, L. J., Vivas, A. B., & Humphreys, G. W. (1999a). Inhibitory tagging of stimulus properties in inhibition of return: Effects on semantic priming and flanker interference. *Quarterly Journal of Experimental Psychology, 52A*, 149–164.

Fuentes, L. J., Vivas, A. B., & Humphreys, G. W. (1999b). Inhibitory mechanisms of attentional networks: Spatial and semantic inhibitory processing. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1114–1126.

Gilbert, S. J., & Shallice, T. (2002). Task switching: A PDP model. *Cognitive Psychology, 44*(3), 297–337.

Glaser, W. R., & Duengelhoff, F.-J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception and Performance, 10*(5), 640–654.

Glaser, W. R., & Glaser, M. O. (1989). Context effects in Stroop-like word and picture processing. *Journal of Experimental Psychology: General, 118*, 13–42.

Gollwitzer, P. M. (1999). Implementation intentions: Strong effects of simple plans. *American Psychologist, 54*, 493–503.

Gopher, D., Armony, L., & Greenshpan, Y. (2000). Switching tasks and attention policies. *Journal of Experimental Psychology: General, 129*, 308–339.

Goschke, T. (2000). Intentional reconfiguration and involuntary persistence in task set switching. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 331–355). Cambridge, MA: MIT Press.

Grant, S. C., & Logan, G. D. (1993). The loss of repetition priming and automaticity over time as a function of degree of initial learning. *Memory & Cognition, 21*(5), 611–618.

Hanewinkel, R., & Ferstl, R. (1996). Effects of modality shift and motor response shift on simple reaction time in schizophrenia patients. *Journal of Abnormal Psychology, 105*, 459–463.

Heckhausen, H., & Gollwitzer, P. M. (1987). Thought content and cognitive functioning in motivational versus volitional states of mind. *Motivation and Emotion, 11*, 101–120.

Hintzman, D. L. (1976). Repetition and memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 10, pp. 47–91). San Diego, CA: Academic Press.

Hintzman, D. L. (1986). "Schema abstraction" in a multiple-trace model. *Psychological Review, 93*, 411–428.

Hommel, B. (1998a). Event files: Evidence for automatic integration of stimulus–response episodes. *Visual Cognition, 5*, 183–216.

Hommel, B. (1998b). Automatic stimulus–response translation in dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1368–1384.

Hommel, B. (2000). Intentional control of automatic stimulus–response translation. In Y. Rossetti & A. Revonsuo (Eds.), *Interaction between dissociable conscious and nonconscious processes* (pp. 223–244). Amsterdam: John Benjamins Publishing Company.

Hommel, B. (2003). *Feature integration across perception and action: Event files affect response choice.* Manuscript submitted for publication.

Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 53–112). San Diego, CA: Academic Press.

Jacoby, L. L., Baker, J. G., & Brooks, L. R. (1989). Episodic effects on picture identification: Implications for theories of concept learning and theories of memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*, 275–281.

Jacoby, L. L., & Brooks, L. R. (1984). Nonanalytic cognition: Memory, perception, and concept learning. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 18, pp. 1–47). San Diego, CA: Academic Press.

Jersild, A. T. (1927). Mental set and shift. *Archives of Psychology*, Whole No. 89.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24*, 175–219.

Kanne, S. M., Balota, D. A., Spieler, D. H., & Faust, M. E. (1998). Explorations of Cohen, Dunbar, and McClelland's (1990) connectionist model of Stroop performance. *Psychological Review, 105*, 174–187.

Koch, I., & Allport, A. (2003). Cue-based and stimulus-based priming of tasks in task switching. Manuscript submitted for publication.

La Heij, W. (1988). Components of Stroop-like interference in picture naming. *Memory & Cognition, 16*, 400–410.

Lhermitte, F. (1983). 'Utilisation Behaviour' and its relation to lesions of the frontal lobes. *Brain, 106*, 237–255.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95*, 492–527.

Logan, G. D., & Compton, B. J. (1998). Attention and automaticity. In R. D. Wright (Ed.), *Vancouver studies in cognitive science*: Vol. 8. *Visual attention* (pp. 108–131). New York: Oxford University Press.

Logan, G. D., & Etherton, J. L. (1994). What is learned during automatization? The role of attention in constructing an instance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 1022–1050.

Lowe, D. (1998). Long-term positive and negative identity priming: Evidence for episodic retrieval. *Memory & Cognition, 26*, 435–443.

Luck, S. J., & Beach, N. J. (1998). Visual attention and the binding problem: A neurological perspective. In R. D. Wright (Ed.), *Vancouver studies in cognitive science*: Vol. 8. *Visual attention* (pp. 455–478). New York: Oxford University Press.

Lupker, S. J. (1979). The semantic nature of response competition in the picture-word interference task. *Memory & Cognition, 7*, 485–495.

Lupker, S. J., & Katz, A. N. (1981). Input, decision, and response factors in picture-word interference. *Journal of Experimental Psychology: Human Learning and Memory, 7*, 269–282.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163–203.

MacLeod, C. M., & Dunbar, K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14*, 126–135.

Malley, G. B., & Strayer, D. L. (1995). Effect of stimulus repetition on positive and negative identity priming. *Perception & Psychophysics, 57*, 657–667.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118*, 35–54.

Mayr, U., & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129*, 4–26.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1423–1442.

Meiran, N. (2000). Modeling cognitive control in task-switching. *Psychological Research, 63*, 234–249.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41*, 211–253.

Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language, 40*, 25–40.

Milliken, B., Tipper, S. P., & Weaver, B. (1994). Negative priming in a spatial localization task: Feature mismatch and inhibition of distractor location. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 624–646.

Monsell, S. (1996). Control of mental processes. In V. Bruce (Ed.), *Unsolved mysteries of the mind: Tutorial essays in cognition* (pp. 93–148). Hove, UK: Erlbaum (UK) Taylor & Francis Publishers.

Monsell, S., Yeung, N., & Azuma, R. (2000). Reconfiguration of task-set: Is it easier to switch to the weaker task? *Psychological Research, 63*, 250–264.

Neill, W. T. (1977). Inhibitory and facilitatory processes in selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 444–450.

Neill, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 1291–3105.

Neill, W. T., & Valdes, L. A. (1992). Persistence of negative priming: Steady state or decay. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 565–576.

Neill, W. T., Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 993–1000.

Neumann, E., & DeSchepper, B. G. (1991). Costs and benefits of target activation and distractor inhibition in selective attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 1136–1145.

Neumann, E., & DeSchepper, B. G. (1992). An inhibition-based fan effect: Evidence for an active suppression mechanism in selective attention. *Canadian Journal of Psychology, 46*, 1–40.

Rist, F., & Thurm, I. (1984). Effects of intramodal and crossmodal stimulus diversity on the reaction time of chronic schizophrenics. *Journal of Abnormal Psychology, 93*, 331–338.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.

Rubinstein, J., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 763–797.

Schriefers, H., Meyer, A. S., & Levelt, W. J. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language, 29*, 86–102.

Shallice, T. (1988). *From neuropsychology to mental structure*. New York, NY: Cambridge University Press.

Shallice, T., & Burgess, P. (1991). Higher-order cognitive impairments and frontal lobe lesions in man. In H. S. Levin & H. M. Eisenberg (Eds.), *Frontal lobe function and dysfunction* (pp. 125–138). New York, NY: Oxford University Press.

Shallice, T., Burgess, P. W., Schon, F., & Baxter, D. M. (1989). The origins of utilization behavior. *Brain, 112*, 1587–1598.

Singer, W., & Gray, C. M. (1995). Visual feature integration and the temporal correlation hypothesis. *Annual Review of Neuroscience, 18*, 555–586.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 174–215.

Spector, A., & Biedermann, I. (1976). Mental set and mental shift revisited. *American Journal of Psychology, 89*, 669–679.

Stoet, G., & Hommel, B. (1999). Action planning and the temporal binding of response codes. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1625–1640.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662.

Sutton, S., Hakerem, G., Zubin, J., & Portnoy, M. (1961). The effect of shift of sensory modality on serial reaction-time: A comparison of schizophrenics and normals. *American Journal of Psychology, 74*, 224–232.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: A Human Experimental Psychology, 37A*, 571–590.

Tipper, S. P., & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology, 37A*, 591–611.

Tipper, S. P., Weaver, B., Cameron, S., Brehaut, J. C., & Bastedo, J. (1991). Inhibitory mechanisms of attention in identification and localization tasks: Time course and disruption. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 681–692.

Treisman, A. (1992). Perceiving and re-perceiving objects. *American Psychologist, 47*, 862–875.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Ward, R. (1999). Interactions between perception and action systems: A model for selective action. In G. W. Humphreys, J. Duncan, & A. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 311–332). Oxford: Oxford University Press.

Waszak, F., Hommel, B., & Allport, A. (2003). *Episodic S–R bindings in task-shift costs: The role of competitor and negative priming*. Manuscript submitted for publication.

Waszak, F., Hommel, B., & Allport, A. (in preparation). *The role of semantic priming in task-switching*.

Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs". *Psychological Research, 63*, 212–233.

Yeung, N. P. (1999). *Switching between simple cognitive tasks: Interactions between executive control and task properties*. Cambridge, England: University of Cambridge.