THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2005, 58A (6), 1023–1041

Psychology Press
Taylor & Francis Group

Task rule-congruency and Simon-like effects in switching between spatial tasks

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In task switching, a response indicated as correct by both task rules is executed more quickly than one for which the rules disagree. This rule-congruency, so far demonstrated unequivocally only in nonspatial tasks, shows that the currently irrelevant task set is kept active. However, in spatial task-switching, rule-congruency could potentially reflect a preexperimental tendency that contributes to a Simon-like effect. In the present study, participants switched between RIGHT–LEFT and UP–DOWN tasks with either a standard key arrangement (e.g., upper key = UP) or a mapping-reversed arrangement (e.g., up = DOWN), which reverses the direction of the potential Simon-like effect but leaves potential rule-congruency effects unchanged. Mapping-reversal did not modulate any other effect, including rule-congruency, and therefore indicated rule-congruency unequivocally. Finally, implications concerning generality versus domain specificity of control processes in task switching are discussed.

It is widely believed that a major role of cognitive control is implementing self-initiated or instructed goals (e.g., De Jong, Berendsen, & Cools, 1999; Duncan, Emslie, & Williams, 1996; Logan & Gordon, 2001; Monsell & Driver, 2000). A reasonable assumption is that goal representation (at least the instructed aspect) must be quite central and independent of modality. More generally, this view of the cognitive system seems to imply some form of relatively general-purpose control processes operating across domains. Evidence supporting this position comes, for example, from studies on individual differences that indicate across-domain communalities (e.g., Kray & Lindenberger, 2000; Miyake et al., 2000). However, the metaphor of cognitive control seems to imply that the relatively general-purpose operations must connect to task execution modules in a chain of control processes. As one nears the end of this chain, one finds processes that become increasingly domain specific. For example, in Logan and Gordon's (2001) theory, a set of parameters is sent to the task execution module, which controls visual attention. Although not specified in the model, there must be processes

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The research was supported by a grant from the Israel Science Foundation. I wish to thank Thomas Kleinsorge, Robert Proctor, Padmaneban Sudevan, and an anonymous reviewer for helpful comments, Rotem Eren Rabinovich for English proofreading, and Roy Luria for assistance in programming and data analysis.

http://www.tandf.co.uk/journals/pp/02724987.html DOI:10.1080/02724980443000421

that translate the behavioural goal into the required parameter values. These processes, by their nature, must be relatively domain specific (they operate in the interface between the goal and visual attention) in comparison to the goal representation itself. Within the present metaphor, a central question arises as to where a given process is located in the control chain: Is it positioned at the beginning, and hence must operate across domains, or is it positioned downstream and is therefore domain specific?

Control processes in WHERE and WHAT task-switching

The task-switching paradigm is a popular tool for studying control in simple cognitive tasks. Studies using this paradigm have revealed a wide range of control-related effects, such as task-switching cost. Most of the task-switching paradigms that have been studied so far involve "object-based" nonspatial tasks such as identifying colours and letters (Fagot, 1994; Hartley, Kieley, & Slabach, 1990), odd–even judgments (Rogers & Monsell, 1995), episodic memory retrieval (Mayr & Kliegl, 2000), and switching between dimensions in Stroop and Stroop-like tasks (Allport, Styles, & Hsieh, 1994; Hübner, Futterer, & Steinhauser, 2001; Waszak, Hommel, & Allport, 2003; Wylie & Allport, 2000).

However, it is widely accepted that there are two separate systems in visual processing, a WHERE system in the dorsal posterior cortex, specializing in determining the relative position of objects irrespective of their identity, and a WHAT system in the ventral posterior cortex, specializing in determining object identity irrespective of position (e.g., Mishkin, Ungerleider, & Macko, 1983). Because these systems show differential specialization, it is quite likely that they involve domain-specific control processes somewhere near the end of the control chain.

An example of what is likely to be a relatively restricted and domain-specific control process is provided by studies on *spatial stimulus–response (S–R) compatibility*. Specifically, it has been shown that right–left responses are quicker if the S–R arrangement is compatible (right → right, left → left) than if it is incompatible (right → left, left → right, Fitts & Seeger, 1953). With respect to cognitive control, the S–R spatial compatibility effect is eliminated if compatible and incompatible S–R mappings are intermixed (De Jong, 1995; Shaffer, 1965) or when the right–left judgements are intermixed with a nonspatial task (colour judgements, Marble & Proctor, 2000) as long as this nonspatial task involves stimuli presented on the right and the left (Proctor, Vu, & Marble, 2003). The elimination of the spatial compatibility effect is attributed to the suppression of the automatic processing route that generates spatial location codes (Proctor et al., 2003; cf. De Jong, 1995; Los, 1996; Van Duren & Sanders, 1988). The involved control mechanism being described in the theories seems to be a set of specific spatial codes. As such, it may be specific to the WHERE system.

In the case of task-switching, several parallel experimental effects have been found in both WHAT and WHERE tasks. These include the task-switching cost, its reduction by preparation (e.g., Meiran, 1996) and the reversal of the response-repetition effect in task-switch trials (Fagot, 1994; Kleinsorge & Heuer, 1999; Meiran, 1996, 2000a; Rogers & Monsell, 1995; but see Ruthruff, Remington, & Johnson, 2001, for an exception). Such isomorphism supports the hypothesis that the underlying control operations are amodal in nature and therefore positioned near the beginning of the control chain.

The rule-congruency effect

In the present paper, I focus on an important exception to the isomorphism described above, namely, the *rule-congruency* effect. Rule-congruency is manipulated by mapping of the task-relevant stimulus dimension and the task-irrelevant stimulus dimension (which is relevant to the task not currently being executed) to the same (congruent) or different (incongruent) responses. An example from the nonspatial domain is a study by Sudevan and Taylor (1987), in which participants switched unpredictably between ODD–EVEN and HIGH–LOW (higher or lower than 5) judgements on single digits. If, for example, ODD and LOW were both mapped to the left response key, the response to the digit "3" would be pressing the left key regardless of which rule was currently relevant. This is an example of a rule-congruent trial. In contrast, if the target stimulus were the digit "7", the correct response according to the ODD–EVEN rule would be pressing the left key, but according the HIGH–LOW rule, it would be the right response key. This is an example of a rule-incongruent trial. Now consider how rule-congruency is defined in the spatial task-switching paradigm described in Figure 1. In this paradigm, participants make RIGHT–LEFT and UP–DOWN judgements concerning the position of a target stimulus. In the standard bivalent response set-up, they respond, for example, by pressing the upper left key on the numeric key-pad to indicate UP and LEFT and pressing the lower right key to indicate RIGHT and DOWN. In this paradigm, if the target position was in the upper left quadrant (an example of a rule-congruent trial), the correct response would be pressing the upper left response key according to both the UP–DOWN and the RIGHT–LEFT rules. An example of a rule-incongruent trial is if a target were placed in the upper right quadrant. The correct response to such a target would be pressing the upper left key in the context of the UP–DOWN task because the key indicates the category UP. However, in the context of the RIGHT–LEFT task, the correct response would be pressing the lower right key to indicate DOWN.

The fact that rule-congruency influences response time (RTs) is taken as prima facie evidence that a task rule is active in spite of being irrelevant to the particular trial (e.g., Goschke, 2000; Hommel, 2000; Rogers & Monsell, 1995; Wylie & Allport, 2000). The reasoning is quite analogous to that discussed in the context of the Stroop task (Stroop, 1935; see MacLeod, 1991, for review), in which participants were asked to report the ink colour of colour-naming words. There, too, the fact that colour responses are quicker if the irrelevant colour word is congruent is taken as evidence for automatic processing of the word, despite it being task irrelevant (see Hommel, 1997; Tzelgov, 1997).

Unlike in the case of the Stroop task, where the tendency to automatically read the words is at least partly preexperimentally induced, in the case of rule-congruency in the task-switching paradigm, the effect is experimentally induced. Specifically, the task-irrelevant pathway may be activated either in anticipation of an imminent task switch or because the related task has just been performed. This is why the congruency effect has such considerable implications regarding how instruction-based control is accomplished. For example, Hommel (2000) suggested that cognitive control operates as a "prepared reflex". The prepared reflex is characterized by its voluntary implementation and consequent involuntary application. One of the central empirical supports for the prepared-reflex metaphor is the rule-congruency effect. This effect is interpreted by Hommel as evidence for the voluntary implementation and the involuntary application of the task rules of both tasks.

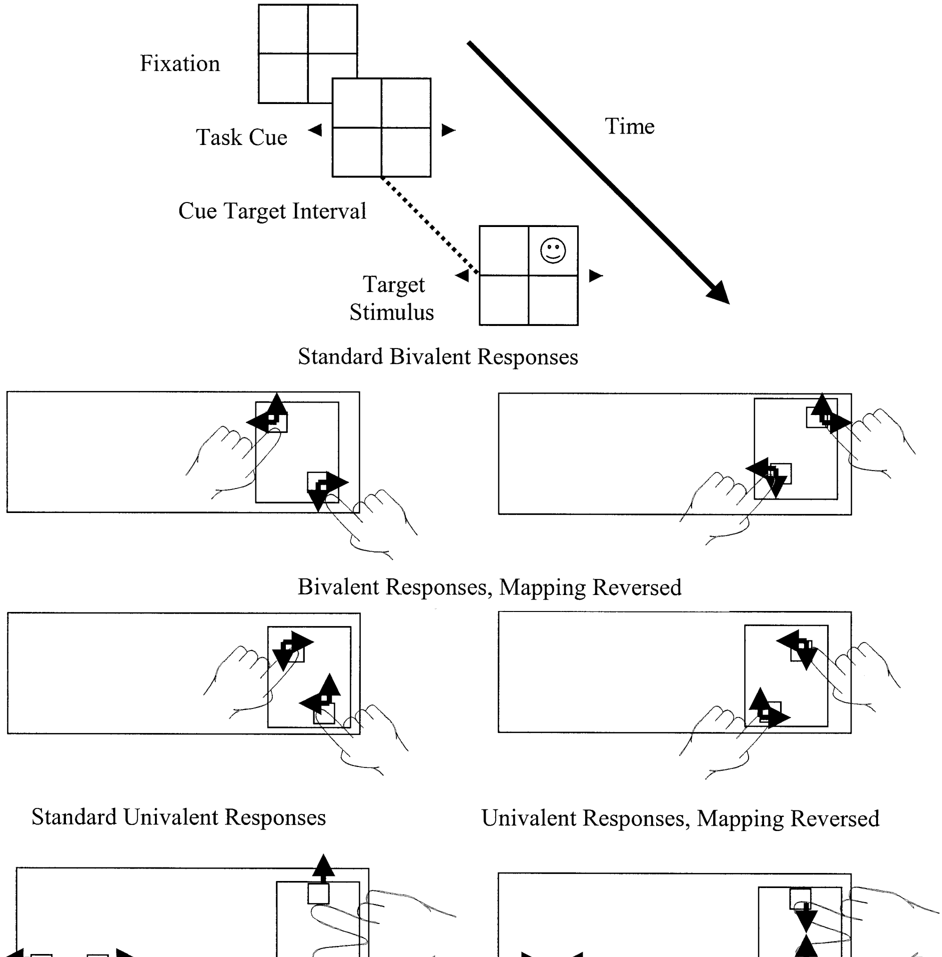

Figure 1. A schematic description of the experimental paradigm. "Standard" refers to setups used in previous studies. Arrows indicate response meanings (e.g., a left-pointing arrow together with an upward-pointing arrow means that the response serves to indicate both LEFT and UP).

Following a similar line of reasoning, Gilbert and Shallice (2002) extended Cohen, Dunbar, and McClelland's (1990) PDP model of the Stroop task to account for Stroop task-switching. One phenomenon unique to task switching and not usually found in standard administration of the Stroop task is the reverse Stroop effect. This effect indicates faster word reading if the irrelevant ink colour is congruent with the word (reading the word RED written in red ink) than if it is incongruent. This reverse Stroop effect can be interpreted as analogous to the rule-congruency effect. Unlike the usual Stroop effect (which is also a rule-congruency effect), it cannot be attributed to a preexperimentally induced bias to read the words but rather to an experimentally induced effect. Specifically, it may reflect persisting task instructions in the form of a prepared reflex. Gilbert and Shallice's model accounts for the reversed Stroop effect by the transient activation of the colour pathway, resulting from the fact that the pathway has just been used. It is interesting to note that the reverse Stroop effect is large and robust even in nonswitch trials (Wylie & Allport, 2000), a finding that seems to support Hommel's position (see also Marble & Proctor, 2000; Proctor et al., 2003, vs. De Jong, 1995).

Meiran (2000a, 2000b) developed another model to explain task-switching in speeded classification paradigms, such as that found in Figure 1. This model accounts for the following effects involving rule-congruency. First, there is a large and robust main effect indicating considerably quicker response in rule-congruent trials than in rule-incongruent trials. Second, rule-congruency effects are much larger in blocks involving task switching than in pure task blocks in which participants perform a single task in the entire block (e.g., Fagot, 1994; Meiran, 2000a). Third, in mixed-task blocks, congruency effects are slightly elevated in trials involving a task switch as compared to trials with a task repetition (e.g., Meiran, 1996, 2000a; Meiran, Chorev, & Sapir, 2000). Finally, rule-congruency is not modulated by the preparatory interval (e.g., De Jong, 1995, Exp. 3; Meiran, 1996, 2000a; Meiran et al., 2000), at least unless extensive training is provided (Sudevan & Taylor, 1987).

Specifically, Meiran's (2000a, 2000b) model argued that participants hold the two relevant category-response mappings as more-or-less equally active. (This does not necessarily mean that they are held in working memory. Alternatively, they could be equally cued by the target stimuli, see Waszak et al., 2003; Wylie & Allport, 2000, for results and theoretical arguments and Gilbert & Shallice, 2002, for modelling.) The implication of Meiran's model is that control is not achieved by the selection of S–R or category-response rules or the activation of pathways implementing such rules, in contrast to arguments such as those by Allport et al. (1994), Gilbert and Shallice (2002), and Mayr and Kliegl (2000). Instead, control is achieved by selecting which input will enter the response selection process, which, as a prepared reflex, is simultaneously ready for both tasks. This selection is achieved by means of dimensional attentional selection (e.g., Meiran, 2000b; Meiran & Marciano, 2002, for empirical support). Similar claims have been made by Logan and Gordon (2001) concerning the task-switching component of the psychological refractory period paradigm. In their model, too, control of task-switching is partly achieved by means of directing attention to the position in the display where the task-relevant stimulus appears.

The rule-congruency effect has been extensively studied using nonspatial tasks (e.g., Allport et al., 1994; Allport & Wylie, 2000; Fagot, 1994; Goschke, 2000; Rogers & Monsell, 1995; Sudevan & Taylor, 1987). In spite of the fact that there are a number of task-switching studies that appear to involve the WHERE system (Hunt & Klein, 2002; Kleinsorge & Heuer, 1999, and studies on the elimination of the spatial S–R compatibility effect described above), the rule-congruency effect in WHERE tasks has only been studied using the paradigm described in Figure 1 (but see De Jong, 1995, Exp. 3, regarding rule-congruency in switching between a spatial and a nonspatial task). The paradigm described in Figure 1 involves switching between two spatial tasks: UP–DOWN and RIGHT–LEFT. The figure depicts the standard response set-ups that were used in our previous studies as well as set-ups with reversed mapping, which were used in the present experiment and are described below. The standard set-ups include two bivalent response setups that are similar to one another in the sense that the key position corresponds to the nominal response it indicates. For example, the key indicating LEFT and UP is located in the upper left corner of the keypad.

Rule-congruency, spatial S–R compatibility, and Simon-like effects

The present paper addresses a special problem associated with studying rule-congruency in the spatial paradigm described in Figure 1: one that results from the dimensional overlap between the target locations and the locations of the response keys. As a result of this overlap, rule-congruency is perfectly confounded with a special type of spatial compatibility effect.

Spatial compatibility is discussed in the literature in relation to two distinct situations (e.g., see Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990; Lu & Proctor, 1995; Umiltà & Nicoletti, 1990, for reviews). In one situation, participants judge the spatial position of a target display. This situation reveals the spatial S–R compatibility effect, which has already been discussed above. The other case is more relevant here because it involves making nonspatial judgements such as judging the pitch of a tone as high versus low. These studies reveal a spatial correspondence effect between the responding hand and the irrelevant position of the target stimulus (e.g., the ear that receives the sound, Simon & Small, 1969). This effect is called the *Simon effect*, and its size is about one half of the spatial S–R compatibility effect.

In the paradigm described in Figure 1 (standard bivalent response), a rule-congruent trial is also spatially compatible along both the relevant and the irrelevant dimensions. However, an incongruent trial, while being spatially compatible along the task-relevant dimension, is incompatible along the task-irrelevant dimension. For example, in the context of the UP–DOWN task, pressing an upper left key in response to an upper left target stimulus is compatible along both the vertical and the horizontal dimensions. However, using the same key in response to an upper right target implies spatial compatibility along the relevant vertical dimension but incompatibility along the irrelevant, horizontal dimension. In a sense, one could argue that the longer RTs in the rule-incongruent condition reflect a Simon-like effect because a currently irrelevant spatial dimension affects the response. Importantly, unlike rule-congruency, which is totally instruction dependent, the Simon effect probably reflects a preexperimental bias as well (De Jong, Liang, & Lauber, 1994; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). In a sense, the rule-congruency effect in the present paradigm is like the Stroop effect, which could reflect an intentionally biased prepared reflex, preexperimental bias, or both.

Is the WHERE rule-congruency effect truly Simon-like?

Meiran's position (2000a, 2000b) that rule-congruency does not reflect Simon-like long-term memory biases (or reflects them minimally) can be defended along the following lines. First, the Simon effect itself is strongly influenced by intraexperimental manipulations, and, therefore, it is not entirely preexperimental in nature. For example, Marble and Proctor (2000) asked participants to switch between a spatial RIGHT–LEFT task and a nonspatial colour task. They showed that if the S–R mapping in the RIGHT–LEFT task was compatible (e.g., right → right), the Simon effect in the nonspatial task was much greater than usual. Importantly, if the S–R mapping in the RIGHT–LEFT task was incompatible (e.g., right → left), the Simon effect was reversed.

Second, spatial compatibility effects behave differently from rule-congruency effects. Spatial compatibility effects become smaller and may even be eliminated in conditions with mixed mapping (e.g., De Jong, 1995; Proctor et al., 2003; Shaffer, 1965). In contrast, rule-congruency effects increase in mixed-task conditions (indicating their sensitivity to control related variables), while they are essentially unaffected by increases in the preparatory interval (Fagot, 1994; Meiran, 2000a; Sudevan & Taylor, 1987, for review).

The third piece of evidence in favour of the rule-congruency interpretation comes from task-switching experiments, such as an experiment reported in Meiran (2000a). First, the typical congruency effect is about three times larger than the typical Simon effect. The size of the effect and its increase in mixed-task conditions are supported by inconclusive evidence, however, because Marble and Proctor (2000) have shown an increased Simon effect from a similar mixing.

EXPERIMENT

All the arguments listed above concerning the fact that the WHERE rule-congruency effect is not a Simon effect, while strongly persuasive, remain inconclusive nonetheless. Therefore, in the present work, I tried to provide evidence from within-paradigm comparisons. This was achieved by a manipulation that kept the potential rule-congruency effect unchanged and reversed the potential Simon-like effect. Specifically, performance in the standard response key set-up was compared to that in a mapping-reversed key arrangement (see Figure 1). This reversal was based on an "opposite" transformation, as in Shaffer's (1965) experiment. Accordingly, in the mapping-reversed response setups, a response key located in the upper part indicated DOWN, a key in the lower part indicated UP, a key on the left indicated RIGHT, and a key on the right indicated LEFT.

To prevent confusion, I use the following terms in the present paper. Rule-congruency refers to correspondence at the category-to-response mapping specified by the task rules. Simon-like effects refer to the spatial stimulus–response compatibility along the currently irrelevant spatial dimension (vertical or horizontal). Mapping-reversal describes the manipulation that mapped the upper key to DOWN, and so forth. For the task-relevant dimension, mapping-reversal is analogous to the manipulation involved in studies on spatial S–R compatibility (Fitts & Seeger, 1953).

A single experiment is reported in which four groups were compared. These groups were formed by a factorial combination of two independent variables: mapping-reversal and valence (bivalent vs. univalent response set-up). The bivalent response set-up has just been described. A univalent key set-up is one in which each nominal response or category (UP, DOWN, RIGHT, and LEFT) is mapped to a separate response key. This set-up does not involve rule-congruency. There were two main reasons for including valence in the experiment. First, it was important to show that mapping-reversal produced similarly large effects in the bivalent and univalent response set-ups. This was required in order to show that these effects were not due to a change in Simon effects, as described below. Such demonstration would strengthen the conclusion that Simon-like effects are not major contributors to rule-congruency effects. Second, in Meiran's model (2000a, 2000b) it was argued that the reason for faster responses in single-task blocks is the opportunity to strongly bias the category-key mapping in favour of one interpretation through the consistent category-response mapping. This means that, after practice, a given key-press can become strongly linked to a particular response category. Such an opportunity is not provided in mixed-task blocks because a bias in favour of one axis (e.g., emphasizing the RIGHT–LEFT categories as a result of executing the RIGHT–LEFT task) is quickly cancelled by a bias in favour of the alternative axis (UP–DOWN, in this example). Consequently, a given key-press becomes roughly equally associated with two categories, one from each task (e.g., UP and LEFT). If this interpretation of the single-task benefit (or mixing cost, see Los, 1996, but also Fagot, 1994; Kray & Lindenberger, 2000) were true, one could predict that it would be greatly reduced or even eliminated in univalent response set-ups that provide consistent category-response mapping regardless of task switching.

The core predictions are straightforward. If the rule-congruency effect is actually a Simon-like effect, it should be reversed (or at least, attenuated) in the reversed-mapping condition. The reason is that, whereas a rule-congruent trial is spatially compatible along both axes in the standard response set-up, such a trial becomes spatially incompatible along both dimensions if the mapping is reversed. For example, the response to an upper left target (see the lower left set-up in Figure 1) is made by the lower right key. A rule-incongruent trial is partially compatible regardless of whether a standard or a reversed mapping is instructed to be used. So, for example, a response to an upper-right target in the UP-DOWN task is made with the upper-left key in the standard mapping and with the lower right key in the reversed mapping. In the former case, the stimulus and response are compatible along the task-relevant dimension (both are UP) and incompatible along the irrelevant dimension (one is LEFT, the other is RIGHT). In the latter case, the stimulus and response are incompatible along the relevant, vertical axis (one is UP, the other is DOWN), but are compatible along the irrelevant, horizontal axis (both are RIGHT).

On the other hand, if the rule-congruency effect reflects persisting rule activation, it should be identical in the standard and the reversed-mapping conditions. Because reversed mappings are known to produce slower responses (e.g., Nicoletti & Umiltà, 1984; Shaffer, 1965), the prediction is for additive effects of mapping-reversal and rule-congruency.

Method

Participants

The participants were 48 students from Ben-Gurion University and its affiliated colleges, Ahva and Sapir, who took part in the experiment for course credit. All of them reported normal or corrected-to-normal vision. A total of 12 participants were assigned to each of the four groups according to their order of entry into the experiment.

Stimuli and apparatus

All testing was performed using an IBM-compatible computer controlled by software written in MEL (Schneider, 1988). Responses were collected with a standard keyboard, with reaction time (RT) recording purported to be accurate to the nearest 1 ms. The stimuli were drawn in white on black using the graphic symbols in the extended ASCII code and included a 2 × 2 grid that was presented at the screen centre, subtending a visual angle of approximately 3.4° (width) × 2.9° (height; these values were calculated assuming an observation distance of 60 cm). The target stimulus was the smiling-face character (ASCII code 1), which subtended approximately 0.3° (width) × 0.5° (height). The arrow-heads (ASCII codes 16, 17, 30, and 31) subtended approximately 0.3° × 0.3° and were positioned 0.7° from the end of the grid.

Procedure

The experiment was run in a single session composed of one warm-up mixed-task block of 25 trials, followed by four identical mixed-task blocks of 96 trials each, and a final block of 96 trials involving a single task. For one half of the participants in each group the single-task block involved the UP–DOWN task, while for the other half it involved the RIGHT–LEFT task. In the bivalent response set-up, half of the participants responded with the upper left key ("7") and the lower right key ("3"), and the other half used the upper right key ("9") and the lower left key ("1"). In the univalent response setup they used the keypad's "8" and "2" and the letter keys "C" and "Z" for UP, DOWN, RIGHT, and LEFT, respectively. In every case, the monitor was aligned with the centre of the corresponding key set. This was achieved by shifting the entire keyboard to the left in the bivalent response set-ups and by aligning the centre of the keyboard with the monitor in the univalent response set-up.

Each trial consisted of a randomly selected task cue, presented for a randomly selected cue–target Interval (CTI, 200 or 1,200 ms), joined by a randomly selected target stimulus until the response was given. After the response was given, an empty grid was presented for a fixed response–cue interval of 1,500 ms.

Results

I have omitted from the analyses the first trial of each block and also any trials preceded by errors. Trials in which RT was exceedingly long (3,000 ms) were analysed for accuracy but not for RT. (This makes it possible to see whether a manipulation affected the ability to respond correctly, irrespective of speed.) We computed the mean correct RT and the proportion of errors (PE) per condition (as defined in the relevant analysis) and participant, and we then submitted these means to analyses of variance (ANOVAs). Alpha level was .05 in all the analyses.

Analysis of all groups

RT. The first ANOVA included mapping-reversal (standard vs. reversed) and response valence (bivalent, univalent) as between-participant variables, and CTI and task-switch (switch, nonswitch, single-task trials) as within-participant variables. For brevity, I only report effects that are not qualified by higher order interactions. There was a main effect of mapping-reversal, $F(1, 44) = 6.62$, $MSE = 74{,}486.89$. The mean RT was 708 ms (PE = .05) for reversed mapping and 625 ms (PE = .02) for the standard mapping. However, this effect did not produce any significant interaction with the other variables, $F\text{s} < 0.6$. There was also a significant two-way interaction between CTI and task-switch, $F(2, 88) = 75.19$, $MSE = 1{,}568.42$, and a marginally significant interaction between response valence and task-switch, $F(2, 88) = 3.05$, $p = .052$, $MSE = 9{,}638.62$ (see Figures 2 and 3).

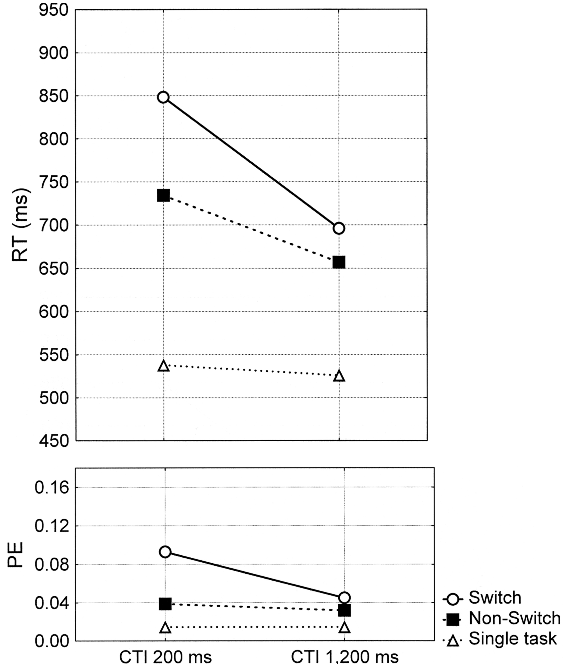

Figure 2. Mean RT and proportion of errors (PE) according to cue–target interval (CTI) and task-switch.

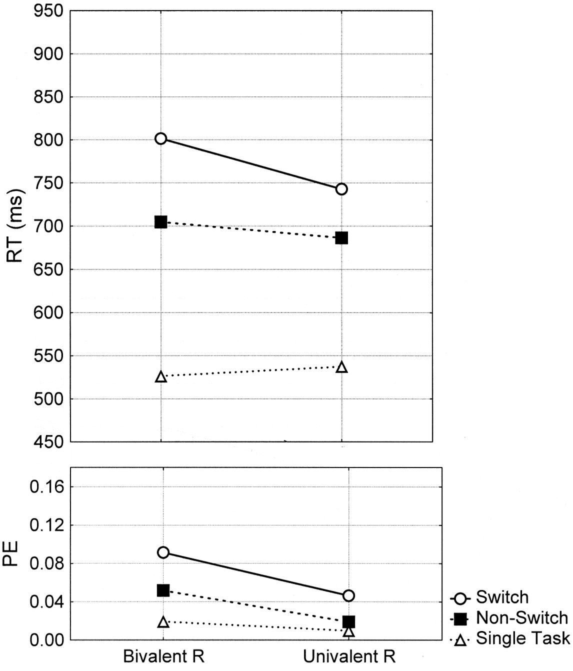

Figure 3. Mean RT and proportion of errors (PE) according to response valence and task-switch.

There was a significant effect of CTI in both switch and nonswitch trials, *F*s(1, 44) = 124.99 and 71.89, *MSE* = 4,445.38 and 1,999.14, respectively, but only a marginally significant simple effect in single-task trials, *F*(1, 44) = 3.89, *MSE* = 898.13, *p* = .055. The marginal switch by valence interaction was broken down into two separate interaction contrasts. One contrast examined the effect of valence on switching cost (switch vs. nonswitch) and was significant, *F*(1, 44) = 5.24, *MSE* = 3,730.23, while the other contrast examined the effect on mixing cost (nonswitch vs. single task) and was nonsignificant, *F* = 1.22, *ns*. The reduction rather than elimination of switching cost in univalent responses is more similar to Brass et al.'s (2003) results than to Meiran's (2000b) results, both of which involved the same paradigm as was used here.

PE. An analogous analysis of PE produced a parallel pattern of results. There was a significant main effect of mapping-reversal, *F*(1, 44) = 6.21, *MSE* = 0.0095, a significant interaction between task-switch and CTI, *F*(2, 88) = 27.86, *MSE* = 0.0161, and between task-switch and valence, *F*(2, 88) = 3.23, *MSE* = 0.0024. Unlike in the RT analysis, mapping-reversal interacted significantly with task-switch, *F*(2, 88) = 4.37, *MSE* = 0.0024. The latter interaction reflects the fact that the set-up with reversed mapping increased PE from .01 to .02 in single-task trials, from .02 to .05 in nonswitch trials, and from .05 to .09 in switch trials.

Analysis of the bivalent condition

The present analyses were conducted on the two groups that used a bivalent response set-up. The analyses included mapping-reversal as a between-participants variable and CTI, task-switch, response-repetition, and rule-congruency as within-participants variables. In order to save space, I only report effects that were not already reported in the preceding analysis.

RT. Of greatest interest are interactions involving rule-congruence and mapping-reversal. None of these eight interactions even approached statistical significance, all *F*s < 0.7. The nonsignificant, *F*(1, 22) = 0.01, interaction between rule-congruency and mapping-reversal is presented in Figure 4. In addition, rule-congruency interacted significantly with task-switch, *F*(2, 44) = 10.44, *MSE* = 6,527.13, see Figure 5, and there was a triple interaction involving switch, CTI, and response repetition, *F*(2, 44) = 3.37, *MSE* = 3,539.50, see Figure 6. The nonsignificant interactions between CTI and mapping-reversal (*F* = 0.01) and between mapping-reversal and rule-congruency consist of a replication of similar effects in De Jong's (1995) and Proctor et al.'s (2003) studies.

Rule-congruency effects were significant in all switch conditions, as examined by a series of planned contrasts, *F*s(1, 22) = 27.38, 27.75, and 13.40, *MSE*s = 20,403.12, 8,810.60, and 3,546.59, for switch, nonswitch, and single-task trials, respectively. A series of planned contrasts tested the response repetition effect within all the six combinations of CTI and switch. In the short CTI, the response repetition effect was significantly reversed in switch trials, *F*(1, 22) = 8.45, *MSE* = 12,589.90, had the usual pattern (faster repeated responses) in nonswitch trials, *F*(1, 22) = 4.42, *MSE* = 7,363.65, and was nonsignificant in single-task trials (although the trend was for reversal), *F* = 2.89, and in all the long CTI conditions,

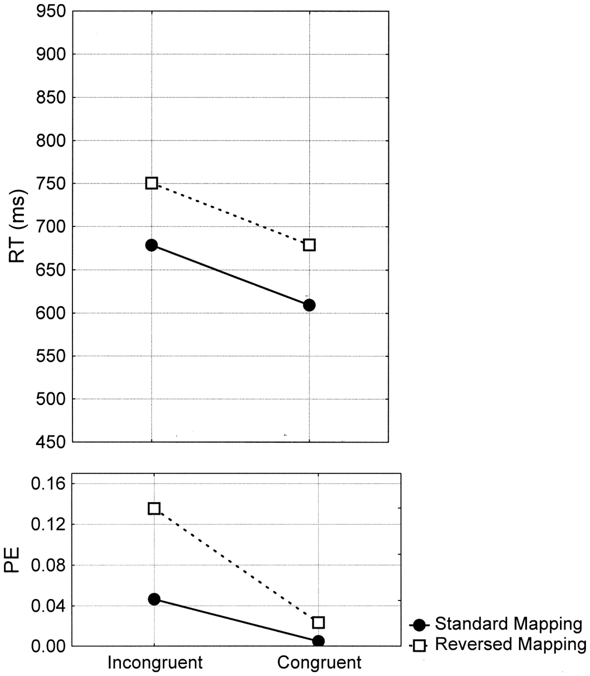

Figure 4. Mean RT and proportion of errors (PE) according to mapping-reversal and rule-congruence (the interaction was nonsignificant, $F = 0.01$).

*F*s = 2.64, 0.04, and 3.55. These effects are standard in task-switching (Fagot, 1994; Kleinsorge & Heuer, 1999; Meiran 1996, 2000a; Rogers & Monsell, 1995), and their discussion is outside the focus of the present paper. They are presented just to show that mapping-reversal did not modulate the processing of task-switching.

PE. Note that if my interpretation of rule-congruency is correct, PEs do not reflect the actual error rate. Specifically, if participants commit a "task error"—that is, they respond correctly according to the currently irrelevant task rule (cf. Meiran & Daichman, in press; Meiran, Gotler, & Perlman, 2001; Meiran, Levine, Meiran, & Henik, 2000)—this would not be seen in corresponding trials. Task errors, by their definition, produce seemingly correct responses in congruent trials. As a result, many PE effects, especially those affecting task errors, are negligible in congruent trials. This, in itself, produced several pseudointeractions. One such interaction was between rule-congruency and mapping-reversal, $F(1, 22) = 5.49$, $MSE = 0.0325$. According to this interaction, the effect of mapping-reversal was larger in incongruent trials (.14 vs. .04 for the compatible and incompatible conditions, respectively) than in congruent trials (.02 vs. near zero). Note that the presence of an interaction accords with my interpretation of the rule-congruency effect.

Because of the considerations above and because the PE was an order of magnitude larger in incongruent trials (.09) than in congruent trials (.01), I ran the RT-parallel analysis on only the incongruent condition. This analysis produced a significant interaction between

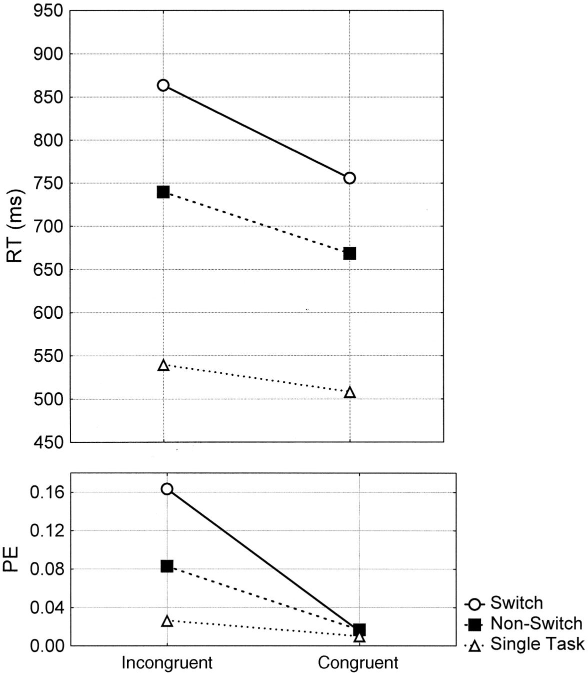

Figure 5. Mean RT and proportion of errors (PE) according to switch and rule-congruence.

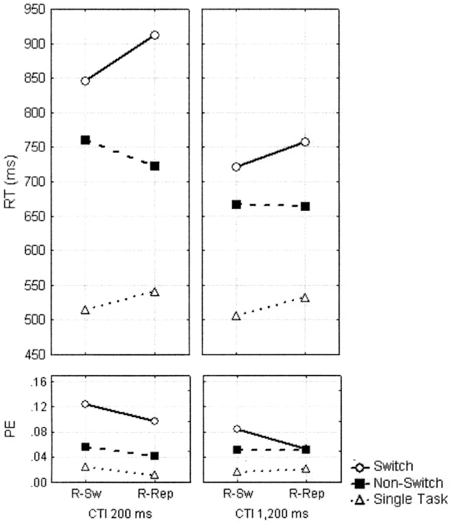

Figure 6. Mean RT and proportion of errors (PE) according to switch, cue–target interval (CTI), and response repetition.

response repetition and mapping-reversal, $F(1, 22) = 6.59$, $MSE = 0.0054$. Response repetition reduced PE from .16 to .11 in the set-up with mapping-reversal but did not affect PE in the set-up with standard mapping (.05 for both repeated and switched responses). No other effect of rule-congruency or response repetition was significant.

Task effects

In the present analysis we included task as an additional independent variable. In order to ensure a sufficiently large number of trials per condition, I omitted response repetition from the analyses. Moreover, because half of the participants in the single-task condition performed the RIGHT–LEFT task while the other half performed the UP–DOWN task, I analysed the mixed-task conditions and the single-task condition separately. To save space, only RT results are presented.

Single-task performance. The present analysis is not powerful because it is restricted to the last block of the session and because task was a between-participant variable in that condition. As a result, none of the effects (except for correspondence, already reported) were significant. Nonetheless, of all these nonsignificant effects, the interaction between task and correspondence had the largest F value, $F(1, 22) = 2.19$. The correspondence effect in the UP–DOWN task amounted to 555 vs. 508 ms, or 47 ms. In the RIGHT–LEFT task it amounted to 535 vs. 514 ms, or 21 ms, only.

Mixed-task performance. The significant interaction between task and rule-congruency, $F(1, 22) = 8.66$, $MSE = 9{,}120.10$, displayed the same trend as that in the single-task case, but this time it was much stronger. The correspondence effect was 843 vs. 733, or 110 ms, in the UP–DOWN task and 778 vs. 726, or 52 ms, in the case of the RIGHT–LEFT task. Nonetheless, this effect was not modulated by mapping-reversal.

Mapping-reversal, CTI, and task were involved in a significant triple interaction, $F(1, 22) = 4.34$, $MSE = 2{,}860.82$. The simple interaction between task and mapping-reversal was marginally significant in the short CTI, $F(1, 22) = 2.84$, $p = .11$, but was nonsignificant in the long CTI, $F = 0.3$. When the CTI was short, mapping-reversal effects were larger in the UP–DOWN task than in the RIGHT–LEFT task. There was a marginal interaction between mapping-reversal, switch, and task, $F(1, 22) = 4.05$, $MSE = 6{,}858.68$. The simple interaction between task and mapping-reversal, whose trend is described above, was significant in the switch condition, $F(1, 22) = 4.48$, but not in the nonswitch condition, $F = 0.06$.

In summary, while task was involved in several significant effects, it did not modulate the insignificant interaction between congruency and mapping-reversal.

Distributional analysis

Hommel (1993, cf. De Jong et al., 1994) showed that long-term memory-based compatibility effects were more pronounced among relatively quick responses. In the present experiment, rule-congruency effects produced the opposite pattern. They increased rather than decreased with response slowing. Specifically, the effect on the first, second, and third RT quartiles was 80, 102, and 154 ms, respectively, in the UP–DOWN task and 41, 60, and 71 ms, respectively, in the RIGHT–LEFT task, $F(2, 44) = 4.47$, $MSE = 3{,}012.29$, for the quartile by task by congruency interaction, and $F(2, 44) = 6.14$ ($p < .05$) and 1.06 (*ns*), for the quartile by congruency interaction within the UP–DOWN task and the RIGHT–LEFT task, respectively. Note that although the quartile by congruency interaction was nonsignificant for the RIGHT–LEFT task, it nonetheless indicated a numerical increase rather than a decrease with response slowing.

Discussion

The rule-congruency effect is critical in the study of task-switching because it indicates persisting rule activation, meaning that task-switching is incomplete even in nonswitch trials (Allport & Wylie, 2000; Meiran, 2000a), and its presence supports theories in which control is mediated by input selection (Meiran, 2000a, 2000b, cf. Logan & Gordon, 2001). So far, the effect had been demonstrated unequivocally only in nonspatial tasks, presumably involving the WHAT visual pathway. In contrast, the evidence from spatial tasks, presumably involving the WHERE pathway, could indicate a Simon-like preexperimental bias. Therefore, one could argue that partial task-switching is a control strategy characterizing only tasks involving the WHAT pathway.

The present experiment used a mapping-reversal manipulation that reverses the direction of the potential preexperimental Simon-like effect without affecting the potential effect of persisting rule activation. The results support the persisting rule activation interpretation unequivocally, by showing additive effects of mapping-reversal and rule-congruency. One could cautiously conclude that preexperimental biases reflected in Simon-like effects contribute only negligibly to the observed rule-congruency effect in the present spatial task-switching paradigm. More generally, the present findings add to the list of parallels between effects found in WHAT-based and WHERE-based task-switching. These include switching cost, its reduction by preparation, the reversal of the response repetition effect, and, now, also rule-congruency. Such isomorphism supports the hypothesis that the control-related effects in the task-switching paradigm reflect relatively general, domain-free processes. Because Meiran's (2000a, 2000b) model, which describes control in task-switching, accounts for all the aforementioned effects, it is likely to explain a rather general control strategy.

Other than the additive effects described above, there is an additional aspect of the results suggesting that rule-congruency is not a Simon-like effect. Specifically, the distributional analyses indicated increasing rule-congruency effects among relatively slow responses. This trend is opposite to that in the unconditional (preexperimental) component of the Simon effect (De Jong et al., 1994; Hommel, 1993).

There is still one way to interpret the present results in terms of a Simon effect. This could be explained through an analogy to studies in which a spatial S–R compatibility task is intermixed with a nonspatial task (e.g., Marble & Proctor, 2000; Proctor et al., 2003). One way to explain the analogy is to momentarily consider space as one dimensional, involving only a horizontal line. From this point of view, the RIGHT–LEFT task is the same as the spatial S–R task in Marble and Proctor's experiments, and the UP–DOWN task is "nonspatial" and therefore analogous to their colour Simon task. Like the colour task, the stimuli on which the UP–DOWN task is being performed vary irrelevantly on the spatial horizontal dimension. Under such conditions, Proctor and Marble observed that the Simon effect is emphasized if the RIGHT–LEFT task is spatially compatible, and it is reversed when the

RIGHT–LEFT task is incompatible (its mapping is reversed). (Of course, an analogous line of reasoning could be made for UP–DOWN as an S–R compatibility task and RIGHT–LEFT as a Simon task.)

In the present case, the Simon effect would appear like a rule-congruency effect. Namely, with standard mapping, UP–DOWN responses would be facilitated if their position would correspond to the target position along the irrelevant horizontal dimension. In the reversed mapping, they would be facilitated if their position would be opposite to that of the target along the irrelevant horizontal dimension. This pattern of results is precisely that observed here, and one that was interpreted as a rule-congruency effect rather than a Simon-like effect. I would argue, however, that, as in the case of the reverse Stroop effect, a reversed Simon effect reflects the persisting activation of short-term links (e.g., Tagliabue et al., 2000), which is also how Marble and Proctor (2000) and Proctor et al. (2003) explain this phenomenon. As such, it is indistinguishable both conceptually and empirically from the rule-congruency effect (see also Hommel, 2000). The critical finding here is that the long-term memory-based (unconditional) Simon effect did not contribute to the rule-congruency effect. Using the present interpretation, this was reflected in a Simon effect and a reversed Simon effect of equal size (as found in Stroop task-switching, see Allport et al., 1994).

One reason why the long-term memory-based Simon effect was not observed is the generally slowed responses. Hommel (1993) argued that the Simon effect results from a temporal-code overlap between stimuli and responses. One could therefore suggest that because RTs were generally slow in the present experiment as compared to the usual two-choice RT experiments, there was less temporal overlap between stimulus and response codes and smaller long-term memory-based compatibility effects.

An interesting question is, why did mapping-reversal produce a reliable overall slowing? First, it is important to note that a similarly additive pattern between rule-congruency and spatial S–R compatibility was obtained by De Jong (1995, Exp. 3) and by Proctor et al. (2003, Exp. 2). However, according to Kornblum et al. (1990), as well as Marble and Proctor (2000) and Proctor et al. (2003), when the responses in a compatible (standard-mapping) condition are relatively faster than in an incompatible (mapping-reversed) condition, this may result from reliance on automatic long-term memory-based S–R translation. However, De Jong (1995), Shaffer (1965), Proctor et al. (2003), and Van Duren and Sanders (1988) have all argued that such long-term memory-based translations are suppressed in conditions analogous to those in the present experiment. It is worth noting, however, that, unlike rule-congruency, the effect of mapping-reversal was statistically the same in mixed-task conditions as it was in single-task conditions. This observation suggests that mapping-reversal was not modulated by the short-term mental-set and therefore, that automatic long-term memory-based S–R translation operated in this experiment. This issue should be clarified in future research.

Broader implications

The present results support the hypothesis that task control operates similarly in the WHERE and WHAT visual systems. This in turn supports another hypothesis that the underlying control processes operate at the level of abstract, amodal codes. The present conclusion adds an important constraint to current theories of cognitive control. For example, in Meiran's (2000a, 2000b) model, task control is achieved by the stimulus-task set, which gives greater weight to the task-relevant dimension at the expense of the task-irrelevant dimension. This weighting process could be interpreted in at least two ways. One is in terms of emphasizing modal (spatial) codes. In the spatial domain this could be achieved by mentally "stretching" the representation of the 2 × 2 grid. Such stretching turns the square grid into a rectangular one and makes target positions more easily distinguishable along the (elongated) vertical axis than along the abbreviated horizontal axis, enabling successful performance of the UP–DOWN task. An analogous mental stretching along the horizontal axis would enable successful performance of the RIGHT–LEFT task. An alternative interpretation concerns abstract category codes. Under this interpretation, there are four category codes: UP, DOWN, RIGHT, and LEFT. An emphasis given to one dimension is achieved by an emphasis on a subset of the categories, such as UP and DOWN. In Logan and Gordon's (2001) theory, task control is achieved, in part, by biasing such category codes. The present results favour the abstract category interpretation, although they do not refute the modal-code interpretation. Namely, it is conceivable, although not parsimonious, to assume that modal codes mediate control within both the WHERE and the WHAT systems, but, in spite of that, the performance profile in both domains is isomorphous for some reason.

Finally, the present results concerning lesser switching cost with univalent response set-ups as compared to bivalent response set-ups consist of a replication of previous studies. As such, they support the contention that part of the switching cost results from the fact that the bivalent response set-up involves temporary changes in response codes. So, for example, having used a given key to indicate UP results in emphasizing the association between this key and the feature UP and de-emphasizing its association with the other feature with which it is bound, such as LEFT. In the context of a task-switch, such changes are counterproductive because they prepare the system for performing the wrong task (Meiran, 2000a, 2000b; Schuch & Koch, 2003). However, aside from explaining the task-*switching* cost, Meiran attributed the task-*mixing* cost (quicker response in single-task trials than in nonswitch trials) to a related process. According to Meiran, the single-task conditions afford an opportunity for forming a response representation that is strongly biased in favour of one response category (e.g., UP). This hypothesis leads to the prediction concerning a smaller or even an absent mixing cost with univalent response setups. The present results show this prediction to be wrong in showing statistically identical mixing costs in univalent and bivalent response setups. Thus, the explanation of task-mixing cost presented in Meiran's model has been refuted by the present experiment.

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Original manuscript received 11 February 2003
Accepted revision received 4 May 2004