RUNNING HEAD: RANDOM AND PREDICTABLE TASK SWITCH

A MORE COMPLETE TASK-SET RECONFIGURATION IN RANDOM THAN IN PREDICTABLE TASK SWITCH

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ABSTRACT

Three experiments are presented which compare the cost found when switching from one task to another in two different conditions. In one of them, the tasks switch in predictable sequences. In the other condition, the tasks alternate at random. A smaller time cost is found at the random-switch condition when enough preparation time is allowed. Such an effect is due to the random-switch cost continuing to decrease with preparation time after the predictable-switch cost has reached an asymptote. Besides, the relationship between number of repetitions of one task and time cost is different in the random- and in the predictable-switch condition, only the latter shows the presence of an “exogenous” component of cost. The implications of this finding are discussed in relationship with the usual distinction between an endogenous component of switch cost that is affected by preparation time and another exogenous, residual component (e. g. Rogers and Monsell, 1995). It is proposed that a different kind of task-set preparation is at work when tasks alternate at random.

One important question about cognitive processing has to do with how different processes are organized and linked together to produce coherent behavior. Studying this issue demands experimental paradigms that isolate the working of individual processes from the general organization of the processing. A paradigm that has proved useful consists in switching between two or more different tasks.

SWITCHING TASKS

When one has to switch from an activity to a new one, there is usually some transient impairment in performance which can be measured both as a decrease in accuracy and as an increase in reaction time (RT). To study such an impairment in laboratory, participants are asked to alternate between two simple cognitive tasks. For example, the participant has to indicate the color of a character on trial N but report its position on trial N+1, the color again on trial N+2 and so on. When participants' performance is measured in this condition a switch cost (increased reaction time or decreased accuracy) is found with respect to pure or baseline conditions in which the participant carries out a single task throughout the experimental session.

In order to perform each of those experimental tasks, participants must set up and link a number of component processes that connect the sensory analysis to the motor response. The same processes can be linked in different ways in different tasks, even if they share the same stimulus and response sets. A task set is a particular set of processes, linked together in a certain way. When the task set has to be reconfigured to perform a new task we term it a set switch. A set switch, either voluntary or not, involves changing the processing priorities to face a new situation. Our everyday interaction with the environment demands us to continuously change our task sets or processing priorities to solve problems and adapt to it. The study of switch cost allows a precise measurement of the relative contribution of automatic tendencies and control mechanisms.

PREPARING FOR A NEW TASK

The task-switch paradigm was first used by Jersild (1927). More recently, Spector and Biederman (1976) and Allport, Styles and Hsieh (1994) have obtained very interesting results with it. One of the main findings of the latter authors referred to the temporal course of switch cost. It did not reduce reliably with the time of preparation. This is a very remarkable result. It implies that the cognitive system has difficulty preparing in advance for a new task. Allport et al. explained their results by assuming the existence of a so-called task-set inertia, i. e., a proactive interference from an old task set upon a new one. Such inertia would be automatic and involuntary in nature. The only way to eliminate the switch cost is by allowing a very long time to elapse, so that the inertia decays and vanishes. This would be a passive, involuntary decay process which does not depend on the availability of information about the next task.

Rogers and Monsell (1995) carried out a series of experiments to further explore the preparation for a new task. Their methodology was designed to insure that no differences in either stimuli or response existed between the tasks. A stimulus pair consisting in a number and a letter was presented on every trial and participants were asked to respond either to the letter or to the number. Both tasks shared the same set of responses. The two tasks alternated every two trials (except in their last experiment, which will be explained later), so that the experiment consisted in repetitions of four-trial sequences like this: letter-letter-number-number (LLNN). On each trial within a given sequence the stimuli were presented in different screen quadrants. This allowed participants to keep track of the task that was required on that trial.

In contrast with Allport et al.'s results, Rogers and Monsell found a reliable decrease in switch cost as preparation time was increased. However, the cost never vanished, even when very long foreperiods were used. The authors concluded that there are two different components in switch cost. One of them cannot be eliminated by an active process of preparation.

Rogers and Monsell (1995, experiment 6) carried out an experiment to investigate the nature of this so-called residual component. Tasks alternated every four, instead of every two, trials, which produced eight-trial sequences (LLLLNNNN). In this case, stimuli were presented in different sectors of a circle divided into eight parts. The results of the experiment indicated that the residual cost dissipated after the first repetition trial, so that no further improvement occurred on subsequent repetitions. An explanation of the residual cost in terms of task-set inertia would have predicted a gradual decrease of cost as the inertia dissipated. An account based on an improvement in performance by means of trial-by-trial feedback (micro-practice hypothesis) would also imply that the decrease takes place on more than one trial. Rogers and Monsell explained the abrupt disappearance of cost on the first trial by assuming the existence of two different reconfiguration processes (p. 224): an endogenous, anticipatory process which is responsible for the non-residual component and which can only achieve part of the reconfiguration and an exogenous process triggered by the stimulus associated with the task.

The fact that it is not possible to attain a complete endogenous task-set reconfiguration is a surprising finding. It hints at the existence of an absolute cognitive limitation for anticipating a change of task set. Subsequent studies have also found evidence of a switch-cost component which does not disappear as preparation time increases (e.g. Dreisbach et al., 1998; Gopher et al., 1998).

PREDICTABLE SWITCH AND RANDOM SWITCH

However, later research has cast doubt on the generalizability of Rogers and Monsell’s findings. For instance, Meiran (1996) used a paradigm similar to Rogers and Monsell’s but found that participants could prepare for the following task to a greater extent than was the case in Rogers and Monsell’s experiments. In Meiran’s words: “It remains unclear why the present paradigm and that used by Rogers and Monsell (1995) produced discrepant results. [...] here the task-shift cost was nearly eliminated” (p. 1439). Meiran advanced an explanation in terms of a difference in the “potency” of the cues used to signal the next task. In his paradigm, different stimuli were presented at the beginning of each trial to indicate which task participants should execute. According to Meiran, this is an “explicit cueing” which may be more effective for inducing a switch of task set than the change of position on the screen used by Rogers and Monsell.

However, there is another important difference between Rogers and Monsell’s and Meiran’s paradigm. In the latter, tasks shifted at random and not in predictable sequences, as was the case in Rogers and Monsell's study. Is it possible that random switch results in a more complete reconfiguration of task set, even if the cueing is held constant?

At first glance, this hypothesis seems counterintuitive. Predictable switch involves giving more information to participants, which should make the task easier.

Besides, predictable switch allows participants to prepare for the new task set even as they are still responding to the previous task. However, there is some evidence supporting such a hypothesis.

We (Milán and Tornay, 1998, 1999) carried out a set of pilot studies as part of a different research. In some of them we used a predictable-switch paradigm and in others tasks switched at random. The same cues were used for both kinds of experiment. We found a smaller cost in the random- than in the predictable-switch condition at long preparation times. However, in those pilot studies there were few observations per participant and the amount of practice was not enough to assure that tasks were well learnt.

AIM OF THE EXPERIMENTS AND HYPOTHESES

The aim of the experiments presented here is to examine the differences in cost between predictable and random switch. We hypothesize that in the latter condition the cost does indeed become smaller, if enough preparation time is allowed.

The random condition produces uncertainty about what the next task will be, which probably makes participants try to guess the task during the interval between trials. Besides, the random condition is more difficult and increases the probability of errors with respect to predictable condition. Guessing (Rees and Dolan, 1999), task difficulty (for a review see Paus et al, 1998) and probability of errors (Carter et al., 1998) have been shown to activate the anterior cingulate cortex, which, in turn, has been associated with attentional or control mechanisms (e. g., Pardo, Pardo, Janer and Raichle, 1990) and impulsivity control (e. g., Bush et al., 1999). Therefore, it is possible that the random condition leads to a more attentional or controlled processing, resulting in a suppression of the current task set, which would begin as soon as a response is emitted. Such a suppression would take time and, therefore, would not be detectable unless enough time elapses between the response and the next trial. When the suppression process is complete, there should be no further exogenous reductions of cost, in contrast to the predictable-switch condition, in which such an exogenous reconfiguration is evident, as shown in Rogers and Monsell's experiment 6. We assume that the reconfiguration process that occurs in the predictable-switch condition (and, in particular, the part that is dependent on exogenous factors) is, comparatively, more automatic in nature than the suppression process that takes place in the random-switch condition. At first glance, it may appear odd to consider a reconfiguration process to be automatic, because it seems intuitively clear that the reconfiguration is a voluntary and, hence, controlled process. That was, for instance, Jersild's (1927) view. However, both Allport et al.'s (1994) and Rogers and Monsell's (1995) results have shown that it may be impossible to completely reconfigure the current task set even if one is willing to do so. Besides, when the reconfiguration does take place, it may depend on processes independent of will: a passive decay of the proactive interference, as suggested by Allport et al., or the appearance of stimuli relevant to the new task (exogenous factors), as shown by Rogers and Monsell. We also assume that the default processing mode is the one that occurs in the predictable-switch condition, that is, the more automatic one. A situation which produces the activation of controlling mechanisms (such as the difficulty and uncertainty present in the random-switch condition) is necessary for the more attentional or controlled processing to operate.

It is not the goal of this study to test the previous account of switch cost completely. We are going to focus on the issue of whether the reconfiguration is more complete in the random than in the predictable condition. We will not directly address the question of whether the former produces a more controlled processing than the latter.

The hypotheses are the following: a) random switch should, indeed, lead to a smaller cost than predictable switch even if the cues are the same in both conditions; b) the advantage of random switch should only be evident at rather long preparation times, i. e., there should be a significant interaction between task predictability (random vs. predictable switch), foreperiod and switch cost; c) the relative importance of exogenous reconfiguration should be smaller in the random-switch than in the predictable-switch condition.

Another issue that will be addressed in the following experiments has to do with the way in which the random-switch reconfiguration process takes place. So far, we have assumed a suppression of the old task set. However, it is only the differential level of activation of the two task sets that is important. A larger activation of the new task set would also lead to a similar reconfiguration process. The experiments to be reported here were not specifically designed for distinguishing between these two alternatives. However, it may be possible to explore the issue by considering the effect of congruency.

In task-switch experiments, there are usually two kinds of trials. On some trials the two tasks would require the same response, whereas on other trials each task would call for a different response. The former are known as congruent trials, the latter are incongruent trials. Performance on congruent trials tends to be better than on incongruent trials. The effect of congruency has been considered an index of the degree of activation of a given task set (for a review see Hommel, in press). If the random-switch condition produces a suppression of the old task set at long foreperiods, congruency effects should be reliably smaller in this condition than when the task switch is predictable.

EXPERIMENT 1

In the first experiment we try to find out whether the reduction in switch cost with the response-stimulus interval (RSI) is larger when tasks switch at random than when they alternate in a predictable way. Our purpose is to make both kinds of task as comparable as possible. It is important to use the same cues in both conditions so that no difference in "potency" is present. As has already been mentioned, two main cueing procedures have been used in previous studies. Borrowing Meiran's terminology we will call them "implicit" and "explicit cueing". The former consists in presenting the stimuli in different spatial positions according to the task to be performed on the following trial. In the latter, different stimuli are used to signal the different tasks. Implicit cueing has been mainly used in experiments in which tasks switched predictably (e. g., Rogers and Monsell, 1995), whereas explicit cueing is typical of random-switching paradigms (e. g., Meiran, 1996). Another difference between both kinds of cueing is worth noting. When tasks switch predictably, there are a number of cycles, which are repeated throughout the experiment. For instance, in most of the experiments carried out by Rogers and Monsell, tasks switch every two trials. Therefore, there are four-trial cycles (LLNN, where L means letter task and N stands for number task). We will refer to each of such cycles as a task sequence. Despite its name, implicit cueing is usually more informative than explicit cueing because it indicates the position of the next trial within the task sequence, i. e., whether it is the first, the second, the third or the fourth trial in the current cycle.

Therefore, there are two ways of comparing the random and the predictable-switch conditions: either the implicit cueing paradigm is adapted to a random-switch condition or explicit cueing is used when tasks switch predictably. The second solution will be used in the experiments presented here. We consider that explicit cueing makes the two switch conditions more comparable. When tasks switch at random, implicit cueing entails a spatial uncertainty that is not present in the predictable switch condition, because participants do not know in advance where the next stimuli will appear. Besides, in the predictable-switch condition implicit cueing provides two different pieces of information: the next task to be performed and the position in the task sequence of the following trial. Only the former is available in the random-switch condition because no such a task sequence exists. Any difference between the random- and the predictable-switch condition may be due either to task predictability per se or to the amount of information available to participants.

In order to avoid confusing those effects, we will use an "explicit" stimulus to signal the next task, so that the cue will not carry any information about the position of the trial in the task sequence. However, such a procedure results in another type of difference between the two conditions. When tasks switch predictably, participants can rely on two different sources to find out which task will be required: the cue and the position in the task sequence, which they have stored in memory even if the cue does not remind them of it. If, as our hypothesis states, a smaller cost is found in the predictable-switch condition, it may be partly attributed to some kind of interference between these two sources of information. However, we think that this difference is not so potentially confusing as the one produced by implicit cueing. In all cases, the two sources of information will coincide, so that there will never be any conflict between them. Besides, any interference should decrease as the RSI increases, because there is more time to reconcile both pieces of information. This would be exactly the reversed temporal pattern as the one we hypothesized, which makes it possible to dissociate between the interference effect and the existence of a more complete preparation in the random than in the predictable switch.

In the following experiment, we will compare two levels of RSI which, according to Rogers and Monsell's findings, should show a clear reduction in cost (200 and 1200 ms). In both conditions the tasks will share the same stimulus and response sets.

Method

Participants

Sixteen undergraduates (nine women, seven men) took part for course credit. Their vision was normal or corrected to normal.

Design

We used a repeated-measures design with five independent variables. Three of them varied on a trial-by-trial basis: congruency (congruent or incongruent responses), task (number or letter task) and switch (shift or repetition trials). The other two variables were blocked, as explained below. These variables were: (a) RSI, which was 200 ms in two of the blocks and 1200 ms in the other two; (b) predictability of the next task, in two of the blocks tasks alternated predictably, switching every two trials (LLNNLLNNLL, where L means letter task and N means number task), in the other two blocks, tasks shifted at random.

Apparatus and stimuli.

The experiments were designed using the MEL program (Schneider, 1988). They were run in dimly illuminated, black rooms, on IBM 486 computers with a SuperVGA graphics card. A chin-rest helped participants to keep their eyes 60 cm away from the screen.

On every trial a fixation point appeared on the center of the screen. It was either an “at” sign (@) or an asterisk (*), depending on which task was to be performed, as explained below. Both signs subtended 2.86º x 2.86º of visual angle. Later on the trial, a stimulus pair, consisting of a number and a letter (e. g., 5A, A7, 2B, P4, ...), was presented on the center of the screen, replacing the fixation point. We manipulated the interval between fixation point (or cue) and stimulus pair, as will be later explained. The stimulus pair remained on the screen for 500 milliseconds. It subtended 4.76º x 4.76º of visual angle.

Procedure.

Participants were asked to carry out one of two possible tasks. They had either to indicate whether the number was odd or even (number task) or whether the letter was a vowel or a consonant (letter task). In both tasks participants responded by pressing the “b” and the “n” keys on the keyboard. This way, both tasks shared the same stimuli and responses. Half of the participants had to press “b” to indicate that the number was even or the letter was a vowel and “n” when the number was odd or the letter was a consonant. For the other half, the reverse stimulus-key mapping was used. Each participant was randomly assigned to either mapping. On 50% of the trials both stimuli required the same response (i. e. they were congruent trials), on the remaining 50% of the trials were non-congruent. Participants were given a maximum of 3 seconds after the appearance of the stimulus pair to emit the response before proceeding to the next trial. The new fixation point was presented as soon as the trial finished (the response was emitted or the 3 seconds elapsed). Therefore, the RSI coincided with the cue-stimulus interval.

Participants knew which task was to be carried out on a given trial by means of the fixation point: an “at” sign (@) signaled the number task, an asterisk (*) indicated that the letter task was required on that trial. Tasks alternated trial by trial. Each trial was either a repetition trial (when the task was the same as that on the previous trial) or a shift trial (when the task was different from the previous trial). There were as many shift as repetition trials.

There were two experimental sessions. Each of them began with two 60-trial blocks, in which participants practiced both tasks (number and letter) separately. The order of these two blocks was counterbalanced across participants and reversed across sessions. In each session participants carried out four trial blocks, each block consisting of 150 experimental trials. The first 30 trials in each block were considered practice and discarded from the analysis. Short breaks were allowed every 30 trials. Blocks differed in the combination of the independent variables RSI and task predictability, as explained in the design section.

The blocks were (incompletely) counterbalanced across participants. In each block all possible combinations of stimuli (even-vowel, e.g. 4A, even-consonant, e.g. 4B, odd-vowel, e.g. 5A, odd-consonant, e. g. 5B, in the two possible orderings, number-letter and letter-number) were presented. All combinations of the trial independent variables (congruency, task and switch) occurred with the same frequency in every block. Apart from the constraints mentioned above, the stimuli were selected at random on a trial-by-trial basis. Participants were instructed to avoid errors while trying to respond as quickly as possible. Therefore, accuracy was emphasized, which usually results in reaction time being a more sensitive performance measure than accuracy.

Results

We submitted both RT for correct responses and accuracy (percentage of errors) data to a 2 (switch) x 2 (RSI) x 2 (task predictability) x 2 (task) x 2 (congruency) repeated measures ANOVA. In all cases we will adopt an alpha level of 0.05 as significance criterion to decide whether a given effect is reliable or not.

The RT data revealed significant main effects of both switch, $F(1, 15) = 37.23$, and RSI, $F(1, 15) = 5.05$. Responses were reliably faster in the number (892 ms) than in the letter task (941 ms), $F(1, 15) = 9.44$. A significant Switch x RSI interaction was also found, $F(1, 15) = 17.04$. Besides, the three-way Task predictability x Switch x RSI interaction was statistically reliable, $F(1, 15) = 7.09$. The Switch x RSI interaction was significant both for predictable, $F(1, 15) = 5.57$, and for random switch, $F(1, 15) = 16.95$. However, in the predictable-switch condition, switch cost was reliable both for the 200-ms, $F(1, 15) = 15.68$, and for the 1200-ms RSI, $F(1, 15) = 10.74$, whereas only the shorter RSI produced a reliable switch cost when tasks alternated at random, for the shorter RSI, $F(1, 15) = 40.39$, for the longer RSI, $F(1, 15) < 1$.

Another important result was a reliable four-way interaction involving task predictability, task, congruency and RSI, $F(1, 15) = 7.68$. The interaction was due to a marginally significant reversal of the congruency effect (faster reaction time for incongruent responses) in the letter task at the 200-ms RSI when tasks switched at random, $F(1, 15) = 4.31$, $p < 0.056$, whereas the usual congruency effect was present in the number task, $F(1, 15) = 6.91$. The congruency effect was also reliable in the predictable-switch condition at the 200-ms RSI, $F(1, 15) = 26.96$, but it was not at the 1200-ms RSI in any condition.

Finally, a significant four-way interaction involving task predictability, switch, task and congruency was present, $F(1, 15) = 8.74$. The Switch x Task x Congruency interaction was reliable when tasks shifted at random, $F(1, 15) = 7.61$, but not when they alternated predictably, $F(1, 15) < 1$. In the predictable-switch condition, the Task x Switch interaction did not reach significance. In the random-switch condition there was a significant Task x Switch interaction for congruent trials, $F(1, 15) = 7.54$, but not for non-congruent trials. The reason for the significant interaction on congruent trials is a tendency for a switch benefit rather than a cost in the letter task. However, such a benefit did not reach significance.

(Please insert Figure 1 about here)

Accuracy data showed reliable main effects of switch, $F(1, 15) = 127.72$, congruency, $F(1, 15) = 11.21$, and RSI, $F(1, 15) = 15.72$, as well as a significant Task predictability x Switch, $F(1, 15) = 22.65$. There was a reliable switch cost both for predictable, $F(1, 15) = 8.23$, and random switch, $F(1, 15) = 132.75$. Neither the effect of task predictability nor that of congruency were significantly affected by RSI.

(Please insert Table 1 about here)

Discussion

RT data show a clear reduction of switch cost with RSI, which agrees with Rogers and Monsell's (1995) reports. The reduction in time cost, however, is reliably different for predictable and random switch. Whereas the cost is almost halved in the predictable condition as the RSI varied from 200 to 1200 ms, in the random condition the cost is more than 10 times smaller at the longer RSI. This is true in terms of both absolute and relative cost. Such a difference is partly due to a larger cost for the random-switch condition at the shorter RSI. The main cause, however, seems to be a much smaller cost at the longer RSI in the random than in the predictable condition, so that the time cost is not even statistically reliable in the former. Please note that, whereas the time cost almost vanishes in this condition, the reduction in error cost does not interact reliably with task predictability, so that there is always a reliable error cost at the longer RSI. Besides, the error cost for random switch is much larger than when the switch is predictable (see table 1), i. e., there is a tendency for speed-accuracy tradeoff in residual cost. However, such a tendency does not seem to interact with RSI, not only because the Switch x RSI interaction is not significant for accuracy data but, more importantly, because the difference in cost between the predictable- and the random-switch conditions seems to be fairly constant across the RSI levels. Therefore, it cannot be concluded that the residual cost is smaller in the random-switch condition, only that switch cost decreases more with RSI.

Taken together, the results seem to support the hypothesis that, with enough time, participants can prepare better for the next task in the random- than in the predictable-switch condition, at least in relative terms. This result agrees both with Meiran's (1996) results and with our own pilot studies (Milán and Tornay, 1998). However, alternative explanations are also possible. For instance, the fact that RTs are slower when the switch is predictable than when it is random, especially on repetition trials, can be interpreted in the sense that the reduction in cost in the random condition is due to a less complete preparation on repetition trials, rather than a more complete preparation on shift trials. This explanation assumes that, for some reason, participants fail to completely prepare for the task, even when they have already carried it out. Only strategic factors could account for such an effect. This hypothesis seems, at first glance, less likely because switch cost is usually supposed to reflect an automatic, non-strategic process. However, Gopher et al. (1998) have shown the influence of strategic factors on switch costs.

An important point is related to the congruency effect. It is not reliable at the longer RSI either for the predictable- or for the random-switch condition. The Congruency x Task predictability interaction was not significant at the 1200-ms RSI, $F(1, 15) < 1$, and the effect of congruency was unreliable both for predictable and for random switch at that level of RSI, $F(1, 15) < 1$ in both cases. Table 2 shows the congruency effect for both conditions at the two levels of RSI. Therefore, there does not seem to be a larger reduction of the congruency effect in the random-switch condition. Such a result is contrary to the hypothesis that the previous task set is suppressed in the random-switch condition.

(Please insert Table 2 about here)

A final issue worth noting is the absence of reliable Switch x Task interactions in most conditions, especially on non-congruent trials. That is, there was, in general, no task asymmetry. This result agrees with Rogers and Monsell's (1995) findings.

EXPERIMENT 2

The RSI levels used in the previous experiment made sure that the cost was non-residual, as was confirmed by the significant reduction in cost with RSI that was found. In this experiment, we use two rather long RSIs (800 and 1200 ms). According to Rogers and Monsell's results, cost should have reached an asymptote at this point, so that it should not differ at both levels of RSI. Rogers and Monsell used predictably alternating tasks. In the following experiment we try to find out whether their results also hold when tasks switch at random. In other words, does random-switch cost keep decreasing after predictable-switch cost reaches an asymptote? If so, there should be no difference in switch cost between the two levels of RSI in the predictable switch condition. However, a clear reduction should be found when tasks switch at random.

In this experiment 2 we also try to replicate the results of experiment 1 at the 1200-ms RSI and, at the same time, gather more data that might help to decide whether the results of the first experiment were due to a more complete preparation in the predictable-switch condition or to a less complete preparation on repetition trials.

Method

Participants

Twelve undergraduates (seven women, five men) with normal or corrected-to-normal vision participated for course credit.

Apparatus, stimuli and procedure

The equipment, stimuli and procedure were identical to those in the previous experiment except for the levels of the RSI variable used, which were 800 and 1200 ms.

Results

The analysis of RT data revealed a significant main effect of switch, $F(1, 11) = 14.33$, congruency, $F(1, 11) = 25.72$, and task, $F(1, 11) = 27.01$, the number task producing faster RTs than the letter task (897 ms and 985 ms, respectively). The three way interaction Task predictability x Switch x RSI was also reliable, $F(1, 11) = 5.17$. Further analyses showed that there was a significant switch cost when tasks switched predictably, $F(1, 11) = 8.72$. Such a cost did not reliably reduce with RSI, $F(1, 11) < 1$. However, when tasks switched at random the reduction of cost with RSI was significant, $F(1, 11) = 6.30$. The switch cost was reliable for the 800-ms RSI, $F(1, 11) = 13.22$, but not for the 1200-ms RSI, $F(1, 11) = 1.27$.

No interaction involving congruency, task predictability and RSI was significant. In particular, there was a significant congruency effect at the 1200-ms RSI, $F(1, 11) = 14.35$, but not at the 800-ms, $F(1, 11) = 2.802$. Neither result depended on task predictability, $F(1, 11) < 1$ for the Task predictability x Congruency interaction at the both RSIs.

Similarly to the previous experiment, there was a significant a four-way interaction involving task predictability, switch, task and congruency, $F(1, 11) = 6.19$. Again, the Switch x Task x Congruency interaction was significant when tasks shifted at random, F(1, 11) = 13.73, but not when they alternated predictably, F(1, 11) < 1. In the predictable-switch condition, the Task x Switch interaction did not reach significance. In the random-switch condition there was a significant Task x Switch interaction for congruent trials, F(1, 11) = 19.13, due to an unreliable tendency for switch benefits in the letter task). On non-congruent trials the Task x Switch interaction was not significant, F(1, 11) < 1.

(Please insert Figure 2 about here)

As for accuracy data, the main effects of switch, F(1, 11) = 160.45, and congruency, F(1, 11) = 60.45, were reliable. The reduction of switch cost with RSI did not reliably interact with task predictability, F(1, 11) < 1. Again, no interaction of either task predictability or congruency with RSI was significant.

Discussion

The predictable-switch condition produced the same results as were reported by Rogers and Monsell, i. e., no reliable reduction in cost took place as RSI varied from 800 to 1200 ms. In the random-switch condition, however, the time cost does reliably decrease with RSI. Again, time cost is not significant in the random-switch condition at the longer RSI. The results agree, therefore, with the hypothesis that the residual component of cost is smaller when the tasks switch at random than when they alternate predictably. Besides, the fact that mean RTs are slower in the predictable-switch condition is contrary to an explanation based on an incomplete preparation on repetition trials when tasks alternate at random. Of course, such an account cannot be ruled out completely but the present data do seem to support the idea that the larger reduction in cost with RSI found in the random condition does not depend solely on strategic factors.

There is again a tendency for a speed-accuracy tradeoff, although more attenuated than in experiment 1, with larger error costs in the random than in the predictable condition (see table 1). As in the previous experiment, this difference does not seem to interact with RSI.

In contrast with the results of experiment 1, there was a clear congruency effect at the 1200-ms RSI (see table 2), which was not reliable at the shorter RSI. It is not clear why there is such a difference between both experiments, because the longer-RSI condition was identical. One possibility is related to the fact that the two levels of RSI are more similar in experiment 2 than in experiment 1, which may increase the temporal uncertainty. It should be noted that participants were not informed about the different levels of RSI in any experiment. However, some of them did notice the difference in experiment 1 but none did in experiment 2. Several studies (see Näätänen and Merisalo, 1975, for a review) have shown that maintaining preparation to respond for a long foreperiod is aversive. (Please note that this refers to a general preparation to make any response, not to be mistaken with the preparation for the new task.) In order to reduce the preparation period, participants seem to try to predict the time of appearance of the imperative signal and maintain an optimal state of preparation to respond around that predicted time rather than staying prepared for the whole foreperiod. Increasing temporal uncertainty makes it more difficult to predict the time of appearance of the stimuli. This may result in the stimuli appearing before the optimal state of preparation period begins of after it is over. Such a possibility is more likely at the longer RSI, because with longer intervals the Weber fraction for time estimation decreases, making the prediction less accurate. If we assume that suppressing incongruent responses requires an optimal state of response preparation, then the suppression would become more difficult in conditions of temporal uncertainty (as in experiment 2) and at longer RSIs, which produces a larger effect of congruency in those cases, as the data show.

This is, of course, only a speculative, post-hoc, explanation. If it were correct, however, it would mean that some kind of suppression of incongruent responses does take place. What is more important for our purposes, however, is that such a suppression (if it were present) would not be responsible for the decreased switch cost in the random condition, because congruency does not interact with task predictability and because there is a larger effect of congruency at the longer RSI, exactly when the switch cost is smaller. In other terms, the results show a dissociation between suppression of incongruent responses and reduction of switch cost, suggesting that the underlying mechanisms differ.

The interactions with task presented exactly the same pattern as in experiment 1, with a tendency for task asymmetry to be unreliable in most cases.

EXPERIMENT 3

In the following experiment we intend to explore the nature of the residual component of cost. Rogers and Monsell (1995, experiment 6) showed that residual cost disappears after the first repetition trial, rather than gradually decreasing with the number of repetitions, which was taken to indicate that residual cost is exogenous in nature, i. e., it depends on the presence of task-relevant stimuli. The results of our previous two experiments seem to imply that this residual component is smaller when tasks switch at random and may even be lacking in terms of time cost. Therefore, the relative importance of the exogenous factor should be smaller in the random-switch condition. In this experiment we intend to test this hypothesis directly. The procedure will be similar to Rogers and Monsell's. In the predictable-switch condition tasks will alternate every three trials, instead of every two trials. Accordingly, there will be six-trial task sequences (LLLNNN). This will allow us to study the effect of the number of task repetitions. If switch cost is affected by exogenous factors, it should disappear after the first repetition trial, as Rogers and Monsell reported. We will also study the effect of the number of task repetitions in the predictable-switch condition. The results of the previous experiments suggest that most of the preparation takes place during the RSI in that condition, so that little or no further reduction should be apparent on the first repetition. This would result in a smaller difference between switch trials and first repetition trials.

Method

Participants

Eighteen undergraduates (ten women, eight men) took part for course credit. Their vision was normal or corrected to normal.

Apparatus, stimuli and procedure

The equipment, stimuli, tasks and procedure were identical to those described in previous experiments except for the following. There was one experimental session. The RSI was 1200 ms throughout the experiment. After the two 60-trial practice blocks, there were two experimental blocks of 450 trials each. In one of the blocks tasks alternated regularly every 3 trials: LLLNNNLLLNNN. In the other block, tasks switched at random with the restriction that the frequency of the following two types of trial was equated: a) shift trials; b) trials on which the task was the same as that of the previous trial but different from that of two trials ago; c) trials on which the task was the same as that on the two previous trials. These three types of trials are, therefore, present in both blocks. In this experiment, the variable switch is replaced by the variable <u>number of repetitions</u> or <u>repetition</u>, for short, which was manipulated at these three levels, which we will call <u>shift trials</u> (or 0 consecutive task repetitions in the previous trials), <u>first repetition trials</u> (or 1 consecutive task repetition in the previous trials), and <u>second repetition trials</u> (or 2 consecutive task repetitions in the previous trials), respectively. In the random-switch trials there were 120 trials for each of the three levels, the remaining 90 trials (of which 6 were considered practice) corresponded to 3 or more repetitions of the same task. These trials did not have an equivalent in the predictable-switch condition. We will initially discard such trials from the analysis but will later describe the main results related to them.

The blocks were counterbalanced across participants. The first 30 trials in each block were considered practice and discarded from the analysis. Short breaks were allowed every 30 trials.

Results

RT and accuracy data were submitted to the same analysis as in the previous experiments, except for the RSI and switch variables, which were absent. Besides, the repetition variable was manipulated and analyzed at three levels (shift trials, first repetition trials and second repetition trials, or 0, 1 and 2 task repetitions). Please, note that a measure of switch cost is still available by comparing shift trials versus first and second repetition trials.

RT measures resulted in a significant main effect of repetition, $F(2, 34) = 9.25$. The effect of task was not significant, $F(1,17) = 1.71$, the mean reaction time in the number task was 683 ms, in the letter task it was 693 ms. There was a reliable interaction involving task predictability and repetition, $F(2, 34) = 3.51$. The interaction stemmed from a significant effect of repetition when the tasks alternated predictably, $F(2, 34) = 8.15$, which vanished when tasks switched at random, $F(2, 34) = 2.14$. However, the linear trend in the random condition was marginally reliable, $F(1, 17) = 3.799$, $p < 0.068$, showing a tendency for RT to reduce with the number of task repetitions.

In the predictable-switch condition, shift trials were reliably slower than the average of first and second repetition trials, $F(1, 17) = 9.80$, whereas the two types of repetition trials were not reliably different, $F(1, 17) < 1$. The effect of congruency was not significant either when tasks shifted at random or when they shifted predictably, $F(1, 17) < 1$ in both cases.

The four-way Task predictability x Repetition x Task x Congruency interaction was, once more, significant, $F(2, 34) = 7.16$. The analysis of the interaction showed a reliable Task predictability x Repetition x Task for congruent, $F(2, 34) = 4.58$, but not for non-congruent trials, $F(2, 34) = 2.35$. On congruent trials, the Repetition x Task interaction was significant when task switch occurred at random, $F(2, 34) = 7.08$, but not when it was predictable, $F(2, 34) < 1$. On congruent trials in the random-switch condition, shift trials were not reliably different from repetition trials (i. e., the average of first and second repetition trials) neither for the letter nor for the number task, F(1,

17) < 1 in both cases. However, there was a significant difference between first repetition trials and second repetition trials for both tasks, $F(1, 17) = 7.64$ for the number task, $F(1, 17) = 5.61$ for the letter task. Besides, second repetition trials are faster than first repetition trials in the letter task, whereas the contrary is true for the number task. In the latter, the second repetition trials are even slower than shift trials, which implies the existence of a switch benefit rather than a switch cost on those trials.

Accuracy data revealed significant main effects of task predictability, $F(1, 17) = 14.10$, and congruency, $F(1, 17) = 7.11$.

(Please insert Figure 3 about here)

(Please insert Table 3 about here)

Discussion

RT data in the predictable-switch condition replicate the same pattern of results as Rogers and Monsell reported: the cost disappears after the first repetition trial, which supports Rogers and Monsell's claim about the existence of an exogenous component in the preparation for the new task. Please, note that this conclusion is supported by the general shape of the function relating number of task repetitions and RT in the predictable switch condition. Both the presence of a reliable decrease in RT between switch and first repetition trials and the lack of a further decrease between first and second repetition trials are necessary. However, the random-switch condition leads to a different conclusion, as is evident from the different shape of the function in this case. Firstly, the difference between shift and repetition trials was much smaller and it did not reach significance. The pattern of data is consistent with the possibility that most of the time cost disappears during the RSI, before the first repetition trial, so that the difference between the first and the second repetition trials is smaller than in the predictable condition, where a substantial part of the cost is still present after the RSI. In other words, the importance of the exogenous factors is much smaller in the random than in the predictable-switch condition. In the latter, exogenous factors are necessary for preparation to complete, whereas in the former they are not even detectable.

As an aside, it is worth mentioning that in this experiment the cost seems to vanish completely in the random condition because it is not reliable even in the accuracy data. Accordingly, the tendency for speed-accuracy tradeoff found in the previous experiments is absent in this case. Such a result, however, may have been caused by a floor effect because of the small proportion of errors found in this experiment (see table 3).

Secondly, the difference in RT between first and second repetition trials is reversed in the random-switch condition with respect to predictable-switch blocks, although it does not reach significance in either case. Whereas RT is faster in the first than in the second repetition when tasks switch predictably, in the random-switch condition there is a marginally reliable tendency for the RT to decrease with the number of repetitions. In order to explore further that tendency, we carried out a new analysis of the random-switch data including the 90 trials before which four or more task repetitions had occurred. This way, there were four different conditions: shift trials (zero previous consecutive repetitions), first repetition trials (one previous repetition), second repetition trials (two previous consecutive repetitions) and four or more previous consecutive repetitions (mean reaction time in this condition 655 ms). We found a significant negative linear effect both if the shift trials were included in the analysis, $F(1, 17) = 7.37$, and if they were discarded, $F(1, 17) = 5.09$. This effect agrees with previous findings reported by Meiran, Chorev and Sapir (in press, experiment 1) using a random-switch paradigm. They explained the result in terms of micro-practice and argued that Rogers and Monsell could not detect it because the predictable switch causes preparation for the next task to begin before the switch occurs, which slows the response on repetition trials (especially on those closer to the expected shift). This would cancel the benefits of the repetitions. The pattern of results we obtained seem to agree with this hypothesis because, as mentioned above, the second repetitions trials are (slightly, unreliably) slower than the first ones in the predictable-switch condition. The same tendency was present in Rogers and Monsell's experiment 6 (see their figure 5, p. 225). More importantly, in the data presented here the second repetition trials in the predictable-switch condition are also slower in comparison with the second repetition trials in the random-switch condition. However, any conclusion should be taken with caution not only because of the relatively few trials with four or more repetitions but also because of the reduced number levels of the variable that we used.

Similarly to the previous experiments, the data do not seem to support the suppression hypothesis because the congruency effect disappears both for the predictable and the random-switch conditions.

GENERAL DISCUSSION

The following points summarize the main findings from the three experiments presented above:

- In the predictable-switch conditions the results reported by Rogers and

Monsell (1995) are replicated. These include a) a significant reduction in switch cost with RSI, which b) eventually reaches a plateau resulting in a "non-residual component", and c) a complete elimination of cost after the first repetition trial. The last result hints at the non-residual component being exogenous in nature.

- However, the random-switch condition produces clearly different results. Firstly, the temporal course of cost is reliably different (experiments 1 and 2). It seems to continue decreasing after predictable-switch cost has reached an asymptote.
- Besides, time cost in the random condition eventually becomes smaller than in the predictable-switch condition. Time cost even becomes unreliable by the 1200-ms RSI. This result is replicated in all three experiments. Error cost, on the other hand, tends to be larger in the random-switch condition (experiments 1 and 2) but the difference does not seem depend on RSI. Taken together, the results indicate that the cost in overall performance decreases more in the random-switch condition.
- Finally, the effect of task repetitions in the random-switch condition also differs from that in the predictable-switch condition. In the former, the results do not agree with an interpretation based on an exogenous component of cost.

Another set of results is related to the effect of congruency. In general, there is no evidence that the effect of congruency is smaller in the random condition at the longer RSI, which is contrary to the hypothesis that the old task set is inhibited when tasks switch at random. The most plausible alternative would be that the new task set becomes more active during the RSI, eventually overcoming the activation of the old one, so that the advantage of the latter with respect to the former is reversed. Nevertheless, this conclusion is a very tentative one. Congruency effects seem to depend on a variety of factors, which makes it difficult to use them as a clear-cut criterion to infer the activation of task sets. For instance, a clear difference in congruency effect is evident in similar conditions of experiments 1 and 3 with respect to experiment 2. We have hypothesized that temporal uncertainty may be partly responsible for the difference. More importantly, the effect of congruency often appears dissociated from that of switch cost. For instance, no reliable congruency effect is present in experiments 1 and 3 in situations in which a clear switch cost is found (predictable-switch conditions at the 1200-ms RSI), whereas a substantial effect of congruency appears in a case of unreliable switch cost (random-switch condition at the longer RSI in experiment 2). This does not mean that congruency and task-set activation are not related but their relationship is complex and more data are needed to draw trustworthy conclusions.

The differences between predictable and random switch are important in two different ways. One aspect has to do with methodological issues: the results found using one of the paradigms may not be directly applicable to the other. The other aspect is theoretical in nature: what underlying mechanisms are responsible for this difference?

At the beginning of this report, we proposed an account of task-set reconfiguration based on Rogers and Monsell’s assumptions about the existence of both an endogenous and an exogenous reconfiguration process. This account consists, essentially, in assuming that residual cost may be reduced in two different ways, depending on task predictability. When tasks switch predictably the appearance of stimuli relevant for the new task seems to be necessary for the cost to disappear. When the task switch occurs at random some kind of endogenous reconfiguration seems to be at work, making the exogenously-triggered reduction (at least partly) unnecessary. Besides, we supposed that the default way of operation of the cognitive system, i. e., the reconfiguration process associated with predictable switch, may be automatic. On the other hand, the more complete reconfiguration found when tasks switch at random may be more attentional or controlled in nature because it takes place in situations of increased difficulty and uncertainty.

In general, the results agree with the hypothesis that some additional mechanism is at work when tasks switch at random, which is lacking in the predictable-switch condition. A mechanism that either suppresses the old task set or activates the new one. Such a mechanism does seem to depend on the task being more difficult and uncertain, and not on the willingness to respond accurately to the new task, because the two conditions differed only in the former but not in the latter factor.

Of course, the results presented in this study do not prove that the underlying mechanisms of switch cost work exactly as we hypothesized. Many aspects have not been addressed directly and alternative accounts are possible. We have already outlined one of them: the possible influence of strategic factors. In particular, the assumption of a more controlled processing when tasks switch at random has not been tested. There is only very indirect support of the idea, stemming from the fact that difficulty and uncertainty, the main differences between the random and the predictable conditions, have been shown to activate the anterior cingulate cortex, as discussed in the introduction.

As for the question of whether the more complete preparation found in the random condition stems from a suppression of the old task set or from an activation of the new one, all we can say at this stage is that the results are not due to a general suppression of the competing, incongruent responses. The most likely alternative would be to assume an increased activation of the new task set. However, we have found no direct support for this hypothesis and there are other possibilities, including some combination of an incomplete suppression of the old task set and an increased activation of the new one.

Further research is needed to tackle these and many other issues. However, any theoretical account of task switch should explain why there is a more complete reconfiguration when tasks switch at random.

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FIGURE CAPTIONS

Figure 1. Mean reaction time for predictable and random switch at the two levels of response-stimulus interval (RSI) in experiment 1.

Figure 2. Mean reaction time for predictable and random switch at the two levels of response-stimulus interval (RSI) in experiment 2.

Figure 3. Mean reaction time for predictable and random switch in experiment 3. Results are shown for the three levels of repetition considered in the experiment. They correspond to the number of consecutive repetitions of the task on previous trials. On shift trials the number of previous consecutive repetitions is zero, on first repetition trials the number is one and on second repetition trials it is two.

TABLE CAPTIONS

Table 1. Percentage of incorrect responses in experiments 1 and 2 according to kind of trial (repetition or shift), response-stimulus interval (RSI) and task predictability (predictable or random switch).

Table 2. Effect of congruency (mean RT on incongruent trials minus mean RT on congruent trials) in experiments 1 through 3 according to task predictability and response-stimulus interval (RSI).

Table 3. Percentage of incorrect responses in experiment 3 according to the number of consecutive repetitions of the same task (shift trials, first repetition trials and second repetition trials), response-stimulus interval (RSI) and task predictability (predictable or random switch).

AUTHOR NOTE

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