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Reconfiguration of Stimulus Task Sets and Response Task Sets during Task Switching

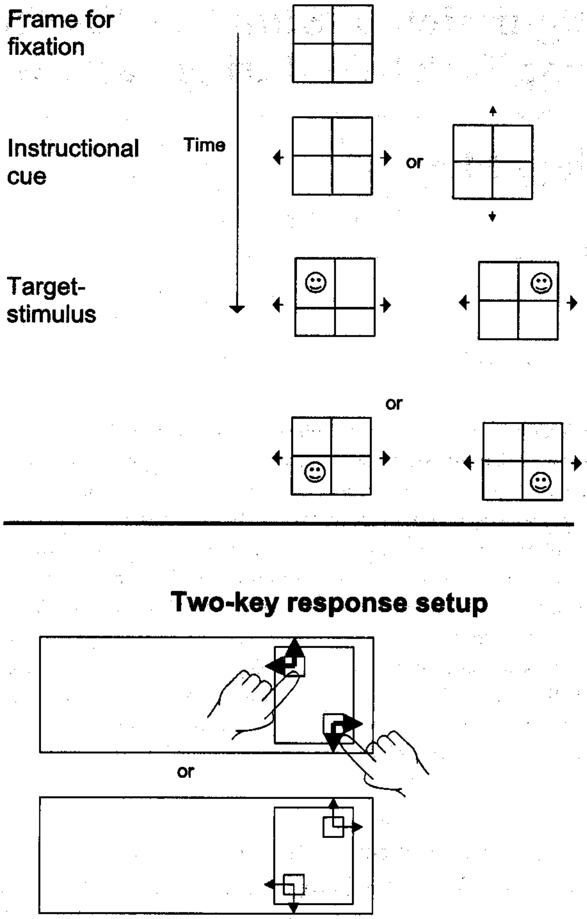
Nachshon Meiran

ABSTRACT A tentative model of task switching was tested in two experiments. The model accounts for the switching costs observed in previous experiments by attributing them to multivalent task elements, in the present paradigm bivalent stimuli (relevant for both tasks) and bivalent responses (used in both tasks). It assumes that stimulus task sets enable nearly univalent mental representations of bivalent stimuli, and that response task sets enable nearly univalent mental representations of bivalent responses. Results support two novel predictions of the model: (1) the residual switching cost is substantial with bivalent responses, but negligible with univalent responses; and (2) the preparatory cost is substantial when bivalent target stimuli follow bivalent stimuli, but negligible when either the current target stimulus or the previous one is univalent. Hence there is an approximate one-to-one mapping between preparatory cost and reconfiguration of stimulus task set, on the one hand, and between residual switching cost and reconfiguration of response task set, on the other.

Despite its obvious importance to the study of cognitive control, task switching was barely studied until recently. Furthermore, what used to be the dominant experimental paradigm (i.e., Jersild 1927) suffers from serious shortcomings (see Pashler, chap. 12, this volume), limiting the usefulness of most previous results. Although two better-controlled paradigms were developed, the alternating-runs paradigm (Fagot 1994; Rogers 1993; Rogers and Monsell 1995; Stablum et al. 1994) and the cuing paradigm (e.g., De Jong 1995; Meiran 1996; Shaffer 1965; see also Sudevan and Taylor 1987), extensive work with these paradigms is so recent that our understanding of the phenomena remains rudimentary, and models based on them should be regarded as first approximations. The present chapter introduces such a model, which accounts successfully for previous results and two of whose novel predictions were tested in two experiments.

16.1 THE EXPERIMENTAL PARADIGM

Two and sometimes more different tasks were performed over a long series of trials; in most of the experiments, the tasks required locating a target stimulus within a 2×2 grid (figure 16.1). Subjects were instructed to indicate either the vertical position (the *up-down* task) or the horizon-



Two-key response setup

Figure 16.1 Experimental paradigm.

tal position of the target stimulus (the *right-left* task). Two keys were used to indicate the four possible nominal responses. For example, the upper left key indicated either *up* or *left*, depending on the task, while the lower right key indicated *down* or *right*.

This paradigm had several critical features:

1. The tasks were of similar difficulty level. This creates a relatively simple experimental situation by avoiding strategies such as being preferentially prepared for more difficult tasks (e.g., De Jong 1995).

2. The tasks varied randomly from trial to trial. Hence the subjects needed to be instructed on each trial which task to perform, and the effect of switching tasks was estimated by comparing performance on *switch trials*, where the task was different from that on the previous trial, to performance on *nonswitch* trials, where the task was the same.

3. In most instances, the instructional cues were uninformative with respect to which of the two responses would be required on the upcom-

ing trial, which target stimulus would be presented, or when exactly the target onset would occur.

4. With the two-key response setup (figure 16.1), some trials were *congruent,* where the same keypress was appropriate whichever task was being performed (e.g., the correct response to the upper left target stimulus was indicated by pressing the upper left key for both the up-down and the right-left tasks). Other trials were *incongruent,* where different keypresses were appropriate for different tasks (e.g., the correct response to the upper right target stimulus was indicated by pressing the upper left key in the up-down task, where it indicated *up,* and the lower right key in the *right-left* task, where it indicated *right*).

5. The use of instructional cues allowed control over two intervals: the *cue-target interval* (CTI), the time allowed for any preparation for the task; and the *response-cue interval* (RCI), the time during which the subject waited for the instructional cue for the next trial.

Because the trials were ordered randomly, subjects were unlikely to prepare for a switch during the RCI. In fact, the results for switching costs were virtually unaffected by a manipulation in which task repetitions exceeded task switches by a ratio of 2 : 1. The manipulation presumably discouraged attempts to prepare for a task switch during the RCI (Meiran, Chorev, and Sapir forthcoming). A third interval, the *response-target interval* (RTI), is simply the sum of RCI and CTI.

Because of its ability to manipulate CTI and RCI, the cuing paradigm offers an advantage over the alternating-runs paradigm (Rogers and Monsell 1995), where the point in time when task preparation begins is not as tightly controlled.

Previous Results

Components of Task-Switching Cost Probably the most prominent finding in previous studies is that task switching is associated with a reaction time (RT) cost (switch RT > nonswitch RT). The present chapter concerns the trial-by-trial switching costs revealed in the alternating-runs and the cuing paradigms. (For a comparison between nonswitch trials from a task alternation block and pure task blocks, see, for example, Fagot 1994; Kray and Lindenberger forthcoming; Mayr and Liebscher forthcoming.)

Manipulating the CTI and RCI reveals three components of the trial-by-trial task-switching cost. Relevant results from two illustrative experiments (Meiran, Chorev, and Sapir forthcoming) are presented in figure 16.2.

The abscissa in figure 16.2 is the response-target interval, allowing the presentation of the two experiments on the same graph. In our first experiment, the RCI was manipulated, and the CTI was fixed at 117 msec, a

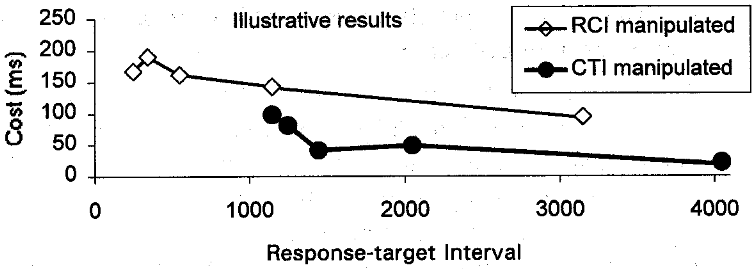


Figure 16.2 Illustrative results from Meiran et al. forthcoming. CTI = cue-target interval; RCI = response-cue interval.

period presumably sufficient for cue encoding but not for task preparation.[1] We found that the task-switching cost first increased and then declined as the RCI increased. The rate of decline was initially fast, but slowed when the RCI exceeded 0.5–1 sec. In our second experiment, the RCI was fixed at 1,016 msec (the time at which the decline in switching cost associated with an increase in the RCI becomes slow), and the CTI was manipulated. The results indicate a sharp decline in the task-switching cost following the presentation of the instructional cue, as the CTI increased. Based on the results of our first experiment, we know that the decline in the cost in our second experiment could not be attributed to the increased remoteness from the previous response, hence must be attributed to processes evoked by the instructional cue. As can be seen in figure 16.2, even when the CTI was relatively long, switching tasks was still associated with a small cost. On the basis of these results and suggestions by Fagot (1994) and Rogers and Monsell (1995), we argued that the task-switching cost has components, of which we identify three: (1) a *waiting component*, related to the effects of the RCI on the cost; (2) a *preparatory component*, related to the effects of CTI on the cost; and (3) a *residual component*, reflecting a portion of the task-switching cost that seems relatively resistant to increases of either interval.

Residual Costs De Jong (chap. 15, this volume) argues that the residual cost reflects a failure to take advantage of the advance information provided in the cue, possibly because of lack of motivation. He proposes that the residual cost results from a mixture of two types of trials: some associated with complete preparation, and others where no preparation took place. Although I believe that motivation may influence the size of the residual cost, it seems that under specific circumstances and without extensive practice, subjects are faced with a genuine limitation in their ability to be fully prepared for task switching. Furthermore, this limitation does not necessarily reflect a lack of motivation to prepare. For example, in previous work (Meiran 1996, exp. 3) two groups of subjects were compared. In the first group, for whom 80% of the trials were incongruent, subjects must have processed the instructional cues to have reached a reasonable error rate. In the second group, for whom 80% of the trials were congruent, subjects could have ignored the instructional cues and still have made only 10% errors. Presumably, the subjects in the first group were more strongly motivated to pay attention to the instructional cues than the subjects in the second group. Nonetheless, the findings indicated a significantly *larger* residual cost in the first ("motivated") condition than in the second ("less motivated") condition—just the opposite to what De Jong's model would have predicted. Furthermore, as explained in "General Discussion" (section 16.3), De Jong's model, at least in its purest form, cannot explain the present results concerning residual costs.

Empirical Dissociations The argument that the trial-by-trial switching costs comprise three components is not merely a summary of the results. It is based on empirical dissociations, suggesting that the components reflect different underlying processes.

Empirical dissociations are indicated when variables selectively affect one component but not another. We found, for example, that the time spent on task reduced the size of the preparatory component of the task-switching cost but affected neither the residual component (Meiran 1996; Meiran, Chorev, and Sapir forthcoming) nor the waiting component of switching cost (Meiran, Chorev, and Sapir forthcoming). Old age (Meiran, Gotler, and Perlman, forthcoming) did not affect the preparatory component of the cost (see also Hartley, Kieley, and Slabach 1990; Kray and Lindenberger, forthcoming; Mayr and Liebscher, forthcoming) but did affect the waiting component. With young and elderly subjects alike, an increase in the RCI led to an initial rise in the switching cost, followed by a gradual decline. On the other hand, the initial rise in the cost among the elderly subjects came later and the rate of the subsequent decline in the cost was slower than among the young. We (Chorev and Meiran 1998) also manipulated phasic alertness by presenting an uninformative highlighted grid before presenting the instructional cue or the target stimulus. In both instances, this alerting manipulation led to faster and more accurate responses, as would be expected from the literature (e.g., Posner and Boies 1971). Interestingly, alertness did not modulate the effect of CTI on the switching cost, although it reduced the residual cost.[2] Finally, in most of the experiments in our lab, congruency affected the residual component of the cost (larger when incongruent), but did not affect the preparatory component of the cost (e.g., Meiran 1996; see also Rogers and Monsell 1995 for a similar effect). The results to be presented in the present chapter constitute additional empirical dissociations.

A Processing Model

Although empirical dissociations strongly suggest that different underlying processes are responsible for the three components of task-switching costs, they do not indicate what these processes might be. The present model describes the underlying processes. I shall outline the model informally (for a formal mathematical description, see Meiran forthcoming). The model has five free parameters, and was fit to explain results from an experiment including 24 conditions, yielding $R = 0.994$ between the predicted mean RT for a given condition and the observed mean RT for that condition. The 24 conditions resulted from orthogonal manipulation of congruency (2), task switch (2), response repetition (2), and CTI (3).

In line with Allport, Styles, and Hsieh 1994 and Rogers and Monsell 1995, our proposed model assumes that task sets have several facets. What is novel about the model, however, is the explicit claim that the various facets of a task set are reconfigured independently of one another, and, under specific constraints, are adopted at specified (and different) points in time. In other words, the model holds that task set reconfiguration cannot be identified with the activation of a unitary algorithm (Dixon 1981) or schema (Norman and Shallice 1986). Moreover, it makes three other critical assumptions.

First, it assumes that task-switching costs arise because the target stimuli, the responses, and possibly other task facets are multivalent with respect to the tasks at hand. In the two experiments to be presented, the target stimuli were bivalent because they had values associated with responses in both tasks. Similarly, the responses were bivalent because they signaled two different properties of the stimulus.

Thus, to execute the correct task, subjects need to recruit task sets, which enable a nearly univalent mental representation of the target stimuli, the responses, or both. *Stimulus task sets* control the representation of the target stimuli, so that the relevant stimulus dimension is emphasized relative to the irrelevant dimension. Similarly, *response task sets* control the representation of the available responses. The suppression of irrelevant information, the activation of relevant information, or both may achieve selective representation.

Second, our model assumes that task-switching costs arise because task sets maintain their configuration until the next trial. This causes interference if the next trial involves a task switch, and hence requires a different configuration of these sets (cf. Allport, Styles, and Hsieh 1994; Allport and Wylie, chap. 2, this volume). Furthermore, if subjects are prewarned of a task switch, some reconfiguration can take place before task execution proper, which results in less interference and smaller task-switching cost.

And third, our model assumes that the stimulus task set can be adopted relatively quickly and efficiently, and hence is usually the one to be reconfigured before task execution proper, that is, during the CTI. In contrast, the response task set is adopted relatively slowly and inflexibly, and hence its reconfiguration is usually completed only *after* responding.

The assumptions listed above lead to an approximate one-to-one mapping between cognitive processes and two of the three components of the task-switching cost. This mapping is the heart of the model. Specifically, it is suggested that the preparatory component of the task-switching cost reflects the reconfiguration of the stimulus task set before task execution proper. In contrast, the residual task-switching cost component is (mainly) attributed to the delayed reconfiguration of the response task set.

Details and Rationale An important characteristic of the model is that response selection is achieved via the interaction of stimulus and response codes.[3] Specifically, response activation is a function of the similarity between the stimulus code and the response code, weighted according to the current status of the stimulus task set and the response task set. To give an example, in the context of the up-down task, an almost fully reconfigured stimulus task set might imply that the vertical dimension is assigned a weight of, say, 0.8, while the horizontal dimension is assigned a weight of 0.2. Consequently, upper right is coded so that the weights for *up* and *right* are 0.8 and 0.2, respectively. The (weighted) stimulus code then interacts with the two response codes, *up-left* and *down-right*. Let us assume, for simplicity, that the response task set is not reconfigured, meaning that neither the vertical dimension nor the horizontal dimension is emphasized in the response task set. This is represented by equal weights (0.5) for the two features in the response code. As a result of the interaction, the stimulus attribute *up* activates the upper left keypress, while the stimulus attribute *right* activates the lower right keypress. Nonetheless, the upper left keypress is more strongly activated (and is thus selected) because *up* is more heavily weighted than *right*.[4]

Congruency effects arise because the irrelevant dimension is represented in the response codes, and because the stimulus task set, although strongly biased, also includes the irrelevant features. This results in the wrong response (e.g., the lower right keypress) being activated, although not selected. The example above also demonstrates why correct responding can be entirely based on the reconfiguration of the stimulus task set.

Another critical assumption is that the response task set is (usually) adjusted after responding. This assumption is based on Hommel's "action-coding theory" (1997), according to which responses are coded (also) in terms of their outcomes. We assume that subjects are more inclined to code their responses (adjust the response task set) when response outcomes are available, that is, after responding.

In the present paradigm, a given response is associated with at least two outcomes. In the first, a key is pressed at a particular position; when this happens, either the vertical dimension or the horizontal dimension is attended, depending on whether the up-down task or the right-left task was executed.

In the second outcome, a key is pressed to express a nominal response. In our experiments, the instructions describe the keypresses as means to express nominal responses. Pressing the key presumably links the motor response to the respective nominal response. Regardless of which outcome is more important, pressing the key results in emphasizing one of its interpretations (e.g., *up*) over the other (e.g., *left*).

In task switching, however, coding responses in terms of their outcomes is counterproductive, and subjects do better if they do not reconfigure the response task set at all. The reason is that the postresponse reconfiguration of the set results in suboptimal response codes in the case of a task switch and, consequently, in a switching cost. One piece of evidence that task set reconfiguration is usually completed after responding is the initial rise in the task-switching cost as a result of increasing the RCI (figure 16.2). The reasoning goes as follows. With sufficiently long RCIs, response codes are determined by the preswitch trial. Hence the response task set is appropriately reconfigured for a task repetition and inappropriately reconfigured for a task switch. If the RCI is extremely short, there is insufficient time to permit response recoding. Consequently, response codes are determined in the trial preceding the preswitch trial. Given the random ordering of tasks, the codes are predicted to be appropriate in 50% of the trials, irrespective of task switching. Hence, with very short RCIs, response recoding does not contribute to the task-switching costs. When the RCI slightly increases, this permits response recoding and increases the overall switching costs.

Accounting for Previous Results

Congruency-Related Effects Switching costs were larger in the incongruent condition than in the congruent condition, indicating that the irrelevant task rule was not completely suppressed, although congruency effects on switching costs did not decrease systematically as preparation time increased (e.g., Fagot 1994; Goschke, chap. 14, this volume;[5] Meiran 1996; Rogers and Monsell 1995). In one exception to this rule, the fifth experiment of Allport, Styles, and Hsieh 1994, preparation did not significantly affect the switching costs.

The aforementioned pattern of results indicates that the reduction in switching costs by task preparation is not usually due to the selection or bias of stimulus-response (S-R) rules, as many researchers seem to believe. If this were the case, task preparation would be accompanied by a reduction in congruency effects in the switch condition. Because this is not usually found, it is suggested that in many circumstances subjects keep all S-R rules active, which is represented by nearly equal weights given to the two attributes (e.g., *up, left*) of each response. Controlling responses is achieved by selectively attending to the relevant stimulus dimension (stimulus set reconfiguration), that is, by controlling the input into S-R rules.[6] Accordingly, the preparatory component of the switching costs reflects the process of selecting the relevant stimulus dimension. Because this precedes response selection, preparation is not reflected in a reduction in congruency effects.

The residual component reflects the delayed, hence counterproductive, incremental change in the response task set and response codes (analogous to reweighting S-R rules). Consequently, in the nonswitch condition, the relevant response codes are primed, whereas in the switch condition, the irrelevant response attributes are primed. Priming the irrelevant response features after a task switch results in an increased congruency effect in that condition.

Interference Due to Response Repetition A surprising finding is that, in the switch condition, response repetition results, not in facilitation, but in interference, slower responses, or a higher error rate (Fagot 1994; Meiran 1996; Rogers and Monsell 1995). This is easily explained if we assume that responses are coded after responding. Consider the following example, where the task is up-down and subjects press the upper left key. As a result of the keypress, the code for that response is adjusted, giving more emphasis to task-relevant features (e.g., assigning the weights 0.6 and 0.4 to the features *up* and *left*, respectively). However, because the lower right key was not pressed, its code is either adjusted more moderately (e.g., 0.55 and 0.45) or not adjusted at all. After switching to the right-left task, pressing the upper left key again would be more difficult than pressing the lower right key. This is because *left* is more strongly deemphasized in the response code (0.4 in the example) than *right* (0.45 or 0.5). Rogers and Monsell (1995, 226) offered several explanations for the effect, one of which is quite similar to the present suggestions.

In summary, the model suggests that, in the present paradigm at least, there is an approximate one-to-one mapping between the task set facet (stimulus or response) and the two components of the task-switching cost. Although the model accounts successfully for basic findings, as shown in the several examples given above,[7] like other models, it should be judged mainly by its ability to generate novel and nontrivial predictions.

Novel Predictions

The assumptions regarding approximate one-to-one mapping between switching cost components and the facets of the task set lead to three straightforward predictions:

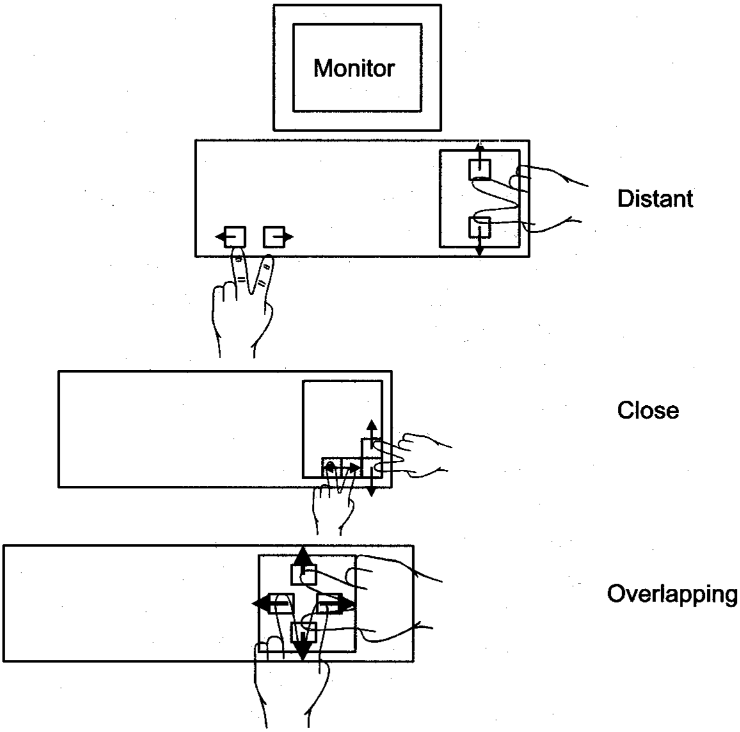


Figure 16.3 Response setups for experiment 1.

1. When the target stimuli are bivalent, but the responses are univalent, the preparatory component of the trial-by-trial cost will be present, whereas the residual task-switching cost will be absent or nearly absent.
2. When the responses are bivalent but the target stimuli are univalent, the residual cost will be present, whereas the preparatory cost will be absent or nearly absent.
3. When both the target stimuli and the responses are univalent there will be no trial-by-trial task-switching cost at all.

Prediction 3 was not tested because it is not unique to the present model.

16.2 EXPERIMENT 1: BIVALENT TARGET STIMULI AND UNIVALENT RESPONSES

The target stimuli were bivalent (figure 16.1), and several response setups were compared. In the standard two-key setup (figure 16.1), the responses were bivalent, as explained above, and both a preparatory switch component and a residual component were predicted for this condition. The two-key setup was compared to three different orthogonal four-key setups: distant, close, and overlapping (figure 16.3), in which the responses were univalent. The prediction was that the task-switching cost in these setups would be eliminated or nearly eliminated by preparation (long CTI), in other words, only the preparatory component would be found, but the residual component would be negligible.

On the basis of previous experiments (e.g., Moulden et al. 1998), it was already known that the residual task-switching cost is abolished in the four-key setup, but there were several problems associated with the interpretation of the results. First, only the distant four-key setup was used, and RT was much faster than in the standard two-key setup. This leaves open the possibility that general speeding led to the reduction of all experimental effects, including the task-switching cost. Second, the two-key setup and the four-key setup were compared across experiments.

The three orthogonal four-key setups differed from one another with respect to perceptual factors. Three different setups were tried because, based on previous literature (e.g., Reeve et al. 1992) it was predicted that proximity and overlap would slow responses and produce average RTs comparable to those in the two-key setup. This, of course, is not the only difference between these setups, which differ in motor aspects as well. The crucial prediction was that, despite all these differences, the three four-key setups would yield similar patterns of switching costs.

Subjects

Twenty-four undergraduate subjects from Ben-Gurion University and the affiliated Achva College participated in this experiment as part of a course requirement. Six subjects were assigned to each group according to order of entry into the experiment.

Apparatus and Stimuli

All testing was performed in front of an IBM PC clone with a 14-inch monitor. The stimuli were drawn in white on black and included a 2 × 2 grid that subtended approximately 3.4 degrees (width) × 2.9 degrees (height). The target stimulus subtended approximately 0.3 degree (width) × 0.5 degree (height). The arrowheads subtended approximately 0.3 × 0.3 degree, and were positioned 0.7 degree from the end of the grid.

Procedure

After the instructions, there was a short warm up block (20 trials) followed by five identical blocks of 96 trials, all in a 1-hour session. The subjects were encouraged to stretch a little between blocks. The keyboard, used to collect responses, was positioned so that its center (distant four-key setup group) or its keypad (for the remaining groups) was aligned with the center of the computer monitor. Each trial consisted of (1) the

Table 16.1 Mean Reaction Times and Error Rates for Experiment 1

				Four-keys (univalent)								
	Two-keys (bivalent)			Distant			Close			Overlapping		
CTI (msec)	S	NS	Cost	S	NS	Cost	S	NS	Cost	S	NS	Cost
166 Reaction time (msec)	1,028	750	278	735	622	113	999	861	138	808	719	89
Error rate	0.081	0.035	0.046	0.067	0.012	0.055	0.040	0.003	0.037	0.085	0.018	0.067
366 Reaction time (msec)	879	748	131	565	538	27	822	747	75	688	656	32
Error rate	0.060	0.036	0.024	0.009	0.006	0.003	0.018	0.000	0.018	0.035	0.009	0.026
716 Reaction time (msec)	846	776	70	532	522	10	759	756	110	646	608	38
Error rate	0.052	0.039	0.013	0.009	0.000	0.009	0.011	0.003	0.008	0.012	0.003	0.009
1616 Reaction time (msec)	827	716	111	520	532	–12	730	727	3	604	628	–24
Error rate	0.054	0.031	0.023	0.006	0.009	–0.003	0.014	0.008	0.006	0.011	0.003	–0.008

Note: CTI = cue-target interval; S = switch; NS = nonswitch.

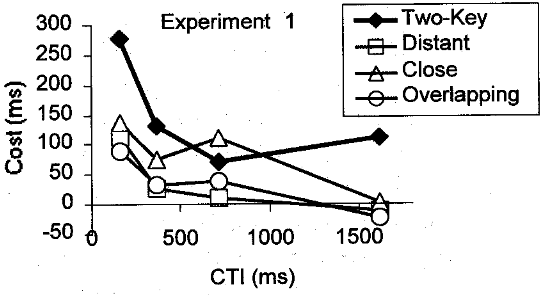


Figure 16.4 Task-switching costs: Experiment 1. CTI = cue-target interval.

presentation of an empty grid for a constant RCI of 1,532 msec; (2) the presentation of an instructional cue for a variable CTI (166, 366, 716, 1,616 msec); and (3) the presentation of the target stimulus along with the instructional cue until the response. A 50 msec 400 Hz beep signaled an error.

Results and Discussion

In the two-key setup, the mean RT was 744 msec, which compares to 555, 763, and 642 msec in the distant, close, and overlapping four-key setups, respectively (see table 16.1 and figure 16.4). The fact that mean RT was similar in the two-key setup and in one of the four-key setups permits a safer interpretation of the results concerning switching costs.

Responses preceded by errors or by RTs longer than 3 sec were discarded. Responses that were either inaccurate or associated with an excessively long RT (3 sec) were included in the error score, but not in the estimate of mean RT. Each cell was represented by the mean, after trimming values exceeding 2 standard deviations (SDs) from the untrimmed mean. Because space is limited and errors were relatively rare, formal statistical analyses of errors are not reported. However, as can be seen in the tables, the critical RT effects do not reflect a speed-accuracy trade-off. The alpha level was 0.05.

Because the assignment of trials to conditions was partly random, the number of analyzable responses per condition was not identical and ranged from 47 to 59. Two focused comparisons were conducted; mean square errors were taken from an analysis of variance, with CTI, task switch, and group as the independent variables. In one analysis, the two-key setup was compared to the three groups with the orthogonal four-key setup. The group main effect was insignificant, while the interaction of CTI and Group just missed significance: $F(3, 60) = 2.74$, $p = 0.051$; and the triple interaction was significant: $F(3, 60) = 2.85$. On the other hand, there was a significant main effect of task switch: $F(1, 20) = 24.40$; a significant interaction between CTI and task switch: $F(3, 60) = 24.56$; and most important, a significant interaction between group and task switch:

$F(1, 20) = 11.20$. The simple interaction of group and task switch at the longest cue-target interval was also significant: $F(1, 20) = 21.46$, reflecting a significant residual cost in the two-key setup: $F(1, 20) = 9.50$, compared to a residual cost that was negative in two of the four-key setups, and was 3 msec in the third group. The significant triple interaction indicates that the group differences in the task-switching cost were somewhat larger in the short CTI compared with the long CTI. In the second analysis, where the three four-key setups were compared to one another, the main effect of group was significant: $F(1, 20) = 5.43$; but none of the interactions involving group approached significance, $F < 1$.

One could argue that the two-key setup yielded larger costs only because it involved an incongruent condition and task-switching costs are known to be larger in that condition. This was not the case, however, because the residual costs (at the longest CTI) were 143 and 93 msec for the incongruent and congruent conditions, respectively.[8] Namely, the costs in the congruent condition were considerably larger than the costs in any of the four-key setups. An alternative explanation is based on Monsell et al. 1998, which showed that switching costs were larger when the responses were incompatible with the stimuli (e.g., pressing a key in response to the words "left" and "right") as compared to a compatible setting (reading the words). One might argue that this is the reason why residual costs were larger in the two-key setup, where the incongruent condition was also incompatible in that the relative position of the target stimulus (e.g., upper *right*) was opposite to the relative position of the response along one dimension (e.g., upper *left*). However, the congruent condition in the two-key setup was highly compatible because the response key occupied the same relative position as the target stimulus. The four-key setups were associated with an intermediate level of S-R compatibility because the response key never occupied the same relative position as the target stimulus, although it was never opposite to it. Nonetheless, the residual cost in the congruent condition (two-key setup) was much larger than in the less compatible four-key setups. Hence compatibility cannot explain the differences in the residual costs in the present case.

The results of experiment 1 generally support the predictions by showing that when the responses were univalent, the residual task-switching cost was eliminated. The small triple interaction may indicate that while most of the preparation applied to the stimulus task set (common to all four response setups), a little preparation also applied to the response task set. The findings therefore indicate an empirical dissociation, namely, response valence affects residual cost, although its effect on the preparatory cost was much smaller. The findings also support the predicted (approximate) one-to-one mapping between response task set reconfiguration and the residual component of the task-switching cost.

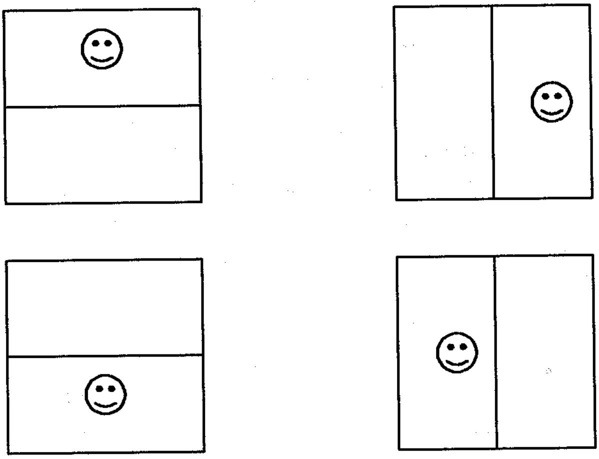


Figure 16.5 Univalent target stimuli.

16.3 EXPERIMENT 2: UNIVALENT TARGET STIMULI AND BIVALENT RESPONSES

The responses were bivalent (the two-key setup was used), but half of the target stimuli were univalent and could be classified only in one manner (figure 16.5). There were two reasons for this manipulation. First, this condition constitutes a replication of the standard conditions using the two-key setup of experiment 1 (figure 16.1). Second, it was hoped that intermixing bivalent and univalent target stimuli in an unpredictable order would encourage subjects to maintain the same strategy they used when both the stimuli and the responses were bivalent. Including only, or too many, univalent target stimuli could potentially lower subjects' motivation to reconfigure the stimulus task set during the CTI because that set would often not be needed. Furthermore, under these conditions, it would make more sense to change strategy and prepare for a task by reconfiguring the response task set during the CTI. This was probably the case in De Jong 1995 and in Rogers and Monsell 1995, exp. 4.

Rogers and Monsell (1995, exp. 3) mixed univalent and bivalent target stimuli. Nonetheless, they did not include the status of the target (univalent, bivalent) in the previous trial as a variable in their analyses. Including that variable allows one to distinguish between two scenarios, as elaborated below. The subjects were assumed to reconfigure the stimulus task set on every trial because, when the instructional cue was presented, they were unable to predict whether the upcoming target stimulus would be univalent or bivalent. On the other hand, using the stimulus set for responding depended on the nature of the target stimulus as univalent or bivalent. The reason is that correct responding depended on the stimulus task set only when the target stimulus was bivalent, where the set enabled univalent representation.

One possible scenario is that the stimulus task set remains roughly unchanged after being reconfigured. In that case, it would not matter if the previous trial involved a bivalent or a univalent target stimulus because in both cases the stimulus task set was reconfigured. This scenario predicts that the presence of a preparatory cost component depends only on the status of the current target stimulus, present when bivalent and absent when univalent. The reason is that the reconfiguration of the stimulus task set may be skipped once the subject realizes that the target stimulus is univalent.

A second possible scenario is that although the stimulus task set is reconfigured during the CTI, if not used (that is, with univalent target stimuli), it returns quickly to its previous or to a neutral state. In either case, this would result in zero preparatory cost on the following trial. Hence this scenario predicts that the preparatory cost would be missing if the previous target stimulus, the current target stimulus, or both were univalent. The preparatory cost would be present only when both trials involved bivalent target stimuli.

Subjects

Twenty students from the Negev College, affiliated with Ben-Gurion University, served as subjects in this experiment. Half were assigned to each of the two possible two-key combinations.

Stimuli

The stimuli were the same as in experiment 1, except for the inclusion of the 4 univalent target stimuli that were identical in size to the target stimuli used in experiment 1.

Procedure

The only changes from experiment 1 were that all the subjects used the two-key setup (figure 16.1) for responses. The CTIs were 166, 516, and 2,516 msec. When the target stimulus was univalent, it was always one that matched the task. For example, when the task was up-down, the target stimuli were either *up* or *down*, but neither *right* nor *left*. The task switch condition, target, target type (bivalent, univalent), and CTI were randomly selected with equal probabilities in each trial. The warm-up block included 25 trials, and each of the 5 experimental blocks included 96 trials.

Results and Discussion

There were between 18 and 20 observations per condition (see table 16.2 and figure 16.6). The triple interaction between target type combination

Table 16.2 Mean Reaction Times and Error Rates for Experiment 2

	Previous target bivalent						Previous target univalent					
	Bivalent target			Univalent target			Bivalent target			Univalent target		
CTI (msec)	S	NS	Cost	S	NS	Cost	S	NS	Cost	S	NS	Cost
166 Reaction time (msec)	971	756	215	744	660	84	906	844	62	720	642	78
Error rate	0.053	0.008	0.045	0	0	0	0.024	0.014	0.010	0.002	0.005	–0.003
516 Reaction time (msec)	827	688	139	673	624	49	812	774	38	660	604	56
Error rate	0.033	0.015	0.018	0.007	0	0.007	0.013	0.010	0.003	0.003	0	0.003
2516 Reaction time (msec)	749	686	63	667	626	41	742	717	25	626	609	17
Error rate	0.012	0.006	0.006	0.005	0	0.005	0.017	0.010	0.007	0	0	0

Note: CTI = cue-target interval; S = switch; NS = nonswitch.

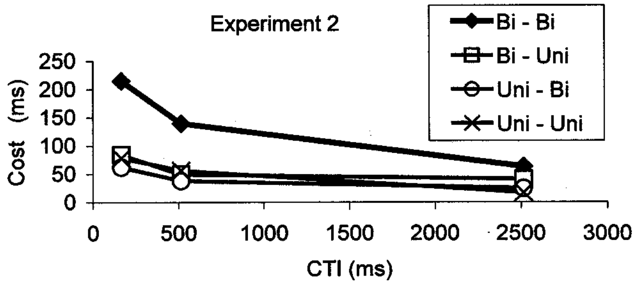


Figure 16.6 Task-switching costs in experiment 2. Bi = bivalent; Uni = univalent; CTI = cue-target interval.

(bivalent-bivalent, bivalent-univalent, univalent-univalent, univalent-bivalent), CTI, and task switch was significant: $F(6, 116) = 2.25$. It resulted mainly from the difference between the bivalent-bivalent combination and the remaining three conditions, $F(2, 38) = 4.44$; and not from the differences among the remaining three conditions: $F < 1$. An increase in CTI was associated with a significant reduction in the task-switching cost in the bivalent-bivalent condition: $F(2, 38) = 12.67$. Nonetheless, there was a small preparatory component even in the remaining conditions, seen in the fact that an increase in the CTI led to a reduction in the task-switching cost even when one or both of the targets were univalent: $F(2, 38) = 4.79$. It was much smaller, however, than that obtained in the bivalent-bivalent condition because task preparation reduced the cost by only 27–61 msec, as compared to 152 msec.[9] It is important to note that there was a significant residual cost even when either the previous or the current trial involved a univalent target stimulus, as seen in the effects of task switch in the longest CTI: $F(1, 19) = 5.90$. Thus including any univalent task element is insufficient to eliminate the residual costs in the present paradigm. The univalent task element must be the responses.

The results may be summarized as follows. When either the current or the previous target stimulus, or both, were univalent, the task-switching cost was relatively small, and barely influenced by the CTI. In other words, the cost comprised mainly the residual component. In contrast, when both the current target stimulus and the preceding target stimulus were ambivalent, the task-switching cost was larger, mainly in the short CTIs. In other words, both the residual component and the preparatory component were present in that condition. In terms of the model, if a stimulus task set was used in the preceding trial, and not merely reconfigured, this made it difficult to adopt a new stimulus task set. In that respect, the current findings support the suggestion of Allport, Styles, and Hsieh (1994) that the task-switching cost results from interference from the task set in the previous trial.

The results of experiment 2 also indicate an empirical dissociation. Namely, the combination of current and previous target valence affected the preparatory component more strongly than they affected the residual component. As in experiment 1, there was an indication that the response task set is slightly prepared during the CTI. The reasoning is that reconfiguring the stimulus task set was unlikely to help when the target was univalent. Finally, the results may also explain why Rogers and Monsell (1995, exp. 3) did not find that stimulus valence affected the preparatory cost: the valence of the previous target stimulus was not included in the analyses. A relevant comparison is between their experiments 3 and 4. In experiment 3, univalent and bivalent stimuli were mixed, and the results indicated that preparation reduced the cost from 207 to 115 msec (a preparatory component of 92 msec). This is probably an underestimation because the experiment included trials in which either the current or previous target stimulus was univalent. In comparison, when there were only univalent target stimuli (experiment 4), the reduction was from 67 to 42 msec (25 msec difference), which is probably an overestimate because having nothing else to prepare, the subjects probably reconfigured the response set, which explains the modest decline in the switching costs. In other words, Rogers and Monsell's results also indicate that target stimulus valence affects the preparatory component of the switching costs more strongly than it affects the residual component.

An unexpected finding was that responses in the nonswitch condition were slower when the current target was bivalent, especially when the previous target was also bivalent (table 16.2). This may have reflected the fact that the bivalent condition included incongruent trials. Although one could argue that this slowing of responses in the bivalent-bivalent condition caused an increase in switching costs, even if switching costs are represented as proportional increases in RT relative to the nonswitch condition, the picture remains essentially unchanged. In the bivalent-bivalent condition, preparation reduced the proportional switching cost by 19.2% (from 28.4% to 9.2%). This value compares to a reduction of 6.2% (12.7% to 6.5%) in the bivalent-univalent condition, 3.8% (7.3% to 3.5%) in the univalent-bivalent condition, and 9.3% (12.1% to 2.8%) in the univalent-univalent condition.

General Discussion

Our proposed model serves as a reasonable first approximation in describing subjects' performance in a particular task-switching paradigm. Like other models, the present model should be judged, not only by its ability to account for previous findings, but more important, by its ability to generate new, nontrivial, and testable predictions. Although alternative explanations may apply to the present results, to the best of my knowledge, none of the existing models could predict these results. Several relevant issues are discussed below.

De Jong's Model According to De Jong's model (chap. 15, this volume), residual costs represent lack of motivation to prepare. When preparation time is short (short CTI), there should thus be no difference between "motivated" and "unmotivated" trials. The difference between the two types of trials should be evident given sufficient preparation time. One may argue that the near-zero residual costs in experiment 1 were due to a higher motivation to prepare with four-key setups. This explanation, besides being ad hoc, leads to the prediction that the switching costs in the two-key and the four-key setups would be similar when CTI was very short, so that the motivation to prepare did not yet affect the switching costs. The results are clearly inconsistent with that prediction, showing a *larger* difference between the setups in the shortest CTI compared to the longest CTI. (A similar argument applies to the results of experiment 2.) In summary, lack of motivation to prepare is not the only reason why residual costs exist.

Applicability to Other Switching Paradigms At the heart of the model is the assumption that task sets are adopted, and hence cause interference, because several facets of the task are multivalent with respect to the tasks at hand. In the present paradigm, both the target stimuli and the responses were bivalent. Certainly, additional task facets may be multivalent and contribute to the task-switching costs in other paradigms. Furthermore, the nature of the approximate one-to-one mapping between task set facets and the two components of the task-switching cost may be specific to the present tasks and the very explicit instructional cues that were used. This may have made it easier to reconfigure the stimulus task set than the response task set. Consequently, the subjects adopted a strategy of preparing by reconfiguring the stimulus task set.

Despite the peculiar aspects, two general principles emerge. First, the task-switching cost should not be treated as a single phenomenon. Within a given paradigm, the components of the switching cost reflect different underlying processes. This general principle allows for some variability. For example, in one paradigm, subjects might prepare by reconfiguring the stimulus task set, whereas, in another paradigm, they might prepare by reconfiguring the response task set, or a rule task set. Thus the processes underlying the preparatory component would not be the same across the two paradigms.

Following the models of other researchers, our model holds that the trial-by-trial switching costs resulted from the multivalence of task elements. The second general principle to emerge is that separate task sets are required to deal with each multivalent task element, and that these task sets need not be adopted at the same time. Using valence-related manipulations, one can determine that task set facet is reconfigured and when. A valence-related manipulation that affects the preparatory switching cost component indicates that the related task set is reconfigured during the CTI. For example, in experiment 2, stimulus valence affected the preparatory cost, indicating that the stimulus task set was reconfigured during the CTI. In contrast, valence-related manipulations that affect the residual cost indicate that the respective task set is reconfigured sometime after target stimulus presentation. For example, in experiment 1, response valence affected the residual cost, which supported the present claim regarding the relatively delayed reconfiguration of the response task set.

NOTES

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1. This presumption can be defended on the basis of a study which employed high-density event-related potential (ERP) recording (Moulden et al. 1998). In that study, the first (cue-locked) switch related component was revealed 200 msec after cue presentation, and the locus of its generator was bioccipital. Based on the commonly accepted assumption that the occipital lobes are involved in encoding visual information, this result suggests that about 200 msec are required to encode the present type of instructional cues.

2. This finding may be specific to the present paradigm. Using a different method to alert their subjects, Rogers and Monsell (1995, exp. 5) did not find that alertness reduced the cost, although the effect of the alerting stimulus on RT was very weak in that study (10–21 msec).

3. My choice of the term *response codes* instead of *S-R rules* allows a natural link to selective attention theories and theories of response coding (Hommel 1997); moreover, it fits well into current cognitive theorizing. Specifically, most cognitive psychologists would agree that S-R rules do not relate physical stimuli to physical responses, instead, they relate stimulus representations to response representations. They would also agree that mental representations are influenced by selective attention.

4. The present formulation may be extended to situations in which a translation must apply to the stimulus code. For example, if subjects switch between odd versus even judgments and larger versus smaller than 5 judgments, the code of a given target digit (e.g., 7) needs to be first translated to either "high" or "odd". This requires a translation phase between stimulus encoding and response activation. If we assume only two responses (e.g., Sudevan and Taylor 1987), the responses may be coded as *high-odd*, and *low-even*, with one set of attributes (e.g., *high*, *low*) being emphasized relative to the other set of attributes (e.g., *odd*, *even*). Once the digit "7" is coded as *high*, this would result in the activation of the response that contains *high* in its code.

5. I am referring here to Goschke's comparison of two conditions. In the first condition, RCI was short and CTI long (short-long); in the second, RCI was long and CTI short (long-short). These conditions are equal with respect to the time allowed for the dissipation of the previous task set, and differ with respect to task preparation only (Meiran 1996). In Goschke's experiment, congruency effects declined with task preparation (from short-long to long-short), but more or less equally in switch trials and nonswitch trials.

6. This partly explains the advantage of pure task blocks (where only one S-R rule is active) over task repetitions within a task alternation block.

7. In the model, it is possible to eliminate residual costs by adopting specific strategies, although subjects rarely employ these strategies. One such strategy is total biasing of the stimulus task set (assigning a weight of 1 to the relevant dimension, and a weight of 0 to the

irrelevant dimension). Another strategy is learning not to reconfigure the response set after responding. In neither case would the irrelevant stimulus dimension activate the wrong response. The model also predicts for these strategies that the two-way interaction between congruency and task switch would be eliminated. The most common strategy, and the one on which the predictions were based, is to sufficiently bias the stimulus task set before selecting the response. A fuller description of the strategy may be found in Meiran forthcoming.

8. As one may notice, the average, 118 msec, is not identical to the residual cost reported in table 16.1, 111 msec. This is because values exceeding 2 SDs were trimmed, and including congruency as a variable changed cell means and SDs. When untrimmed arithmetic means were used, the pooled residual cost in the two-key setup was 105 msec, which reflected a cost of 113 msec in the incongruent condition and 97 msec in the congruent condition. These values were compared with −10 , 8, and −23 msec (based on arithmetic means) in the distant, close, and overlapping setups, respectively.

9. There is no agreed-upon method to compute the reduction in the costs by preparation. I tried two methods: the first based on raw costs (figure 16.6); the second based on the proportional reduction in raw cost, that is, switch RT minus nonswitch RT in milliseconds. The reduction in the bivalent-bivalent condition was 71% (raw cost was reduced from 215 to 63 msec). This value is compared to a reduction of 78% in the univalent-univalent condition, 51% in the bivalent-univalent condition, and 60% in the univalent-bivalent condition. Although the last analysis may suggest that the efficiency of preparation does not depend on target stimulus valence, if the same logic were applied to the results of experiment 1, the conclusion would be that using univalent responses resulted in complete or close to complete reduction in switching cost (~ 100 %). Thus the present results indicate a dissociation of response valence and stimulus valence, regardless of the computational method. Specifically, univalent responses resulted in improving the proportional reduction in switching costs (experiment 1). On the other hand, univalent responses did not result in such improvement (experiment 2). The reasons to prefer the computational method used is that it is the one most commonly used. Moreover, the emergent picture fits the predictions of a model successfully fit to RT results (Meiran forthcoming). The last statement holds, of course, as long as there is no alternative model that can account for the results concerning proportional effects on switching costs.

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