# Flexibility and Stability in a Task-Switching Paradigm

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## Introduction

Behaving in an efficient manner to achieve one's goals depends on executive control settings that specify what internal and external information is currently relevant in a particular context. The task-switching paradigm investigates how one's executive control settings can flexibly adapt to changing environmental demands. Subjects in this paradigm alternate between tasks based on cues that instruct them in which task is currently relevant when reaction time (RTs) is the primary dependent variable. A common finding of this paradigm suggests that flexible behavior is costly. The so-called switch cost is the difference between repeat (no switch) and switch trials, where RTs are larger for switch trials compared to no-switch trials (Mayr, 2006; Mayr, Kuhns, & Rieter, 2012; Kiesel et al., 2010).

Competing explanations of switch costs exist in the literature—the carry-over account and the long-term memory (LTM) account. The carry-over account suggests that the executive control settings of the task used prior to a switch subsequently carry over when a different task set is introduced. The resulting interference between competing tasks leads to switch costs (Gilbert & Shallice, 2002; Bryck & Mayr, 2008; Mayr, Kuhns, & Hubbard, 2014). Unlike the carry-over account, the LTM account suggests that interference comes from memory traces that are automatically encoded in LTM for every experience with a given task set (Bryck & Mayr, 2008; Mayr et al., 2014). Support for the latter explanation arises from research that provided evidence of a switch cost in the absence of an actual task switch (Bryck & Mayr, 2008). The LTM interference position of Bryck and Mayr (2008) gained additional support with O'Reilly and Frank's (2006) gating theory of working memory. This model suggests that when the gate to working memory is closed, no new sensory information can enter. Consequently, working memory is biased and operates in a maintenance mode during which current representations (e.g., task-sets) are maintained and protected from interference. When the gate is open, however, new sensory information can enter. This explanation corresponds to an "update mode," so that current representations can be updated to the relevant task set, but they are prone to interference. Bryck and Mayr (2008) explain that when a task set needs to be updated (i.e., update mode), competing LTM traces of task sets can interfere with one another, resulting in switch costs.

Additional research on executive control has investigated how switch probability influences one's cognitive flexibility and the working memory processing modes mentioned above. Generally, as the probability of a task change increases, switch costs are reduced, a result typically caused by an increase in repeat trial RTs rather than because switch trial RTs decrease (Monsell & Mizon, 2006; Mayr, 2006; Mayr et al., 2012). Researchers have tended to interpret that pattern of results as support for an internal reconfiguration process. High switch rate conditions may influence subjects toward updating representations to reflect the relevant task set because of a greater frequency of switch trials compared to repeat trials. That result may be an optimal solution in times of an actual task switch, but in the cases of a non-switch, a RT cost would result (Monsell & Mizon, 2006; Mayr, 2006, 2012). On the other hand, the low switch rate conditions may encourage subjects to stay in maintenance mode because repeat trials occur more frequently than switch trails. This circumstance may be beneficial in times of a no-switch, but would be costly in times of a switch (Monsell & Mizon, 2006; Mayr, 2006;

Mayr et al., 2012). This explanation in the literature adequately accounts for the observed pattern of decreasing switch costs as the probability of a switch increases. Additionally, the hallmark finding of reduced switch costs as preparation intervals increase also seems to generalize across switch probability conditions (Rogers & Monsell, 1995, Mayr et al., 2012).

Prior research investigating the influence of switch rate on switch costs utilized between-subject designs. The question of how well people adapt their behavior to meet the demands of stability or flexibility within the same experimental session has not been investigated. To explore this issue, we adopted a typical task-switching paradigm with varying switch-rate conditions as a within-subject manipulation to promote either flexibility or stability. We predicted that people can quickly adapt to the changing environmental demands. Consequently, we expected to observe the typical pattern seen in previous between-subjects work involving changing switch rates. We expected that high switch rate conditions would be associated with reduced or absent switch costs because of an increase in no-switch RTs. Similarly, we expected that low switch rate conditions would be associated with significant switch costs. In addition, we predict that longer preparation intervals would reduce switch costs in both switch probability conditions.

## Method

*Participants*

A total of 24 participants from the University of Oregon participated for course credit.

*Task and Procedure*

A 4:2 cue-task design was adopted to reduce cue repetitions and possible cue-priming effects that previous research has highlighted (Mayr & Kliegl, 2003). In this design, 2 different cues are used for instructing each task. Participants in the current experiment were cued aurally in preparation for the upcoming trial. The cue-stimulus interval (CSI) was either 300ms or 1000ms. For each trial, subjects were presented with three circular stimuli arranged along a virtual equilateral triangle on a computer monitor. One of these stimuli was a colored circle that was either light blue or purple. A second item was a blue, segmented circle with gaps on opposing arcs of the circle, oriented towards the upper-left, lower-right, upper-right, or lower-left. The final circle stimulus was a neutral circle that was the same color as the segmented circle. Across trials, the virtual triangle was randomly rotated, so that the positions of the stimuli were not predictable. There were two tasks: one associated with the uniquely colored item, and one associated with the gap stimulus. In the ***Color/ Hue*** task, subjects responded to the light blue or purple stimulus. If the circle was light blue, the left arrow key was the correct response. If the stimulus was purple, the right arrow key was the correct response. In the ***Gap/Space*** task, the segmented circle was the target circle. A gap pointing to the left was associated with the left arrow key, and a gap pointing to the right was associated with the right arrow key. Subjects practiced each task separately, followed by a practice block with alternating tasks. After practice was completed, subjects began the experimental session. See *Figure 1* for an outline of one completed experimental trial and the stimuli used.

For the switch rate manipulation, a 75% switch probability was used for the high switch rate condition, and a 25% switch probability was used for the low switch rate condition. Subjects switched conditions every 4 blocks, and order was counterbalanced across subjects. Subjects were provided visual instructions about the switch rate condition prior to each block: "Task switches in 1 out of 4 trials"/ "Task switches in 3 out of 4 trials." The CSI changed halfway through the experiment, and the order was counterbalanced across subjects.

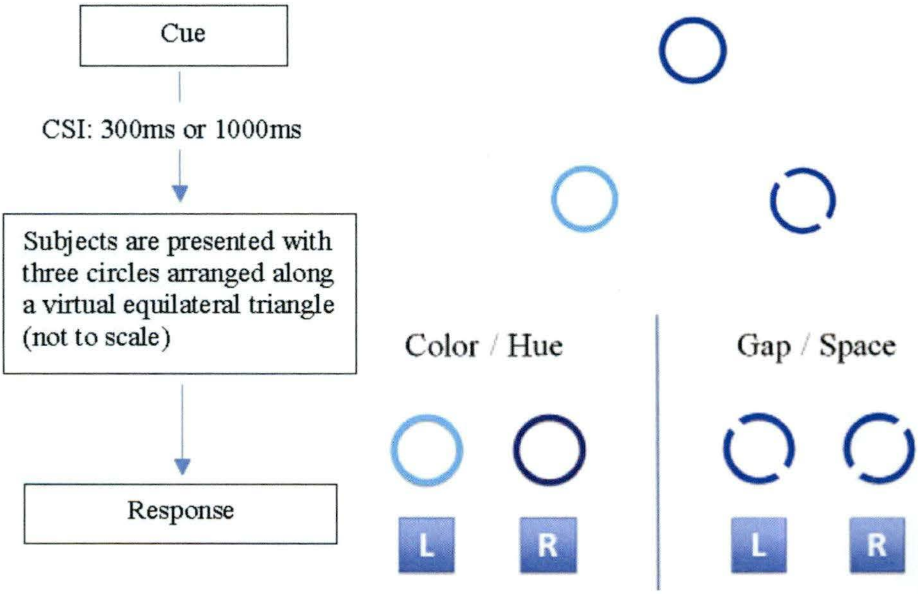


Figure 1: Subjects are presented with three circular stimuli arranged along a virtual equilateral triangle. If performing the color/hue task, a left arrow response is correct for a light blue circle, whereas a right arrow response is correct for a purple circle. If performing the gap/space task, a left key response is correct if the segment is pointing to the left, whereas a right key response is correct if the segment is pointing to the right.

## Results

Trials with reaction times greater than 4000ms, errors, and post-error trials were discarded from analyses. We ran a Repeated Measures Analysis of Variance (ANOVA) with CSI (300ms vs 1000ms), Switch (switch vs no-switch), and Switch Rate (high vs low) as within-subject factors. Providing support for the hallmark finding from the task-switching paradigm was a main effect of switch ($F(1,23) = 65.556$, $p < .001$) where RTs were larger in switch trails compared to no-switch trials ($M_{No\text{-}Switch}$ = 670, $M_{Switch}$ = 739). In addition, there was a main effect of switch rate ($F(1,23) = 32.336, p < .001$) where a higher switch probability is associated with larger RTs than a lower switch probability ($M_{Low\text{-}Switch}$ = 688, $M_{High\text{-}Switch}$ = 741). Lastly, longer preparation intervals (CSI) were associated with faster RTs than shorter preparation intervals in both switch rate conditions ($M_{Long\ CSI}$ = 652, $M_{Short\ CSI}$ = 757, $F(1,23) = 265.433, p < .001$). All 2 and 3 way interactions were significant at the .05 level. For the interaction of switch and switch rate (see *Figure 2*), a large switch cost was ob-

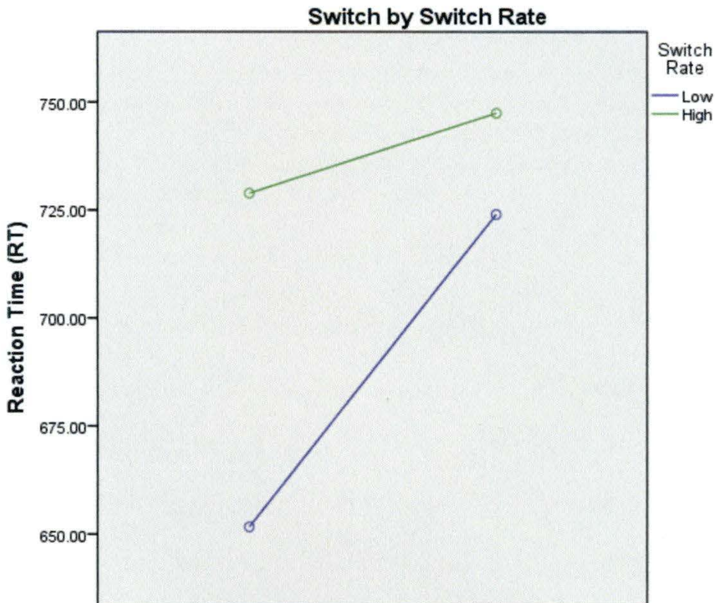


Figure 2: Large switch costs resulted when switch probability was low, and this cost was reduced when the switch probability increased.

served in the low switch rate condition, but this cost was reduced in the high switch rate condition ($F(1,23) = 30.104$, $p < .001$). The switch cost reduction in the high switch rate condition resulted from an increase in repeat trial RTs not because switch trial RTs decrease. In addition, the longer CSI condition resulted in reduced switch costs compared to the shorter CSI condition (see *Figure 3*, $F(1,23) = 13.486$, $p = .001$). Lastly, the three-way interaction of CSI, switch, and switch rate was significant (see *Figure 4*, $F(1,23) = 13.283$, $p = .001$). This suggests that the longer CSI condition had the most beneficial impact on switch costs when the switch rate was low.

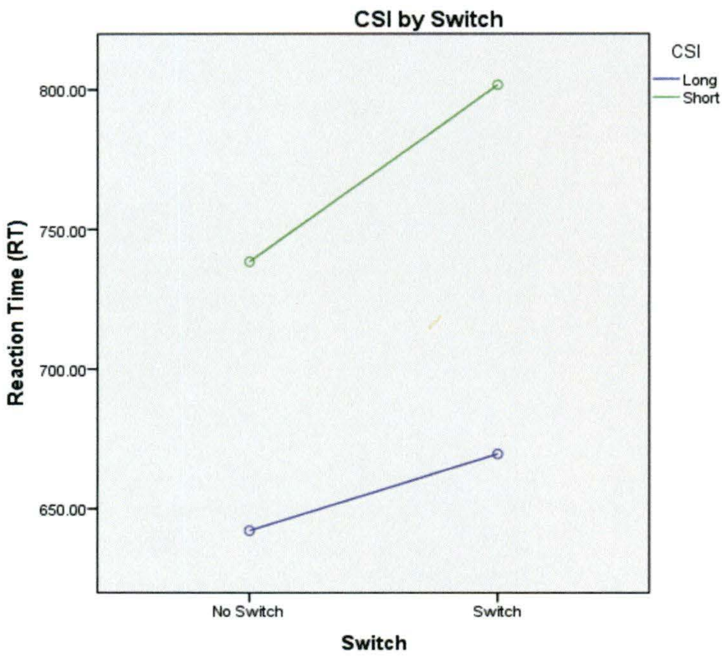


Figure 3: Reduced switch costs in longer CSI condition compared to the shorter CSI manipulation.

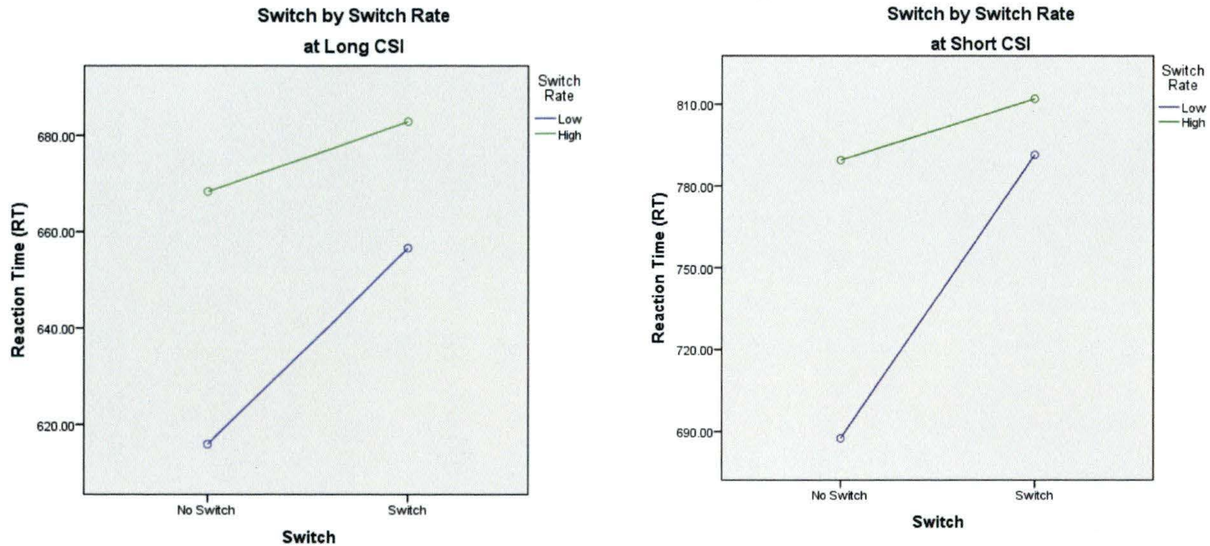


Figure 4: Longer preparation intervals seemed to have the greatest impact at reducing switch costs in the low switch rate condition.

## Discussion

It was predicted that people would be able to rapidly adapt to the demands of flexibility and stability in a task-switching paradigm that involved changing control demands. This prediction was supported by a significant increase in no-switch RTs when the switch rate was high and when the switch rate manipulation seemed to promote the working memory processing modes outlined in O'Reilly & Frank (2006). The low switch rate conditions seemed to facilitate a bias toward maintenance mode, as indicated by large switch costs. On the other hand, high switch rate conditions seemed to promote a bias toward an update mode associated with increased no-switch RTs and reduced switch costs. To our knowledge, this was the first study to use switch probability as a within-subject manipulation, which suggests that this internal reconfiguration process (Mayr, 2006) can rapidly adjust to the demands of flexibility and stability of the environment. High switch rate conditions seem to orient our executive control system to remain in a flexible state, which is beneficial when the task changes. However, low switch rate conditions seem to orient our executive control processes to remain in a more rigid state. The latter case may be costly in times of a task switch, but beneficial when the task remains the same across subsequent trials. It was also predicted that the benefit of longer preparation intervals, which was replicated in the current experiment, would generalize across switch rate conditions. It seems, however, that this benefit was greater in the low switch rate condition, even though this effect was present in both switch rate conditions. This result supports the idea that longer preparation intervals help orient our cognitive system, and that the preparation process helps us overcome switch-costs, especially when the task switches infrequently.

One limitation of the current project concerns generalizability. How well does this rapid reconfiguration process seen in a sample of college students generalize to different age groups? There is evidence that there are age differences in terms of executive control. For example, older adults show larger local switch costs (the RT difference between repeat and switch trials within heterogeneous task blocks only) than younger adults (Kray & Lindenberger, 2000; Mayr, 2001). In addition, older adults seem to benefit from longer preparation intervals than younger adults, even though preparation reduces switch costs in general (Kray & Lindenberger, 2000). The extent to which these age differences influence performance in low and high switch rate conditions is a topic for future work. Perhaps this effect would be seen only in the low switch rate condition in a sample of older adults.

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