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Stimulus-cued completion of reconfiguration and retroactive adjustment as causes for the residual switching cost in multistep tasks

Roy Luria, Nachshon Meiran, and Chen Dekel-Cohen
Department of Behavioral Sciences and Zolotowski Center for Neuroscience, Ben-Gurion University of the Negev, Beer-Sheva, Israel

In two experiments, participants indicated the identity of a target stimulus along three of its dimensions (shape, fill, and size) in two possible orders that were randomly intermixed. In Experiment 1, the last dimension was identical in both responding orders (i.e., shape-fill-*size*, and fill-shape-*size*). The results indicated that order switching produced a residual switching cost that was confined to the first response. In Experiment 2, the first dimension was identical in both responding orders (*size*-fill-shape and *size*-shape-fill), and residual cost was found in both the first and the second response. The results support a revised retroactive-adjustment hypothesis, according to which the final tuning of subtask order control is performed during the execution of the subtask that most distinguishes the orders (the first subtask in Experiment 1 and the second subtask in Experiment 2).

In everyday life, people often switch between activities, such as reading this paper and answering the telephone. Research indicates that this task switching is usually accompanied with a cost in performance: Reaction times (RTs) are usually slower and responses are more error prone after a task switch (e.g., Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995), and this difference has been termed "switching cost" (or repetition benefit, see Ruthruff, Remington, & Johnston, 2001). Switching cost is reduced but not eliminated by preparation (Meiran, 1996; Rogers & Monsell, 1995). Accordingly, some "residual switching cost" remains even after very long preparation time (e.g., 10 s; Meiran & Chorev, 2005).

There are several interpretations of the residual switching cost in the literature. In the present work we tried to distinguish between two of them.

Correspondence should be addressed to Roy Luria, Department of Behavioral Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel, 84105. E-mail: rluria@bgumail.bgu.ac.il

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Understanding these two hypotheses is easiest when they are discussed in the context of the entire range of adjustment processes involved in task switching. In general, four classes of adjustment processes are discussed in the literature. One is *advance reconfiguration* (Rogers & Monsell, 1995), which refers to task adjustments taking place during the empty preparation interval that follows task foreknowledge and precedes the target stimulus. Another process is *stimulus-cued completion of reconfiguration* (SCCR; Rogers & Monsell, 1995), which is like advance reconfiguration in the sense that it needs to be completed before actual task execution, but is carried out only after the imperative stimulus has been presented (cf. de Jong, 2000), because this SCCR is exogenously triggered. Note that the literature often refers to SCCR as lack of preparation. This is inaccurate according to our understanding, because SCCR still assumes that reconfiguration precedes task execution. An even more delayed form of adjustment is one taking place after the processing of the imperative stimulus (either during response selection of afterwards, *retroactive adjustment*, RA; see Meiran, 1996, 2000a, 2000b; Schuch & Koch, 2003). This adjustment affects the response in the following trial in case of a task switch, because the system will be suboptimally reconfigured. Retroactive adjustment is a very efficient adaptation strategy in elementary tasks because, in most cases, people are likely to continuously perform the task for some time. Finally, there are several *priming* processes discussed in the literature, such as the lingering activation of the task set (Allport et al., 1994) and the binding of the target stimulus with the task set (Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2003). The crucial difference between retroactive adjustment and priming is that the former is analogous to advance reconfiguration, except being shifted in time, whereas the latter is a passive process that results from task execution.

In the present work, we tried to distinguish between SCCR and RA as accounts for the residual switching cost. Note that the difference between the two accounts is in the degree of the shift in time of task preparation. According to SCCR, task preparation is completed only after the target stimulus is presented. Because a part of task reconfigurations is triggered by the imperative stimulus, reconfiguration time adds to the measured RT in switch trials and generates a residual switching cost. In contrast, RA assumes that final task preparation processes occur during or after task execution. Therefore, the residual switching cost, according to this account, reflects a prolongation in task execution processes (rather than an added stage of reconfiguration), and this prolongation is due to performance being generated from a suboptimally tuned system.

Traditionally, task switching designs involve only one stimulus and one response in each trial. This aspect of the design makes it difficult to determine when, following target presentation, reconfiguration took place.

Note that the answer to this question is what differentiated SCCR from RA. To address this difficulty, we designed a task switching paradigm in which task execution was stretched in time and intermediate results were observed. Specifically, in our paradigm participants gave three different responses to each target stimulus. We presented participants with three-dimensional target stimuli varying on size, fill, and shape (e.g., a large-filled circle) and required them to identify the stimuli along all three dimensions in a particular order. Critically, in each experiment we created two different multistep tasks by changing the order in which the dimensions were to be identified. Hence, each trial involved a single target stimulus followed by three separate responses (labelled R1, R2, and R3), one for each dimension. In each of the two experiments, participants switched between two randomly ordered, multistep tasks. The responses were given by pressing three symmetric but separate pairs of keys, each used for a separate dimension (see Figure 1). A cue that signalled the subtask order preceded each trial, and we manipulated preparation time by varying the cue-to-target interval. The short preparation time was 600 ms, a period long enough for maximal reduction in switching cost in both single-step tasks (Rogers & Monsell, 1995; see also Meiran, Chorev, & Sapir, 2000) and multistep tasks (Luria & Meiran, 2003). The long preparation time was 1900 ms, and was added to validate our interpretation of the switching cost as residual in nature.

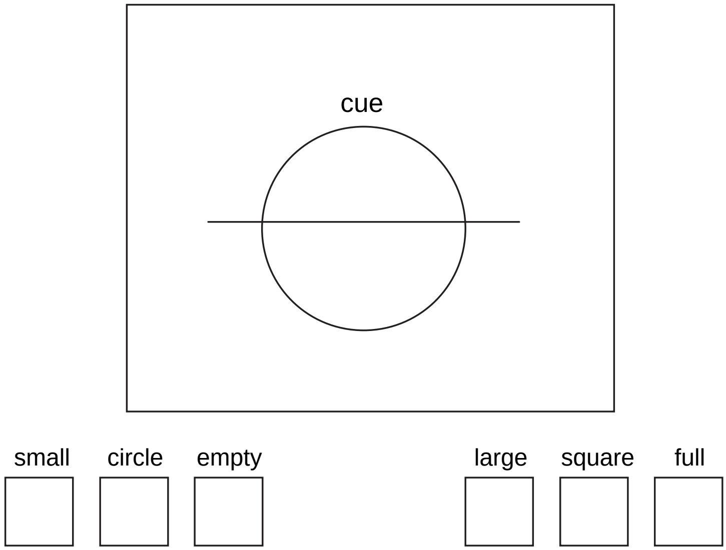

Figure 1. The experimental design. The target stimulus appeared in the middle of the screen below the order cue, with a vertical line in the middle. The actual cue was a nonword accompanied with a tone. The response keys were arranged in triplets.

An additional motivation for using varying preparation time was a set of previous studies that found that such variation is critical to induce advance preparation (Altmann, 2004).

We now turn to discuss the different predictions made by SCCR and RA. We begin by discussing only the simplest and most straightforward predictions, deferring discussion of complex versions of each account until the results of Experiment 1 are presented.

According to Rogers and Monsell (1995), SCCR is an exogenous process triggered by the stimulus that serves to complete the task reconfiguration in switch trials. The SCCR takes time to complete, so that when a new task should be preformed its processing is delayed. However, after SCCR has been completed, no additional residual switching cost should remain. Thus, in our design, the residual switching cost should be confined to R1 (assuming that sufficient time to complete the SCCR process has elapsed between the presentation of the stimulus and R2).

In the present paradigm, retroactive adjustment may form either a sequence of stimulus dimensions to be processed, a sequence of responding pairs of keys, or both. Regardless of the precise locus, this account predicts residual switching cost for all three responses. The reason is that forming a sequence of dimensions or forming a sequence of responding involves all responses, and thus should affect all of them.

Note that each stimulus had three separate responses. Because we wanted to isolate the effects of RA and SCCR on each response, we chose to analyse the data as reaction time for Subtask1 (RT1), interresponse interval for Subtask2 (IRI2), and interresponse interval for Subtask3 (IRI3; see Figure 2). Using RT2 and RT3 would not have permitted us to isolate the effects of RA and SCCR on each response. For example, assuming that

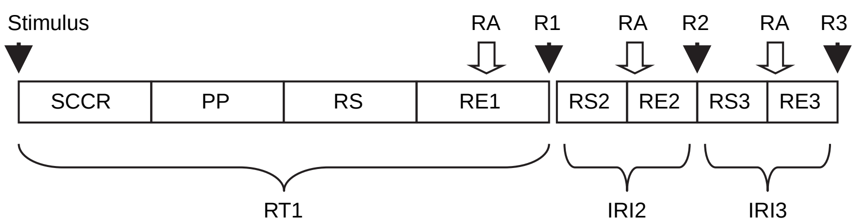

Figure 2. Summary of the predictions for the SCCR and RA, and an explanation of the way the data were analysed. Note that R1 is measured as reaction time (the time between the onset of the stimulus until the response), but R2 and R2 are measured from the onset of one response to the other. RT1 = reaction time for Subtask 1, IRI2 = interresponse interval for Subtask 2, IRI3 = interresponse interval for Subtask 3, R1 = response to the first subtask, R2 = response to the second subtask, R3 = response to the third subtask, SCCR = stimulus-cued completion of reconfiguration, RA = retroactive adjustments, PP = perceptual processing, RS = response selection, RE = response execution.

SCCR adds to RT1 (see Figure 2), and then measuring RT2 (instead of IRI2) would capture both the effect on RT1, plus any additional effects on R2. Thus, any RT2 prolongation cannot serve as evidence for processes that are specific for R2. In order to discriminate between SCCR and RA, we needed to examine prolongation of processes that are unique to each of the three responses and analysing the data as RT1, IRI2, and IRI3 was ideal for this purpose. The predictions of the SCCR and RA are summarised in Figure 2. Note that IRI reflects the time elapsing between one response and another.

Note that our switching manipulation is actually an order switching manipulation, so that participants alternate between two possible subtask orders. Relevant studies have been conducted by de Jong (1995), Luria and Meiran (2003, 2006), and Pashler (1990). These researchers studied order switching using two subtasks in the Psychological Refractory Period (PRP) paradigm, in which two stimuli (S1 and S2) are presented in rapid succession and require two separate responses, R1 and R2. Following Lashley (1951), Luria and Meiran argued that the order of the tasks is explicitly represented. When a new order has to be performed, a new order set (a representation in memory that includes the specific task order instructions) has to be loaded into working memory. Progress through the task sequence is accomplished through moving from one item to the next in the list of dimensions, as suggested, for example, by Rubinstein, Meyer, and Evans (2001) for switching between simple tasks when the task sequence is known in advance. According to Rubinstein et al., a switch of dimensions/subtasks within the sequence is accomplished by a goal shifting control process that selects and activates the appropriate dimension according to the appropriate sequence representation, deletes it from the sequence after execution, selects and activates the next dimension, and so on.

Accordingly, in the case of an order switch, a new sequence has to be loaded into some form of working memory. RT1 should be prolonged in case of an order switch, because of this need to load a new sequence representation. In addition, there should be a decrease in RT/interresponse interval (IRI) from R1 through R3 because R1 is chosen among two additional alternative subtasks by the goal shifting process, R2 is chosen among one additional alternative, and R3 does not have an alternative.

Another issue that can be explored using the present multistep paradigm is the role of preparation. In single step tasks, only one task can be prepared, so the question that has been asked is: *What* are participants preparing? However, in multistep tasks, preparation can be towards more than one subtask, hence the question we can ask is: *For which task* are participants preparing? Luria and Meiran (2003) using the PRP paradigm (which involves two discrete tasks) found that advance preparation, manipulated by extending the cue–target interval, affects only the early (preresponse selection) stages in the first subtask. This means that, in their paradigm, at least, the second subtask was not influenced by advance preparation. However, in the PRP paradigm, the two stimuli were separated by a varying stimulus–onset asynchrony (SOA). This feature of the design, which makes the onset of the second stimulus unpredictable, could encourage a strategy of preparing only the first subtask. Here, we presented a single stimulus in each trial, which could have encouraged participants to prepare more than just the first subtask. Thus, we also investigated whether preparation would have an effect on the second or even the third subtask.

EXPERIMENT 1

The main purpose of Experiment 1 was to differentiate between two explanations regarding the residual switching cost. To this end, we presented one stimulus that required three responses in two possible orders. We manipulated preparation time by presenting a cue that signalled the upcoming response order by either 600 ms or 1900 ms. If residual switching cost is the result of SCCR we should have found residual switching cost only in R1, and there should have been no residual cost in R2 or R3. The reason is that RT1 includes stimulus encoding time as well as SCCR. If residual switching cost is the result of RA, we should have found residual switching in IRI2 and IRI3 as well. In this experiment, the two subtask orders that we used were Task 1: shape-fill-size, and Task 2: fill-shape-size. Note that the last subtask (size) did not change its relative position in the sequence.

Method

Participants. Twelve undergraduate students from Ben-Gurion University participated in two 1 hour sessions as a part of the requirements for the course Introduction to Psychology, or, alternatively, for 25 NIS (New Israeli Sheckles) per session (approximately $5). All the participants reported normal or corrected-to-normal vision.

Stimuli. All testing was conducted in front of an IBM clone controlled by software written in MEL 2.0. Target stimuli were presented in white on a black background in the middle of the screen and varied along three dimensions. These stimuli were either a small/large circle (with a diameter subtending a visual angle of approximately 1.4° or 3.0°, in visual angle, assuming a distance of 60 cm from the screen) or a small/large square (each side subtending 1.4° or 3.0°), that was either empty (only the circumference depicted in white on black) or filled (the entire figure filled with a light grey colour). A thin vertical line, which subtended 4.5°, crossed the figure through its middle. This line was task irrelevant.

The task cues were composed of two-letter nonsense Hebrew syllables and a tone, presented simultaneously. Task 1 was cued by the nonword "bak" and by a low (80 Hz) tone. Task 2 was cued by the nonword "tad" and a high (900 Hz) tone. The visual cue subtended 1.4° (width) $\times$ 1.0° (height) and was positioned above the to-be-presented target stimulus. The position of the cue was 2.5° from the upper edge of the small figure and 1.5° above the upper edge of the large figure.

Procedure. The tasks were defined as two orders of response. Task 1 was shape-fill-size, and Task 2 was fill-shape-size. Neither of these orders conformed to the usual order of a verbal description (i.e., size-fill-shape, e.g., "a large empty circle"). There were two sessions. Session 1 was entirely devoted to practising the sequences and its results are not analysed. In this session, the participants performed four single task blocks (100 trials each), with their order being Task 1, Task 2, and again Task 1 and Task 2. The assignment of tasks to blocks was counterbalanced across participants. The fifth block involved randomly mixed trials involving the two tasks. In Session 2 (the one being reported) participants repeated the single-task practice in four short blocks of 20 trials each (in an opposite order to that used in Session 1) followed by a short practice mixed-tasks block (20 trials) followed by four identical mixed-task blocks, 100 trials each. Each trial consisted of the presentation of the instructional cue for a randomly chosen short (600 ms) or long (1900 ms) preparation time The auditory cue was emitted by the internal speaker of the computer for 400 ms. The target stimulus was determined randomly, except for the restriction that there could be no target repetitions. The target was presented after the preparation time, along with the instructional cue, and both were erased after the last response. Participants emitted three responses according to the relevant order. They responded by hitting keys on a standard keyboard. The keys were arranged in triplets. The triplet on the left consisted of "A" (ring), "S" (middle), and "D" (index), and the triplet on the right consisted of "L" (ring), "K" (middle), and "J" (index). Response to one subtask (e.g., shape) was accomplished with the index fingers, to another subtask with the middle fingers, and to yet another subtask with the ring fingers. The assignment of tasks to responding keys was counterbalanced across subjects. However, "small", "circle", and "empty" were always indicated by a right key press, while "large", "square", and "full" were always indicated by a left key press. The third response was followed by a constant response–cue interval of 3000 ms. A 400 Hz, 500 ms tone followed errors in practice blocks only.

Results

Each trial was associated with three responses, and hence with three reaction times (RTs)/interresponse intervals (IRIs). The first trial in each block was omitted from the analysis (because its status as switch or nonswitch was unclear). We also omitted from the analyses a fairly constant proportion of exceptionally slow or quick responses: R1s outside the 100–4500 ms range (.04 trimmed responses), R2s outside the 100–2500 ms range (.03 trimmed responses), and R3s outside the 100–1500 ms range (.02 trimmed responses). Mean RT/IRI was submitted to three-way analysis of variance (ANOVA) according to response (1–3), preparation time (600 vs. 1900 ms), and order-switch (switch, no-switch). The triple interaction is presented in Figure 3. All main effects were significant: response, $F(2, 22) = 159.70$,

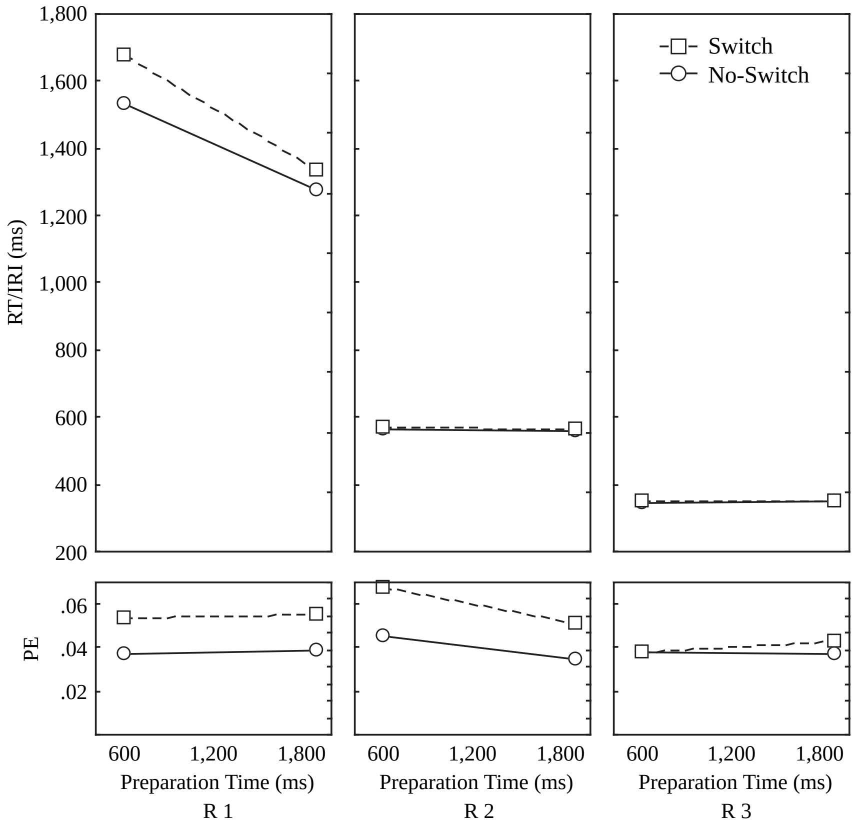

Figure 3. Mean RT/IRI according to response, preparation time, and order-switch in Experiment 1. RT = reaction time, IRI = interresponse interval, R1 = response to the first subtask, R2 = response to the second subtask, R3 = response to the third subtask, PE = proportion of errors.

$MSE = 103{,}600.39$, $p < .05$, preparation, $F(1, 11) = 62.06$, $MSE = 5975.92$, $p < .05$, and order-switch, $F(1, 11) = 7.41$, $MSE = 6511.38$, $p < .05$. The interactions between response and preparation, $F(2, 22) = 42.77$, $MSE = 8301.64$, $p < .05$, and response and order-switch, $F(2, 22) = 7.54$, $MSE = 4768.16$, were also significant.

Importantly, the triple interaction was significant, $F(2, 22) = 5.32$, $MSE = 1306.63$, $p < .05$. The triple interaction reflected a significant simple interaction between preparation and order-switch, $F(1, 11) = 6.37$, $MSE = 3363.36$, $p < .05$, in RT1, indicating a reduction in switching cost (switch RT vs. nonswitch RT) as a result of increasing preparation interval. Although the order switching cost was reduced by preparation in spite of the fact that the short preparation interval was quite long, we can still safely interpret the switching cost at the long preparation interval as residual in nature. This residual switching cost of 60 ms was significant, $F(1, 11) = 5.25$, $MSE = 3788.78$, $p < .05$. The simple-simple effects of switch, preparation, and their interaction were nonsignificant in IRI2 and IRI3, all Fs < 1 (see Figure 3). The residual switching cost was nonsignificant in IRI2 and IRI3 (9 and 3 ms, receptively, both Fs < 1).

The only significant effect on the proportion of errors (PE) was an interaction between response and order-switch, $F(2, 22) = 4.78$, $MSE = 0.0002$, $p < .05$. In the nonswitch condition, PE was the same in all three responses (.04), but in the switch condition PE was greater in the first two responses (.05 and .06) than in the third response (.04). Note that while IRI2 did not decrease from the short to the long preparation time, we did observe this pattern in the PE2 data. This is a first indication that participants can prepare towards Subtask 2 even before R1, a point that is also addressed in Experiment 2 and in the General Discussion.

It is noteworthy that RTs in the first response were remarkably slow. Pashler (1994), using serial performance tasks, also observed slow RTs in R1 relative to subsequent responses. In Pashler's study, this slowing was even magnified when a preview for successive stimuli was presented before R1 was executed. Presumably, this indicates that some additional processing takes place before R1. For example, in our design, participants should have loaded the plan for the entire subtask order. This should considerably delay R1, but at the same time should save processing time for the other responses.

Discussion

The most important result of Experiment 1 is that the residual switching cost was restricted to RT1, which is precisely what SCCR predicts. The fact that RT1 was prolonged relative to subsequent responses indicates that participants were loading a global task before responding, rather than treating the subtasks separately. We argue that general decrease in RT across responses is the result of a goal shifting mechanism (Rubinstein et al., 2001), which selects the appropriate subtask, executes it, and deletes it from the "mental list" afterwards. Thus, when the first subtask is activated, this goal shifting mechanism selects one subtask out of three, when the second subtask is activated it selects one subtask out of two possible tasks, and the third subtask is activated and not selected.

The finding that residual switching cost was confined to R1 cannot be explained in a straightforward manner by RA (Meiran, 1996). The question remains whether a complex version of the retroactive adjustment hypothesis can explain the results. For this revised hypothesis, we invoke a new distinction between critical and noncritical subtasks. Critical subtasks are ones that determine the rest of responding order (i.e., their conditional probabilities, given previous subtasks in the sequence, are the lowest). Thus, determining the identity of these critical subtasks is most informative with respect to subtask order, or conversely, knowing the subtask order mostly affects these responses. In the present experiment, the first subtask (either shape or fill) was most critical (conditional $p = .50$). The reason is that given the identity of the first subtask, the rest of the sequence can be determined. The third subtask (size) was least critical because it was the same for the two orders (conditional $p = 1.0$), thus knowing the identity of Subtask 2 did not contribute to determining rest of the responding order.

According to the revised RA, the adjustment takes place after (Meiran, 1996) or during (Shuch & Koch, 2003) the execution of the critical subtask. This means that in Experiment 1, RA took place after Subtask 1, because this subtask was the most critical in determining the rest of the responding order. Therefore, Experiment 1 cannot decide between SCCR and the revised RA because if RA took place after or during R1, then R2 and R3 were performed under optimal preparation and therefore without residual switching cost.

Thus, in Experiment 2 we used two orders that had an identical first subtask (namely, *size*-fill-shape and *size*-shape-fill), and differed in the successive second and third subtasks. Thus, Subtask 1 was no longer critical (its conditional p was 1.0). Instead, the critical subtask was Subtask 2 (conditional $p = .50$). According to the revised RA, there should be a residual switching cost for R1 as well as for R2, but not R3. The reason is that until R2 was executed, the system was suboptimally tuned. However, according to SCCR, we should still find residual order switching cost only in R1. The reason is that SCCR is an exogenous process triggered by the target stimulus, regardless of the exact order of the tasks being performed.

Another interesting question is whether participants would still hold a global task set even in conditions in which the first subtask is constant. In such conditions, a possible strategy would be to activate the first subtask, and only then to activate the order information regarding Subtask 2 and Subtask 3. This strategy, if employed, should result in relatively fast RTs in R1, because now there is no need to activate a complex plan before responding to the first subtask. In addition, there should not be a difference in performance between switch and no-switch trials, because activating the first subtask is identical in switch and no-switch trials. However, if participants would still hold a global task set, and select the task using the suggested goal shifting mechanism, it should result in slow RTs in R1 accompanied with substantial switching cost. Note that, in order to be able to test our critical prediction, we must show that participants used a global task set. Otherwise, one could make the case that R2 was functionally the first subtask in the order.

EXPERIMENT 2

In this experiment, we used two new orders: size-fill-shape and size-shape-fill. This time, the first subtask was the same in the two orders. This change in design makes no difference with respect to the SCCR account. However, according to the revised RA, this change predicts switching cost for R1 as well as for R2, but not for R3.

Method

Participants. Eighteen new participants similar to those in Experiment 1 took part in this experiment.

Stimuli and procedure. These were exactly the same as in Experiment 1, except that Task 1 was size-fill-shape and Task 2 was size-shape-fill.

Results

Outlier trimming rules were the same as Experiment 1. This resulted in .025 trimmed responses in R1, .085 in R2, and .038 in R3. Mean RT/IRI was submitted to three-way analysis of variance (ANOVA) according to the same design as in Experiment 1. All the main effects were significant: response, $F(2, 34) = 98.96$, $MSE = 256{,}720.72$, $p < .05$, preparation, $F(1, 17) = 35.85$, $MSE = 6344.84$, $p < .05$, and order-switch, $F(1, 17) = 20.05$, $MSE = 7223.56$, $p < .05$. The interactions between response and preparation, $F(2, 34) = 16.67$, $MSE = 7026.02$, $p < .05$, and response and order-switch, $F(2, 34) = 10.08$, $MSE = 2679.01$, $p < .05$, were also significant. No other effects approached significance (all $F\text{s} < 1$).

To verify whether switching cost was present across the three responses, we computed a planned comparison, contrasting the switch and no-switch conditions in the long preparation time. This comparison was significant in both R1 (113 ms), $F(1, 17) = 19.36$, $MSE = 11{,}257.80$, $p < .05$, and in R2 (49 ms), $F(1, 17) = 7.09$, $MSE = 1975.91$, $p < .05$, but did not reach significance in R3 (9 ms), $F < 1$. This means that we found residual switching cost in R1, as predicted by SCC processes, but we also found residual switching cost in R2, which was only predicted by our revised retroactive adjustments account. To further verify the cost as residual in nature, we contrasted the residual cost given short preparation with the cost given long preparation. This was done for RT1 and IRI2, where switching cost was found. Both of these planned interaction contrasts were nonsignificant, both Fs < 1 (see Figure 4).

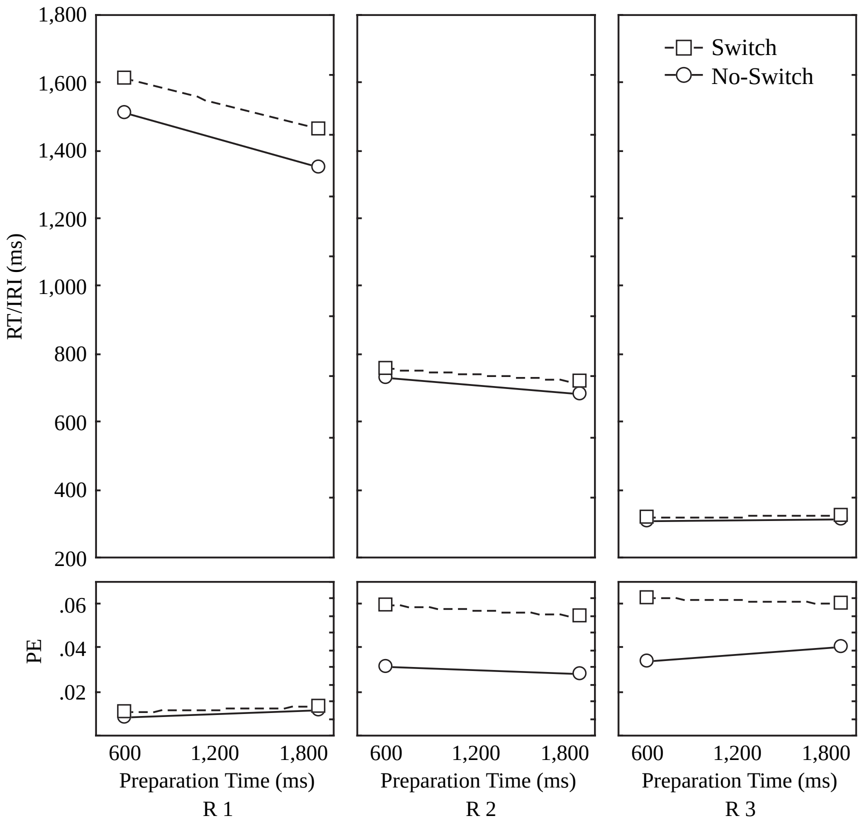

Figure 4. Mean RT/IRI according to response, preparation time, and order-switch in Experiment 2. RT = reaction time, IRI = interresponse interval, R1 = response to the first subtask, R2 = response to the second subtask, R3 = response to the third subtask, PE = proportion of errors.

As in Experiment 1, overall RTs decreased from RT1 to IRI3. Furthermore, as in Experiment 1, IRI3 was below 400 ms. In Experiment 1 this could have been a result of the specific design—the third subtask was always the same regardless of the specific order. However, in Experiment 2 the third subtask was different across the two subtask orders. The mean IRI3 was considerably slower than typical simple RTs, and slightly quicker than standard two-choice RTs. This last aspect could be due to the fact that the perceptual processing was accomplished beforehand.

The results of Experiment 2 also provide further evidence that participants used a global task set. A possible strategy that does not involve a global task set, could have been to first activate Subtask 1 (Subtask 1 was identical regardless of the specific responding order), and only then relate to the specific responding order. This strategy should have led to a relatively fast RT1, because it is now activated as a single task. However, RT1 was considerably longer than single task RT. In fact, it was roughly the same as RT1 from Experiment 1 (i.e., 1400–1600 ms). This means that participants were activating a global task set before emitting R1. Another related evidence supporting a global representation is the switching cost found in R1. Because Subtask 1 was the same regardless of the specific responding order, the same subtask was performed in either switch and no-switch trials. Thus, locally repeating the same single task should not have resulted in switching cost. Overall, we argue that participants used a global task set also in Experiment 2, despite the fact that Subtask 1 was identical.

Interestingly, we found preparation effects in both R1 and R2. Namely, RT1 and IRI2 were reduced by 154 ms, $F(1, 17) = 26.47$, $MSE = 16{,}211.75$, $p < .05$, and 44 ms, $F(1, 17) = 9.61$, $MSE = 3740.51$, $p < .05$, respectively, from the short to the long preparation interval. We address this point in the General Discussion.

A similar ANOVA was conducted on PE, and revealed main effects of response, $F(2, 34) = 41.71$, $MSE = 0.0007$, $p < .05$, and order-switch, $F(1, 17) = 8.85$, $MSE = 0.001$, $p < .05$. The interaction between those variables was also significant, $F(2, 34) = 7.12$, $MSE = 0.0004$, $p < .05$. The PE was very low in R1 (.01) for both switch and no-switch trials ($F < 1$), but it increased in R2 (.03 and .06 for no-switch and switch trials, respectively); this time the difference was significant, $F(1, 17) = 8.20$, $MSE = 0.001$, $p <$ .05, and in R3 (.04 and .06 for no-switch and switch trials, respectively); again the difference was significant, $F(1, 17) = 9.49$, $MSE = 0.001$, $p < .05$. The low error rate in R1 accords with our distinction between critical and noncritical subtasks. Although the increase in errors rates from R1 to R3 may indicate speed–accuracy tradeoff (because RT *decreased* from R1 to R3), we argue that it cannot fully account for the results. The same effects in RT/IRI, namely a constant decrease from R1 to R3, was also apparent in Experiment 1, in which there was no sign for a speed–accuracy tradeoff.

Furthermore, the apparent (but unreal) tradeoff is exactly what the revised RA hypothesis predicts. The reason is that Subtask 1 is identical between the two orders, which means that it is performed with a $p = 1.0$ probability. In terms of order control, deciding the nature of Subtask 1 is an effortless decision.

GENERAL DISCUSSION

The most important results of Experiment 2 can be summarised as follows: First, we found residual switching cost in both R1 and R2. Second, we found a decrease in RT/IRI from R1 through R2 to R3, as in Experiment 1. Finally, we found evidence for order preparation effects for both R1 and R2.

In order to account for the results of both experiments, we combine the revised RA with the order control mechanisms proposed by Luria and Meiran (2003, 2005). We argue that RA fine-tunes the order representation in switch trials, but mostly so after the maladaptation of the current tuning state is most evident. This happens during the execution of the critical subtask. Apparently, RA is not a discrete processing stage, because had it been such, R3 would have been prolonged as well. RA is probably taking place during the ultimate processing stages, as suggested, for example, by Schuch and Koch (2003). These authors showed evidence for RA affecting response codes, which took place during response selection.

A peculiar finding is the preparation effects observed in PE of Subtask 2 in Experiment 1, and in both RT1 and RT2 in Experiment 2. The R2 effect is most interesting here because the preparation that had caused it took place before the target was presented and surely also before R1 (that is, between the presentation of the cue and until R1 was emitted). To account for this finding we use the distinction between the duration of control processes and the resultant system's state that they obtain (see Meiran, 2000a). Accordingly, the resultant state was optimal order configuration. In Experiment 2, this state affected R2 because Subtask 2 was most critical (for this subtask, determining the particular order was most informative). When this optimal readiness was not achieved, IRI2 was prolonged. If preparation time was long, the time taken to achieve optimal readiness was absorbed into the preparation time. However, if preparation time was short, some R2 preparation took place while R1 was processed, resulting in a prolongation of RT1. Further assuming that, given short preparation time, participants did not wait until optimal configuration was achieved, this resulted in a less prepared state and in a prolonged IRI2. To summarise, the preparation effects in RT1 and IRI2, although similar, reflect different things. The first reflects the duration of order reconfiguration time, while the second reflects performance under more or less prepared states.

We argue that the decrease in RT across responses that occurred in both experiments is a result of a goal shifting mechanism that activates the tasks in the correct order. For the first subtask, this mechanism has to select the correct subtask among three alternatives, for the second subtask among only two alternatives, and the third subtask is activated rather than selected. Accordingly, RT3 was relatively fast. In Experiment 1, this could be explained because the third subtask was identical between the two orders. However, in Experiment 2 this was not the case, yet RT3 was below 400 ms.

Although our results support the revised RA, the revision made the hypothesis somewhat similar to SCCR. Both mechanisms indicate reconfiguration taking place after the target stimulus has been presented, both indicate that, when the target is presented, the system is not yet ready to perform the task, and both mechanisms are invoked in what may be called bottom-up processes. Although the process is reflexive and bottom-up in nature, SCCR indicates stimulus triggering, and hence is an exogenous process, while RA is triggered endogenously by the negative feedback resulting from poor performance. This is why RA is invoked (mostly?) during the execution of the critical subtask, which is the one suffering most from suboptimal reconfiguration. In that respect, RA is endogenous because it is based on the system's feedback mechanisms. Such mechanisms have been discussed, for example, by Rabbitt and Vyas (1970) who found substantial slowing following erroneous responses. Similar online "reflexive" control mechanisms are discussed in the context of conflict monitoring. For example, Carter, Braver, Barch, Botvinick, Noll, and Cohen (1998) found increased activation in the anterior cingulate cortex in error-prone situations even without an actual error.

Summary

In two experiments, we tried to differentiate between two explanations of the residual switching cost, RA and SCCR. In Experiment 1, residual switching cost was confined to R1, but in Experiment 2, residual switching cost was found in both R1 and R2. The results can be accounted for, by a revised RA process. We argue that RA is triggered by the subtask that is most informative with respect to subtask order. In Experiment 1, it was Subtask 1, thus performing this subtask triggered the RA processes. Then, R2 and R3 were performed without any residual switching cost. In Experiment 2, Subtask 2 was the most relevant in determining the responding order, triggering the RA processes and in turn R3 was performed without any residual switching cost.

Our data also supported the conclusion that participants can prepare towards the second task even before R1, and that responding to a sequence of subtask is accomplished by a goal shifting control process that selects and activates the appropriate dimension according to the appropriate sequence representation, deletes it from the sequence after execution, selects and activates the next dimension, and so on.

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