Effect of arousal increase in predictable and random task switching: Evidence for the involvement of the anterior attentional network in random but not in predictable task switching

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ABSTRACT

Switch cost does not disappear as more preparation time for the next task is allowed. On the other hand, Tornay and Milán (2001) showed that such a residual cost is smaller when tasks switch at random than when they alternate in predictable sequences. They proposed that the difference was due to control mechanisms (anterior attentional network) being activated in the random condition because of the overall difficulty of the random condition. Besides, it has been shown that increasing arousal levels inhibits the anterior attentional network. Therefore, Tornay and Milán's account predicts that high arousal should result in switch cost for the random condition increasing to the levels of predictable switching. In this work such a prediction is tested by assessing the interaction between increased arousal and switch cost with both predictable and random task switching. The results may help solve the ongoing controversy about the causes of switch cost.

Author Key words: Attentional Network, switching task, Reaction time. PsycINFO Classification: Motor Process 2330 Cognitive Processes 2340; Attention 2346

1. Introduction

Jersild (1927) was the first to study systematically the impairment in performance that occurs when changing from one task to another. Fifty years later, Spector and Biederman (1976) continued that line of research. In a typical experiment, participants are asked to alternate between two different tasks. Performance is usually worse on trials on which a different task is required from the one carried out on the previous one (shift trials) than when the same task is repeated (repetition trials). Such a difference in performance can be measured both as an increase in reaction time and as a decrease in response accuracy and is called switch cost.

Allport, Styles and Hsieh (1994) showed that cost did not vanish even when a fairly long amount of preparation time (1100 ms) for the next task was allowed. Later, Rogers and Monsell (1995) further studied this effect and reported that switch cost diminished with preparation time but reached an asymptote, so that it did not disappear even after long preparation times (up to 1200 ms). The authors interpreted this pattern of results by assuming that there are two components of switch cost: one that decreases with preparation time and one which remains constant. The latter is the so-called residual cost.

This is a surprising effect that may indicate the existence of a cognitive limitation for preparing for a new activity. There is an ongoing controversy about the reason for the existence of residual cost. Some authors think that it is due to a proactive automatic interference from the previous task set. This controversy is far from being settled. Recently, Waszak, Hommel and Allport (in press) have shown that not all switch cost can be attributed to a control mechanism, whereas Monsell, Summer and Waters (in press) have argued to the contrary.

2. Predictable and random task switching

One way of solving the controversy may be to distinguish between different variations of the task switching paradigm. Tornay and Milán (2001) showed that residual switch cost is smaller when tasks alternate at random than when they shift in predictable sequences (as was the case in the work of both Allport et al., 1994, and Rogers and Monsell, 1995). This is a counterintuitive finding: The more difficult condition results in less cost. This finding has been replicated a number of times, both in our laboratory (Milán and Tornay, 2001) and in other laboratories (Morra, Stablum and Umiltà, submitted). Recently, Monsell et al. (in press) have also compared predictable and random task switching. Their procedure differed in a number of ways from that used by Tornay and Milán and some of their results were different, for instance random switch cost was still large at long preparation times and the temporal course of the interaction between random task switching was also different, switch cost being small in the random condition even at short preparation times. These differences are potentially very interesting and we are currently trying to explain them. For our current interest, however, what is important to note is that even Monsell et al. found smaller cost when tasks changed at random than when they switched in predictable sequences. Therefore, there seems to be an agreement in the literature about the fact that switch cost is smaller in the random switching paradigm, at least with long preparation times.

Tornay and Milán (2001) suggested that 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. The uncertainty and difficulty of the task may activate the anterior attentional network, which, in turn, would help reconfigure the current task set. To sum up, the authors propose that processing in the predictable condition with long preparation time is more automatic, that is, it does not depend on the functioning of the anterior attentional network. On the other hand, the random condition leads to a comparatively more controlled way of processing. The present study aims at finding evidence that may confirm or discard this account.

3. Hypotheses and overview of the experiments

One way to check Tornay and Milán's explanation is to try to affect the functioning of the anterior attentional network. Cohen et al. (1988) found that increasing the level of arousal inhibits the anterior attentional network. Posner and Rothbart (1992) have argued about the theoretical plausibility of such an effect and have called it clearing of consciousness. Such a relationship has also been found by Fan et al. (2002) and by Callejas, Lupiáñez and Tudela (in press). This finding allows us to propose a detailed hypothesis based on Tornay and Milán's proposal:

Increasing arousal level should affect residual switch cost in the random switching condition because the anterior attentional network, which would be responsible for the decreased cost, would be inhibited and, therefore, unable to reconfigure the current task set. In particular, increasing the arousal should result in residual switch cost for the random condition being similar to that found in the predictable condition, where (according to Tornay and Milan's account) the anterior attentional network is not playing a role in residual switch cost. We will call such an effect switch cost recovery. On the other hand, an increase in arousal should not interact with residual switch cost when tasks alternate in predictable sequences because the anterior attentional network would not be reconfiguring task set in this condition.

4. Experiment 1

Predictable switching paradigm with long preparation time. Tornay and Milán's proposal predicts no interaction between tone presentation and switch cost.

4.1. Method

4.1.1 Participants

Twenty-four Psychology students (17 women and 7 men) took part for course credit. They all had normal or corrected-to-normal vision. Their average age was 20.2 years.

4.1.2 Instruments

The experiment was run in PC with Pentium III processor, using the E-prime 1.0 software. Auditory stimuli were presented by means of MS 108 headphones. Their intensity was measured with a Brüel & Kjaer calibrator.

4.1.3 Stimuli

Two different fixation points were used. They also acted as predictors for the new task, as will be explained later. One of them was an at sign (@), the other was a hash sign (#).

As will be explained below, on some of the trials a tone was presented at the same time as the fixation point. Its duration was 100 ms, their wave length was 500 Hz and its intensity was 80 dB (cfr. Cohen et al., 1988). Target stimuli consisted of a capital letter and a digit.

4.1.4 Procedure

On every trial a fixation point (either @ or #) was presented on the centre of the screen for 1200 ms. In order to manipulate the level of arousal, a tone might appear simultaneously with the fixation point. The tone was presented at random, with a 50% probability and lasted 100 ms. After the disappearance of the fixation point, a target stimulus pair, consisting of a number and a letter, was presented, to which participants had to respond. After response, or after 2000 ms if no response was made, participants were given visual feedback about the speed and accuracy of their response, the feedback screen remained for 1500 ms.

On every trial, participants had to carry out one of two different tasks: a) if the fixation point was an at sign, they had to decide whether the letter was a vowel or a consonant (letter task); b) if the fixation point was a hash sign, participants had to respond whether the number was odd or even (number task). The same response keys were used for both tasks.

Participants were instructed to alternate between these tasks in predictable sequences: LLNN, where L indicates letter task and N number task. The first trial of every task was a shift trial, the second a repetition trial.

Before the experimental trials, participants carried out a 40-trial practice block for each task. Then there was an additional 80-trial practice block with alternating tasks. Two 160-trial experimental blocks followed. Short breaks were allowed between blocks. All the stimuli and conditions were randomised.

4.1.5 Results

In order to eliminate outliers, we discarded the trials on which reaction time was more than 2.5 standard deviations from the average. A 2,51 % of the trials were discarded. Besides, the data from one of the participants were discarded from the analysis because more than 50% of their responses were incorrect. Including this participant did not change the pattern of results.

We submitted the reaction time data for correct responses to a 2 (task switching, either shift or repetition trials) x 2 (tone presentation, either present or absent) repeated-measures ANOVA. There was a significant main effect of task switching, F(1,

22) = 10.63, MSE = 6292, $p < 0.01$, but neither the effect of tone presentation nor the interaction was reliable, both $F(1, 22) < 1$. See Figure 1.

Insert Figure 1 about here

An equivalent ANOVA performed on response accuracy data (proportion of errors) only revealed a significant main effect of the task switching variable, $F(1, 22) = 9.61$, MSE = 2, $p < 0.01$. See Table1.

Insert Table 1 about here

4.2 Discussion

The results of this experiment replicate the finding that there is a significant residual switch cost even with fairly large preparation times (e.g., Allport et al., 1994; Rogers and Monsell, 1995; Tornay and Milan, 2001).

Besides, the presentation of the tone did not affect switch cost. This is apparent not only in the unreliable interaction but also in the sizes of the switch cost for trials with and without sound, which were virtually identical (see Table 1).

This pattern of results agrees with our hypothesis: increasing the level of arousal has no effect on predictable task switching. In turn, this conclusion supports the idea that the anterior attentional network is not playing an important role in the appearance of residual cost. Thus, the results favour the accounts proposing that switch cost is due to automatic processing, such as the task set inertia hypothesis.

However, it is not possible to draw firm conclusions from the data at this stage. It is always tricky to interpret nonsignificant results. Besides, the data may also indicate that the presentation of the tone did not increase the level of arousal, especially because the tone presentation variable did not reach statistical significance. Therefore, we postpone a more elaborated discussion of the results until the next experiment, in which we use a random task switching paradigm and predict a significant interaction between tone presentation and task switching.

5. Experiment 2

According to Tornay and Milan's proposal, random task switching should lead to a qualitatively different kind of processing than predictable task switching. In the former case, the anterior attentional network should be activated because of the general difficulty and high error probability associated with the paradigm, which would result in a more complete task-set reconfiguration and, thus, in a smaller cost.

Therefore, inhibiting the anterior attentional network by means of an increase in arousal should prevent such a reconfiguration and, thus, recover switch cost.

In this experiment we repeat the same procedure as in Experiment 1 but with random task switching. In contrast to the previous experiment, we predict a reliable interaction between tone presentation and task switching, in the direction of a smaller switch cost when no tone is presented.

5.1 Method

5.1.1 Participants

Twenty-four Psychology students (19 women and 5 men) took part. Their age averaged 23.9 years. Their vision was normal or corrected to normal. Each participant received course credit.

5.1.2 Procedure

The procedure, as well as the instruments and stimuli, were identical to those of the previous experiment, including the practice blocks and the duration of the different stimuli and events. The only difference was that tasks did not switch in predictable sequences. There were a set of all possible sequences, with one to three repetitions of each task. Such sequences were selected at random and presented to the participants. They did not know what sequence was being used at a given time or on what trial within the sequence they were at a given moment. As a matter of fact, they were not even aware of the existence of the sequences, which resulted in a complete randomisation of the task switching while, at the same time, it was possible to keep track of the number of repetitions easily and make the different conditions as comparable as possible.

5.1.3 Results

The same outlier-elimination procedure as in experiment 1 was used, which resulted in 2.69% of the trials being discarded from the analysis. The data from one of the participants were also eliminated because response accuracy was lower than 50%. An analysis including this participant's data revealed the same pattern of results.

An ANOVA of reaction time data for correct responses showed a reliable main effect of the task switching variable, $F(1, 22) = 7.778$, $MSE = 982$, $p < 0.01$. The Tone Presentation x Task Switching interaction was also significant, $F(1, 22) = 4.873$, $MSE = 704$, $p < 0.05$. See Figure 2.

Insert Figure 2 about here

Further analyses showed a significant cost switch on the trials on which the tone was presented, $F(1, 22) = 8.118$, $MSE = 1312$, $p < 0.01$, whereas there was no reliable switch cost on trials with no tone present, $F(1, 22) = 1.11$, $MSE = 33707$, $p > 0.3$.

The analysis of the response accuracy data only revealed a significant effect of the task switching variable, $F(1, 22) = 4.77$, $MSE = 0.1$, $p < 0.05$. See Table 2.

Insert Table 2 about here

5.2 Discussion

The first important result is the reduction of switch cost on trials without tone as compared to the same condition in experiment 1. This result replicates the findings reported by Tornay and Milán (2001). Time switch cost virtually disappears, although it still remains to some extent in terms of response accuracy. This is exactly the pattern found by Tornay and Milán.

On the other hand, trials on which the tone was present showed a completely different pattern. Switch cost is much larger and similar to the one found in the previous experiment using predictable task switching (compare Table 1 and Table 2). It seems that the presentation of the tone recovers residual switch cost with random task switching.

These results are congruent with our hypothesis and, thus, provide indirect evidence about Tornay and Milan’s account of random switch cost. The appearance of the tone would result in an increase in arousal which, in turn, would inhibit the anterior attentional network, preventing it from reconfiguring task set. The outcome would be a more automatic processing, similar to the one found when tasks switch predictably.

Another detail that seems to support this interpretation is the fact that the only significant difference is that between shift trials with and without tone. That is, the presence of the tone only impairs performance when a task-set switch is called for. This is exactly what would be expected if the reconfiguration process had been inhibited during the preparation time for the next task.

6. General Discussion

The main results of the experiments presented this work can be summarised as follows. There is a substantial switch cost when tasks switch in predictable sequences even if a long preparation time is allowed (residual cost) but such a cost is much smaller when tasks switch at random (compare trials without tone in Experiment 1 and Experiment 2). Besides, the presentation of a surprising tone does not affect residual cost in predictable task switching (Experiment 1) but causes residual cost for random switching to increase to the same levels as in the predictable switching condition (Experiment 2).

Taken together, the results agree with the hypothesis that increasing arousal levels inhibits the additional task reconfiguration found when tasks alternate at random. In turn, such a finding provides evidence in favour of Tornay and Milan's account of the difference between predictable and random cost: Predictable task switching with long preparation times is relatively independent of the anterior attentional network (control mechanism) whereas such a network is involved in the reconfiguration of task set found in the random switching condition. The support for such a proposal is indirect but we think it is important because the data agree with a fairly detailed hypothesis with very low a priori probability, which would have been difficult to propose without the theoretical framework provided by Tornay and Milan's account. The data presented here are, therefore, a severe test of such an account.

The implications of both the results of the experiment and the theoretical explanation are far reaching. The anterior attentional network may play a minor role when residual switch cost is larger, that is, in the predictable switching condition. Therefore, such a cost does not seem to be dependent on the action of a control mechanism but, rather, appears to reflect a default or automatic kind of processing. On the other hand, control mechanisms seem to try to overcome such a processing and the cost that it produces.

At this stage, we can only speculate about the way both automatic and control mechanisms operate in the task switching paradigm. However, a simple explanation compatible with the findings reported here may run as follows. When control mechanisms do not take part in processing (predictable task switching with a long preparation time and random task switching when high arousal inhibits control mechanisms), performance in the current task seems to be highly dependent on the previous task. On the other hand, when control mechanisms are activated (random task switching with no tone present) current performance becomes more independent of the previous task, suggesting that the role of such mechanisms is to reduce the interference from the previous task set. Therefore, the results of the present research seem to agree with other studies which have shown that residual switch cost cannot be explained by the working of a control mechanism. We argue that much of the mixed results present in the literature in this regard may stem from a failure to distinguish between the role of control mechanisms as the cause of cost and their implication as cost reducers, which makes it possible to increase cost indirectly by preventing them from reducing interference from the previous task. A careful comparison between the predictable and the random task switching paradigms may help reduce such possible sources of confusion.

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Table 1. Mean reaction time and percentage of errors for the different conditions in experiment 1. Time switch cost (mean reaction time for shift trials minus mean reaction time for repetition trials) is also indicated for trials with and without tone.

Sound present				Sound absent			
Shift trials		Repetition trials		Shift trials		Repetition trials	
RT (ms)	% errors	RT (ms)	% errors	RT (ms)	% errors	RT (ms)	% errors
669	14%	634	11%	663	15%	627	11%
Switch cost = 35 ms				Switch cost = 36 ms			

Table 2. Mean reaction time and percentage of errors for the different conditions in Experiment 2. Time switch cost (mean reaction time for shift trials minus mean reaction time for repetition trials) is also indicated for trials with and without tone.

Tone present				Tone absent			
Shift trials		Repetition trials		Shift trials		Repetition trials	
RT (ms)	% errors	RT (ms)	% errors	RT (ms)	% errors	RT (ms)	% errors
705	12%	674	10%	681	12%	675	10%
Switch cost = 31 ms				Switch cost = 6 ms			

Figure 1. Mean reaction times for shift and repetition trials when a tone was presented (dotted line) and when there was no tone (solid line) in Experiment 1.

Figure 2. Mean reaction times for shift and repetition trials when a tone was presented (dotted line) and when there was no tone (solid line) in Experiment 2.