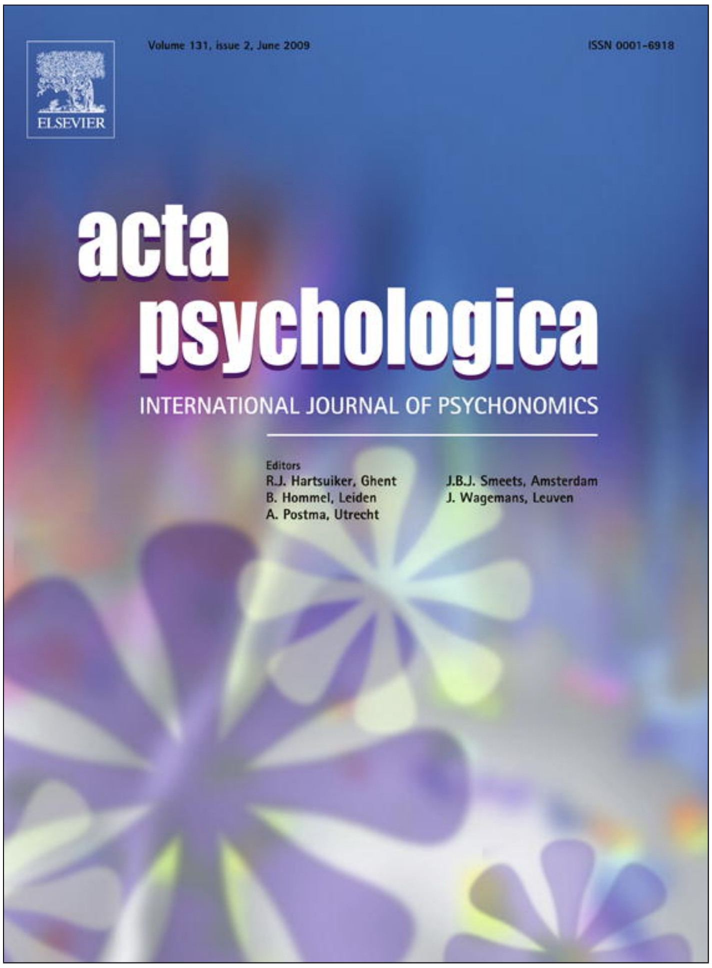
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Choosing to switch: Spontaneous task switching despite associated behavioral costs

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ABSTRACT

The literature shows that switching among simple cognitive tasks is difficult and involves a performance cost. Accordingly, cost-benefit considerations seem to predict that task switching would not occur spontaneously. Here we show that spontaneous task switching is a robust phenomenon, despite its costs. In Experiment 1, participants had to judge shapes according to one of three possible dimensions. Importantly, they were given the option to choose another relevant dimension or let the computer program change the dimension for them, but only if they wanted to do so. The results showed that spontaneous task switching was prevalent, despite robust switching costs. Experiment 2 extended this finding in showing spontaneous switching from an easy task to a more difficult task. The authors provide two possible explanations for the phenomenon that posit that spontaneous switching may be unpreventable or even advantageous.

1. Introduction

Humans are very flexible organisms. They can adapt to radically different environments within short periods of time, and can act upon the environment efficiently in order to adapt it to their needs. Their everyday lives are composed of numerous goals and subgoals, whose fulfillment require frequent changes in the course of thought and action. The cognitive processes that give rise to flexible goal-oriented behavior are termed executive functions (see Miyake et al., 2000), and they include the ability to inhibit a potent action or train of thoughts (e.g. Friedman & Miyake, 2004; Logan, 1994), the ability to update the contents of our working memory (e.g. Kessler & Meiran, 2006, 2008; Morris & Jones, 1990), and the ability to switch between tasks (e.g. Meiran, in press; Monsell, 2003).

Given its central role in cognitive flexibility, task switching has attracted a lot of research. Most of these studies instruct participants to switch between several cognitive tasks. The most prevalent result is that switching is associated with a performance cost, expressed in reaction time (RT) and error rates (PEs, proportion of errors). It is worth noting that such a cost is not always observed. In fact, Arthur T. Jersild (1927), in the first systematic study of task switching, claimed "...that shift does not invariably involve a loss in efficiency, that the loss effected by shift varies considerably in various combinations of tasks, that in some cases it makes for a gain in efficiency" (p. 41). However, the current Zeitgeist tends to overlook this claim, and regards switching as a difficult and costly process. This view is well supported by empirical results. Data taken from a recent meta-analysis of task 34 task-switching papers showed that the mean switching cost in each study varied between 6 and 308 ms, with an average of 126 ms and median of 108 ms (Altmann, 2007).

With such persistent behavioral data, it seems reasonable to expect that people would not switch between tasks at all, had they been given the opportunity to stay on the same task. This prediction is supported by both empirical data from different paradigms and theoretical considerations. Empirically, the status quo bias in decision making (Samuelson & Zeckhauser, 1988) shows the tendency of decision makers to adhere to the present situation, even in cases where a better alternative is available. This effect was shown to reflect a range of emotional and motivational factors such as anticipated regret, selection difficulties, and switching costs (Anderson, 2003). These factors were also shown to affect consumer behavior in marketing and economics (Burnham, Frels, & Mahajan, 2003). In a broader theoretical context, the tendency to adopt the present set point and to resist changes can be explained by the optimality principle in cognition (Bogacz, 2006; Todorov, 2004). According to this prevalent postulate in cognitive psychology, an observed behavior is selected among multiple alternatives according to optimal weighting of the underlying outcomes across many dimensions. Back to task switching, the optimality principle predicts that since (a) switching between tasks involves a behavioral cost, (b) high level performance is usually required,

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and (c) switching does not seem to produce any benefits, certainly not benefits that outweigh the costs, switching would not be voluntarily chosen unless it is forced by an external demand.

In the present study we show that despite the above prediction, people switch spontaneously between cognitive tasks, in situations where such switches were not only unnecessary, but even disadvantageous in terms of performance efficiency. To anticipate, we had participants performing choice-RT tasks on stimuli that varied in several dimensions. In each trial, the participants could decide whether to keep responding to the same dimension as in the previous trial (that is, to repeat the task), or to switch to a different dimension (and hence to switch the task). Importantly, we also incorporated a choice alternative in which participants who chose to switch could not anticipate with certainty the nature of the upcoming task because this task was chosen at random. Surprisingly, almost all the participants switched among tasks, although they suffered from behavioral switching cost.

Although most of the task-switching literature looked at switching as a reactive process that serves to adapt the cognitive system to external demands, there are several works that looked at switching as a proactive behavior. In these studies, participants were asked to decide which task to perform in each experimental trial, and to implement the chosen task. Arrington and Logan (2004, 2005) introduced the "voluntary task switching procedure", in which the participants were instructed to decide in each trial which task (parity or magnitude decisions made on digit stimuli) to perform, at random, with the restriction that both tasks should be applied with equal probabilities. Switching costs were observed, although smaller than in a matched paradigm in which the tasks were externally cued. Mayr and Bell (2006) showed that voluntary switches in these tasks are more likely to occur when the stimuli change, suggesting that these switches are not purely voluntary but influenced by external factors. Another approach to study voluntary task switching was proposed by Forstmann, Brass, Koch, and von Cramon (2006), who had participants switch between three different tasks, using "stay" and "switch" cues. Note that when a "switch" cue was presented, participants were given the opportunity to voluntarily choose among the two tasks that had not just been executed. The crucial difference between these previous studies on the one hand and our paradigm on the other hand is that the previous studies required the participants to switch between tasks, while in our paradigm they were permitted to repeat the same task, without any restrictions as long as they kept a high level of accuracy. The crucial prediction based on utility considerations was that participants would choose not to switch tasks.

2. Experiment 1

The goal of Experiment 1 was to examine whether people spontaneously switch among simple cognitive tasks, and whether these switches are associated with behavioral costs. If spontaneous switching is found, it might be associated with a behavioral cost (such as the usual case with task switching), or not. In the latter possibility, it might be possible that switches only occur at a point where they do not carry any behavioral cost.

Participants were presented with stimuli that varied along three dimensions, shape, color and size. Two experimental groups differed in the amount of control they had over a task switch. In the Task Group, the participants could indicate in any trial that they wanted to switch to a different task, by selecting the task they wanted to switch to. In the Switch Group, the participants could indicate in any trial that they wanted to switch to a different task, but then the task was randomly selected among the two other possible tasks. Importantly, the instructions given at the beginning of the experiment did not require any switching at all. Thus, participants in both groups could, in principle, stay on one task and not switch at all. The main difference between the groups was that the Task Group knew which task came next had they chosen to switch while the Switch Group could not predict exactly which task would be next if they chose to switch tasks. We incorporated the Switch Group because we reasoned that switching would be more strongly discouraged in this group relative to the Task Group. Namely, showing that participants choose to switch despite loosing their ability to anticipate the next task would make an especially strong case that spontaneous switching is a robust phenomenon.

2.1. Method

2.1.1. Participants

Twenty undergraduate students from Ben-Gurion University of the Negev and the affiliated Achva College took part in the experiment in return for partial course credit. All the participants reported having normal or corrected-to-normal vision, right hand dominance and no learning disabilities. The participants were assigned to the experimental groups according to the order in which they entered the study.

2.1.2. Apparatus and stimuli

The experiments were run on Pentium 4 computers with 17″ monitors. The software was programmed in E-Prime (Schneider, Eschman, & Zuccolotto, 2002). The target stimuli were colored shapes, which varied in three dimensions: color (red or blue), shape (circle or triangle) and size (small or large). The stimuli were presented at the screen center, and were drawn on a black background. The large stimuli subtended a visual angle of approximately $7.2° \times 7.2°$, assuming a 60 cm viewing distance. The small stimuli subtended a visual angle of approximately $3.3° \times 3.3°$. The Hebrew words for "shape", "color" and "size" served as task cues. The cues were presented in white, and were positioned in the middle of the screen above the shapes, and subtended approximately 1.9° (width) × 0.5° (height).

2.1.3. Procedure

In each of the groups, the experiment began with verbal instructions accompanied by visual illustrations of the stimuli and responses. Participants received the following instructions (in Hebrew):

> "In every trial of the experiment you will be presented with one of the following shapes. These shapes are vary in three dimensions: size (large, small), color (red, blue) and shape (circle, triangle). In every trial you are required to perform one task involving one dimension solely. Namely, you will have to decide whether the shape is large or small, or whether it is red or blue, or whether it is a circle or a triangle. You will be able to do that by pressing the appropriate key with your right hand, according to the key mapping in front of you. In each trial you will be presented with a word above the shape, which will instruct you which task to perform. After every trial a fixation cross will be shown in the center of the screen, please keep your eyes on it".

Then the Task group received this sentence:

> "During this time you may switch to another task, if you wish, by pressing one of the keys: "*A*", "*S*", "*D*" with your left hand, according to the key mapping ahead of you" (see Fig. 1).

and the Switch group received this sentence:

> "During this time you may switch to another task, if you wish, by pressing the "*S*" key with your left index finger. By pressing the key a new task will be chosen randomly out of the

remaining tasks. For example, if the current task is "size" and you press the key "*S*" the task will be switched to either "shape" or "color". The name of the task will be shown in every trial above the shape".

The remaining instructions were identical for the two groups:

"If you wish to stay in the same task, do not press anything. Please keep your fingers of the right hand on the keys: "1", and "3", and your left index finger on the key "*S*" during the whole experiment. Please be accurate in your responses. Every time you will make an error you will hear a beep tone".

The instructions were followed by two experimental blocks of 160 trials each, separated by a short break. The experiment lasted about 25 min. In each block, the task for the first trial was randomly selected. Each trial began with a white central fixation cross that was presented for 3000 ms (see Fig. 1). During this time, the participants could indicate if they want to switch the current task. In the Switch Group, this was done by pressing the *S* key. If the participant decided to switch the task, a new task was randomly chosen out of the two remaining tasks. Otherwise, the task was repeated. In the Task Group, the participants could indicate which task they wanted to switch to. This was done by pressing the *A*, *S*, or *F* key, each indicating which task they chose to perform. The fixation was followed by the presentation of the instructional cue and the target stimulus simultaneously. Participants performed the color, the shape or the size task on each trial, in accordance with their previous choice response (or lack of it). The "1" and "3" keys of the numerical pad on the right side of the keyboard served for responses, using the index and the middle fingers of the right hand. The following trial began after a response was given. A 350 Hz tone was presented for 500 ms after an error was commited. The task- and response-key mappings were counterbalanced across participants. The key mapping of the tasks and the responses was presented above the keys during the whole experiment.

2.1.4. Analyses

Several dependent variables were examined. In most cases, we compared the means against the expected mean based on the hypothesis that spontaneous switching would not take place. We also compared between the experimental groups mainly to show

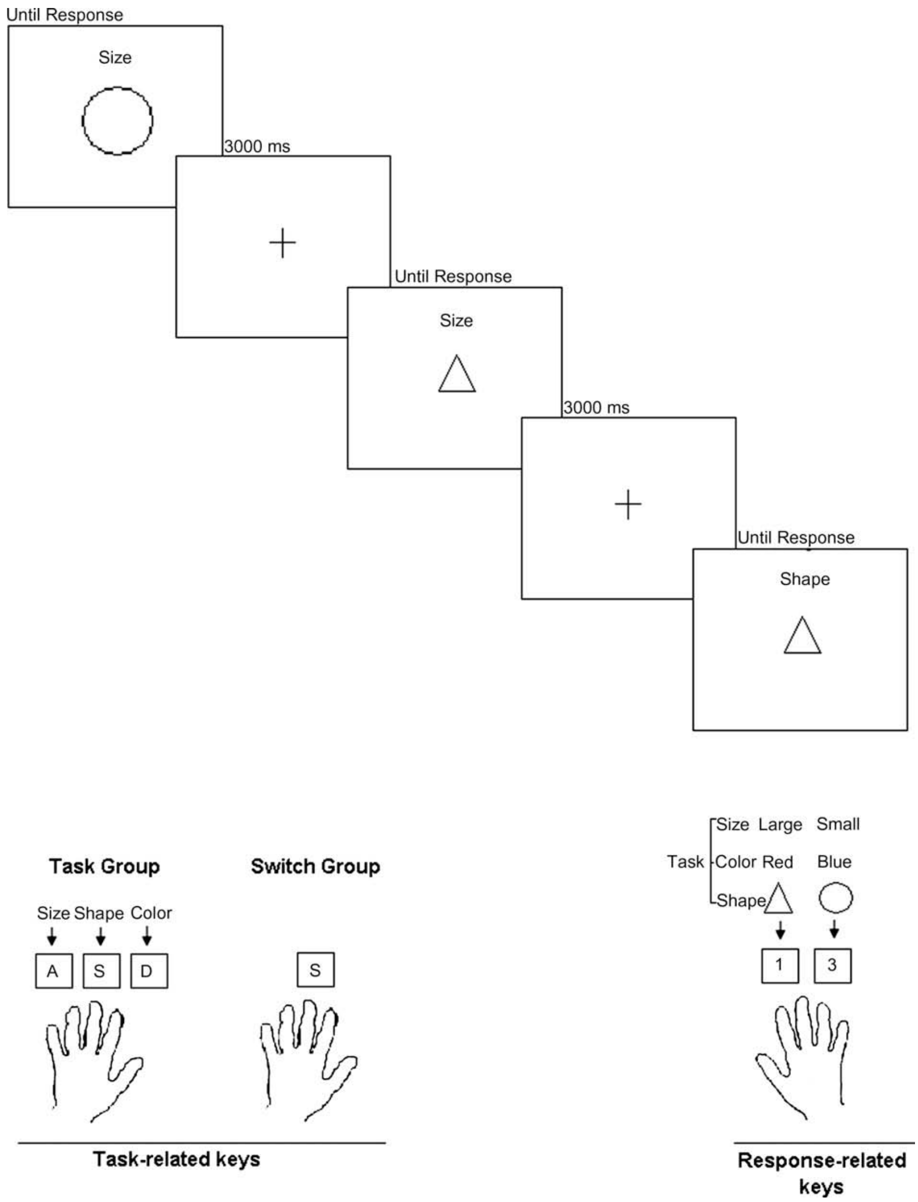

Fig. 1. Schematic description of the trial sequence and response-key mappings in Experiment 1.

that the groups are similar to one another, thereby demonstrating the robustness of spontaneous switching. The primary variable was the number of task switches conducted throughout the experiment. Overall switching cost was the performance difference between switch trials and repetition trials, across the whole experiment. This measure corresponds to the conventional calculation of task-switching cost in standard task-switching experiments. Immediate switching cost was the performance difference between switch trials, and the immediately preceding repetition trials. The reasoning here was to assess whether switching is immediately beneficial, regardless of its overall efficiency. Positive values on this index show that switching impaired performance. The two switching cost indices were examined both in RT and in PE. Finally, a finer grained analysis looked at RT performance as a function of the position of the trial relative to a switch, as explained below (namely, whether it was a pre-switch or a post-switch trial, and what was the lag between it and the switch trial). Error trials or trials that immediately followed an error were removed from the RT analysis, as were RTs that deviated more than two standard deviations from the average RT for each participant in each of the conditions. Alpha was 0.05 in all the analyses.

2.2. Results

Table 1 presents the performance in the two experimental groups. In order to enable the assessment of the stability and reliability of the findings, individual participants' data are presented.

The most remarkable finding is that all the participants, except one, switched between the tasks. If one translates current theorizing into a prediction that most (over 50%) of the participants would not switch, this rate significantly violates this prediction, $\chi^2(1) = 8.10$, $p < .005$. Although the groups are not strictly comparable, it is interesting to see that switch rate did not differ significantly between them, $t(18) = .81$, $p = .43$. This suggests that foreknowledge about the upcoming task did not affect the general tendency to switch, and was clearly not a prerequisite for switching.

We next turned to look at the possibility that the spontaneous switching observed in this experiment stemmed from boredom that was developed throughout the experiment. According to this account, the participants switched among the tasks in order to refrain from boredom. The reasoning is that switching might have enabled them to perform a newer task that might be more challenging after performing the same task many times (see Jersild, 1927). In order to examine this account, we looked at the difference in the number of switching between the first and the second halves of the experiment, since boredom is expected to be larger as the experimental session prolongs. In both groups, the number of switches was statistically the same in the first and second halves of the session. In the Task Group, the mean number of switches was 6.50 in the first half and 5.70 in the second half, $t(9) = .55$, $p = .59$. In the Switch group, the mean number of switches was 14.90 in the first half and 17.20 in the second half, $t(9) = .61$, $p = .56$. It should be noted that these results rule out another possible account for spontaneous switching. According to this account, switching among the tasks is beneficial in the first stages of the experiment, in order to explore which task is preferable. Once the preferred task is determined, the participant keeps on performing this task only. However, the lack of difference in the number of switches between the two halves of the experiment clearly rules out this account. More evidence against this possibility is given by looking at the trial number in which the first switch occurred. In the Task Group, the first switch was in the 27th trial in the first block and was in the 15th trial in the second block, on average. In the Switch Group, the first switch was in the 46th trial in the first block and was in the 35th trial in the second block, on average. Accordingly, switching was not restricted to the very beginning of the block.

In the next stage, we turned to look at the performance cost associated with task switching. An analysis of variance was conducted with Group as a between-subject variable and overall Task-Switch (switch vs. all non-switch trials) as a within-subject variable. The analysis was conducted for the RT and PE data, separately. For RTs, the main effect of Task-Switch was significant, $F(1,17) = 41.73$, $MSe = 181{,}239.37$, $\eta_p^2 = .71$. The main effect of Group, as well as the two-way interaction, failed to reach significance, $F(1,17) = 2.37$, $MSe = 293{,}698.49$, $\eta_p^2 = .12$, $p = .14$, and $F(1,17) = 2.84$, $MSe = 181{,}239.37$, $\eta_p^2 = .14$, $p = .11$, respectively. The same picture emerged for PEs. The main effect of Task-Switch was significant, $F(1,17) = 4.89$, $MSe = .0002$, $\eta_p^2 = .22$, however the main effect of Group and the two-way interaction were non-significant, $F(1,17) = .76$, $MSe = .0003$, $\eta_p^2 = .04$, $p = .39$, and $F(1,17) = 1.85$, $MSe = .0002$, $\eta_p^2 = .10$, $p = .19$, respectively. Similar analyses of variance were conducted in order to examine the immediate switching costs. In these analyses, the Task-Switch had two different levels, namely switch and pre-switch trials. For RTs, the main effect of Task-Switch was significant, $F(1,17) = 31.02$, $MSe = 143{,}545.20$,

Table 1
Experiment 1. SC = switching cost; RT = reaction time; PEs = proportion of errors. Single-sample *t*-tests were conducted against zero.

Task Group						Switch Group					
Subject	Number of switch trials	Overall SC		Immediate SC		Subject	Number of switch trials	Overall SC		Immediate SC	
		RT	PE	RT	PE			RT	PE	RT	PE
N.G	8	−43	−.02	−8	.00	H.D	10	1560	-.04	1226	.00
C.G	8	576	.00	542	.00	A.D	4	1927	-.02	1868	.00
G.H	11	244	−.04	−71	.00	S.B	8	1262	−.01	1275	.00
T.S	15	1	.03	−192	.00	A.F	16	1150	.00	1172	.00
N.G	2	768	−.01	624	.00	N.G	5	1686	−.01	984	.00
L.B	5	901	.00	866	.00	M.Y	4	1335	−.01	847	.00
O.F	9	328	−.02	33	.00	Y.R	249	110	−.01	29	.01
N.S	53	702	.05	565	.06	E.S	4	316	−.03	128	.00
M.P	6	1223	−.01	909	.00	L.A	0	–	–		–
L.K	5	1904	−.02	1297	.00	S.B	21	791	−.03	703	−.05
Mean	12.20	661	.00	456	.01	Mean	32.10	1126	−.02	915	.00
S.D.	14.02	562	.02	471	.02	S.D.	72.55	578	.01	544	.02
$t(9)$	2.61[a]	3.53	.51	2.91	1.00	t(9)	1.33[a]	5.51	3.64	4.76	.81
Sig.	*	*	.62	*	.34	Sig.	.22	*	*	*	.44

* $p < .05$.
[a] Due to the skewed distribution of the number of switches, a more conservative *t*-test was performed in each group, in which the most extreme observation was removed. The mean number of switches was significantly different than zero in both groups, $t(8) = 6.04$ and $t(8) = 3.59$ for the Task and Switch Groups, respectively.

$\eta_p^2 = .65$. The main effect of Group was non-significant, $F(1,17) = 1.79$, $MSe = 401{,}363.47$, $\eta_p^2 = .10$, $p = .20$, but the two-way interaction was marginally significant, $F(1,17) = 3.47$, $MSe = 143{,}545.20$, $\eta_p^2 = .17$, $p = .08$, reflecting a larger switching cost in the Switch Group. This trend can be explained as follows: While in the Task Group the participants could use the inter-trial interval for preparation to the upcoming task, this was impossible in the Switch Group since the identity of the next task was chosen randomly. Accordingly, the immediate switching cost in the Task Group might be an underestimate of the time required for switching, as some of the preparation processes were already conducted before stimulus presentation. The same analysis of immediate switching cost was conducted for PE. None of the main effects were significant, $F(1,17) = .09$, $MSe = .0001$, $\eta_p^2 = .01$, $p = .77$ for Task-Switch, and $F(1,17) = .69$, $MSe = .0005$, $\eta_p^2 = .04$, $p = .42$ for Group. Also, the two-way interaction was non-significant, $F(1,17) = 1.88$, $MSe = .0001$, $\eta_p^2 = .10$, $p = .19$ (see Fig. 2).

We now turn to analyze the trials that preceded a task switch, as well as the trials that followed a task switch, in order to examine the sequential dynamics of spontaneous switching. To this end, the data were analyzed according to the sequential position of each trial relative to a task switch. The position variable had 11 levels, denoted as (−5) to 5: the switch trial was denoted "0", the trial before a switch "−1", the preceding trial "−2", and so forth until "−5", which represented trials that were five steps *or more* before a task switch. In a similar fashion, the trial after a switch was denoted "1", the following trial "2", and so forth until "5" that represented trials that were five steps *or more* after a task switch. Due to inconsistent patterns in the PE data, and due to the relatively high accuracy, these analyses were conducted for RT only. Participant Y.R. of the Switch Group was omitted from all these analyses due to missing values in some of the conditions. At first, we analyzed the trials before a task switch (positions −5 to −1). An ANOVA was conducted with positions (−5 to −1) as a within-subject variable, and Group as a between-subject variable. The main effect for position was significant, $F(4,68) = 4.72$, $MSe = 27{,}237.57$, $\eta_p^2 = .22$. The main effect for Group, as well as the two-way interaction, were clearly non-significant (Fs < 1). The effect for position reflects an increase in RT before a task switch. A series of Helmert contrasts were administered in order to examine whether it results from the pre-switch trial only (position −1), or rather reflects a longer-term process. The first contrast comparing position −1 and positions −2 to −5, was significant, $F(1,17) = 13.64$, $MSe = 26{,}153.43$, $\eta_p^2 = .45$. However, the second Helmert contrast, comparing position −2 and positions −3 to −5, was already clearly non-significant, $F < 1$. Accordingly, the performance decrement before a switch did not extend beyond a single trial.

We next turned to analyze trials that followed a task switch. A similar ANOVA was conducted, this time with positions 1–5. Participant Y.R. of the Switch Group was omitted from this analysis as well. The main effect for position was significant, $F(4,68) = 3.20$, $MSe = 22{,}532.50$, $\eta_p^2 = .16$, but not the main effect for Group, $F < 1$. This time, the two-way interaction was nearly significant, $F(4,68) = 2.40$, $MSe = 22{,}532.50$, $\eta_p^2 = .12$, $p = .06$. The simple effect of position was non-significant in the Task Group, $F < 1$, but significant in the Switch Group, $F(4,32) = 4.05$, $MSe = 25{,}268.05$, $\eta_p^2 = .34$. A series of Helmert contrasts were administered on the Switch Group data in order to examine the extent of influence of a task switch on subsequent performance. The first Helmert contrast, comparing position 1 and positions 2–5, was significant, $F(1,8) = 6.72$, $MSe = 45{,}572.78$, $\eta_p^2 = .46$. The second contrast, comparing position 2 and positions 3–5, was marginally significant, $F(1,8) = 3.71$, $MSe = 9636.55$, $\eta_p^2 = .32$, $p = .09$. The third contrast, comparing position 3 and positions 4–5, was clearly non-significant, $F < 1$. The difference between the two groups in post-switch performance might reflect residual adaptation to the new task in the Switch Group, where the task that was randomly selected in the task switch trial was not always the expected, or even the "desired" one. Such adaptation might have been unnecessary in the Task Group, in which preparation toward the upcoming task could be completed much earlier.

Finally, we compared the trials before and after the switch, in order to examine whether switching improved performance. In the Task Group, the trial after a switch was faster than the trial before the switch, $F(1,9) = 6.43$, $MSe = 22{,}613.71$, $\eta_p^2 = .42$. This finding suggests that switching is locally beneficial, namely leads to a temporary improvement in performance that is observed only after the toll for switching has been taken. In the Switch Group, however, this difference was in the opposite direction, although non-significant ($F < 1$). This result can be explained by the fact that the adaptation to the new task is not complete after one trial and there is some residual adaptation taking place afterwards, all that in the Switch Group. The local benefits of switching, however, are very limited. No difference was found, in both groups, between the five pre-switch positions and the five post-switch positions (both Fs < 1). Accordingly, even if switching is locally beneficial, the benefit is short lived.

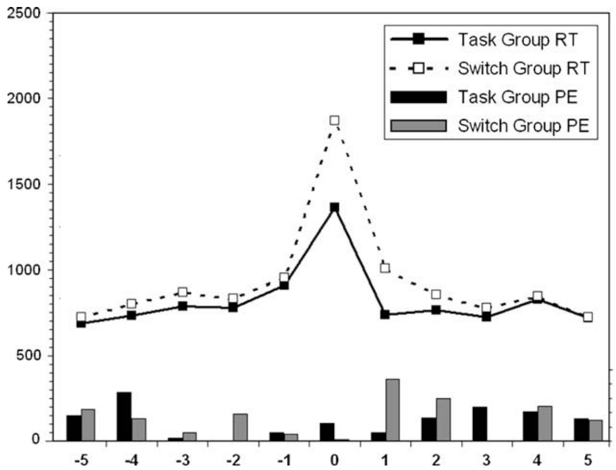

Fig. 2. Serial position effects for Experiment 1. Position "0" denotes a switch trial, positions 1–5 are post-switch trials, and positions (−1)–(−5) are pre-switch trials. Note that position 5 includes all the positions beyond 5 and position (−5) include all the positions before (−5).

3. Experiment 2

Experiment 1 showed that participants switched between the tasks, although such switches were both unnecessary and often caused marked performance costs. Experiment 2 examined whether participants would spontaneously switch even from a relatively easy task to a more difficult task. Four tasks were used in this experiment. The size and filling tasks each involved a decision among two alternatives, and therefore were considered as relatively easy. The color and shape tasks each involved a decision among four alternatives, and therefore were considered to be relatively difficult. The experiment involved two groups, similar to those in Experiment 1.

3.1. Method

3.1.1. Participants

Twenty undergraduate students with similar attributes to those who participated in Experiment 1 participated in the present experiment, and were assigned to the experimental groups according to the order in which they entered the study. Also, the response-key mappings were counterbalanced between the participants in each of the groups.

3.1.2. Stimuli

The target stimuli were colored shapes, which varied in four dimensions: color (red, yellow, green or blue), shape (circle, square, diamond or triangle), size (small or large) and filling (empty or full). The stimuli and cues were presented in the same fashion as those presented in Experiment 1, except for adding the Hebrew word for "Filling" as an additional task cue.

3.1.3. Design and procedure

As in Experiment 1, the experiment began with verbal instructions accompanied by illustrations of the stimuli and the responses. The instructions were similar to those presented in Experiment 1, apart from the fact that they introduced the four tasks (shape, size, color and filling) instead of three tasks. The keys "*a*", "*s*", "*d*" and "*f*" were served to select a new task in the Task Group, while the keys "*h*", "*j*", "*k*" and "*l*" served for responding in both groups ("*k*" and "*l*" were used for the two-response tasks, and all the four keys served for the four-response tasks). The rest of the procedure was exactly the same as that in Experiment 1.

3.2. Results

All the participants switched between the tasks (see Table 2). The switch rate did not differ significantly between the groups, $t(18) = .11$, $p = .91$. This finding replicates the findings of Experiment 1.

Before turning to analyze switching costs, we examined whether the hypothesized task difficulty manipulation (number of alternatives) affected performance in the predicted direction. Only repetition trials that were not immediately followed by a task switch entered this analysis. RTs for the difficult tasks were slower than those for the easy tasks, both in the Task Group, 1105 and 819 ms, respectively, $t(9) = 2.30$, and in the Switch Group, 893 and 687 ms, respectively, $t(9) = 4.08$. Task difficulty did not affect error rates, which were 2% and 4% for the difficult and easy tasks in the Task Group, respectively, $t(9) = 1.81$, $p = .10$, and 4% and 8% for the difficult and easy tasks in the Switch Group, respectively, $t(9) = .89$, $p = .40$. These results validate our task difficulty manipulation.

First, all the participants switched tasks. This rate was significantly different that the (moderately formulated) prediction of current theorizing of 50%, $\chi^2(1) = 10.00$, $p < .005$. The participants performed the more difficult tasks in about 47% of the trials, despite being less advantageous in terms of RTs (see Table 2). In order to examine whether the participants actually switched to a more difficult task, we analyzed the Task Group data. We categorized each switch trial according to the difficulty of the previous task (the task from which the switch was made) and of the present task (the task to which the switch was made; see Table 3). The number of switches within each of the resulting four categories was entered to a repeated-measure ANOVA with the previous task's difficulty and the present task's difficulty as independent variables. Both main effects were non-significant, $F(1,9) = .07$, $MSe = 13.12$, $p = .80$ for the previous task's difficulty, and $F(1,9) = .07$, $MSe = 13.46$, $p = .80$ for the present task's difficulty. Interestingly, the two-way interaction was significant, $F(1,9) = 8.37$, $MSe = 61.96$. This interaction reveals that participants made more switches from an easy task to a difficult one or vice versa, than between tasks of the same difficulty. Most importantly, since no difference was found between the number of switches to an easy and

Table 3
Experiment 2, Task Group: number of switches by the difficulty of the previous and the present tasks.

Subject	From easy		From difficult		Total
	To easy	To difficult	To easy	To difficult	
E.A	19	50	50	36	155
T.S	5	16	17	4	42
O.G	1	3	2	1	7
I.O	0	3	2	2	7
M.E	21	32	32	8	93
M.F	0	7	6	2	15
O.S	6	5	7	6	24
A.S	5	4	5	5	19
H.B	0	4	4	1	9
R.H	2	10	9	0	21
Mean	5.90	13.40	13.40	6.50	39.20
S.D.	7.38	14.86	14.94	10.12	45.67

Table 2
Experiment 2. SC = switching cost; RT = reaction time; PEs = proportion of errors; % difficult = percentage of the trials where the more difficult task was performed. Single-sample *t*-tests were conducted against zero.

Task Group						
Subject	Number of switch trials	Overall SC		Immediate SC		% Difficult
		RT	PE	RT	PE	
E.A	155	417	–.01	29	.01	49.06
T.S	42	378	.02	321	.02	48.11
O.G	7	1243	.00	–87	.00	49.69
I.O	7	1054	–.02	864	.00	64.47
M.E	93	625	.07	369	.12	44.03
M.F	15	1712	.02	945	.07	42.77
O.S	24	473	.09	243	–.03	24.53
A.S	19	138	.02	–108	.05	58.18
H.B	9	1131	–.01	924	.00	47.80
R.H	21	730	–.01	815	.00	44.03
Mean	39.2	790	.02	432	.02	47.26
S.D.	45.67	459	.03	402	.04	9.92
$t(9)$	2.58[a]	5.17	1.61	3.22	1.77	14.30[b]
Sig.	*	*	.14	*	.11	*

Switch Group						
Subject	Number of switch trials	Overall SC		Immediate SC		% Difficult
		RT	PE	RT	PE	
T.K	8	939	.00	1032	.00	57.55
S.G	15	1715	.05	1759	.07	55.03
A.P	12	871	.06	822	.08	49.06
S.S	9	939	–.03	1064	.00	51.57
Y.H	60	1155	.01	843	.02	53.46
R.S	16	2135	–.02	1885	–.08	14.15
Y.A	261	250	.01	275	.11	48.74
N.M	10	1557	–.02	1548	.00	52.20
O.N	20	926	.08	989	.10	55.97
D.S	12	3332	.00	3194	.00	36.16
Mean	42.3	1382	.01	1341	.03	47.39
S.D.	74.33	819	.04	768	.06	12.44
$t(9)$	1.71[a]	5.06	1.09	5.24	1.55	11.43[b]
Sig.	.12	*	0.30	*	.16	*

* $p < .05$.
[a] As in Experiment 1, a more conservative *t*-test was conducted, in which the most extreme observation in each group was removed. The number of switches was significantly different than zero in both groups, $t(8) = 2.90$ and $t(8) = 3.33$ for the Task and Switch Groups, respectively.
[b] The percentage of difficult trials did not differ significantly from 50%, $t(9) = -.83$, $p = .43$ and $t(9) = -.63$, $p = .54$, for the Task and Switch groups, respectively

to a difficult task, it was shown that the participant not only switched to more difficult tasks, but also did it equally often as switching to an easy task.

As in Experiment 1, we examined the possibility that switching was related to boredom, by comparing the number of switches between the two halves of the experiment. Again, no significant differences were found between the two halves. In the Task Group, the mean number of switches was 22.50 in the first half and 16.70 in the second half, $t(9) = .96$, $p = .36$. In the Switch Group, the mean number of switches was 21.90 in the first half and 20.40 in the second half, $t(9) = .46$, $p = .66$. In the Task Group, the first switch occurred in the 18th trial in the first block, and in the 17th trial in the second block, on average. In the Switch Group, the first switch occurred in the 27th trial in the first block and in the 11th trial in the second block, on average. Interestingly, the position of the first switch depended on the task difficulty of the first trial in the block. In the first block, participants who began with a difficult task switched for the 1st time in the 10th trial, on average, and participants who began with an easy task switched for the 1st time in the 28th trial, on average, $t(18) = 2.27$ (note that participants form both groups were pooled together for this analysis). The difference in the second block was much smaller, and non-significant. Specifically, participants who begin with a difficult task switched for the 1st time in the 12th trial, on average, and participants who began with an easy task switched for the 1st time in the 16th trial, on average, $t(18) < 1$. This analysis reveals that some part of the spontaneous switching behavior may be attributed to strategic choice of the desired task.

Overall and immediate RT switching costs were found in both groups.

As in Experiment 1, an analysis of variance was conducted with Group as a between-subject variable and overall Task-Switch (switch vs. all non-switch trials) as a within-subjects variable. The analysis was conducted for the RT and PE data, separately. For RTs, the main effect of Task-Switch was significant, $F(1,18) = 48.19$, $MSe = 244{,}762.68$, $\eta_p^2 = .73$. The main effect of Group was non-significant, $F(1,17) = .25$, $MSe = 365{,}274.89$, $\eta_p^2 = .02$, $p = .63$, however the two-way interaction was marginally significant, $F(1,18) = 3.58$, $MSe = 244{,}762.68$, $\eta_p^2 = .17$, $p = .07$. The same picture emerged for PEs. The main effect of Task-Switch was significant, reflecting a larger overall switching cost in the Switch Group. For the PE data, the main effect of Task-Switch was marginally significant, $F(1,18) = 3.62$, $MSe = .0007$, $\eta_p^2 = .17$, $p = .07$. The main effect of Group, as well as the two-way interaction, was clearly non-significant, $F(1,18) = .29$, $MSe = .0044$, $\eta_p^2 = .02$, $p = .60$, and $F(1,18) = .11$, $MSe = .0007$, $\eta_p^2 = .01$, $p = .74$, respectively. As in Experiment 1, similar analyses of variance were conducted in order to examine the immediate switching costs, comparing switch and pre-switch trials. For RTs, the main effect of Task-Switch was significant, $F(1,18) = 37.65$, $MSe = 208{,}642.61$, $\eta_p^2 = .68$. The main effect of Group was clearly non-significant, $F(1,18) = .08$, $MSe = 511{,}233.00$, $\eta_p^2 < .01$, $p = .78$. However, the two-way interaction was significant, $F(1,18) = 9.91$, $MSe = 208{,}642.61$, $\eta_p^2 = .36$. As in Experiment 1, the immediate switching cost was larger in the Switch Group, in which the inter-trial interval could not be used for preparation. The same analysis of immediate switching cost was conducted for PE. The main effect of Task-Switch was significant, $F(1,18) = 6.61$, $MSe = .0012$, $\eta_p^2 = .27$, but not the main effect of Group, $F(1,18) = .51$, $MSe = .0051$, $\eta_p^2 = .03$, $p = .49$. Also, the two-way interaction was non-significant, $F(1,18) = .03$, $MSe = .0012$, $\eta_p^2 < .01$, $p = .87$.

We turned to analyze sequential position effects relative to a task switch, as done in Experiment 1 (see Fig. 3). Participant Y.A. of the Switch Group was omitted from all these analyses due to missing values in some of the conditions. We began by looking at

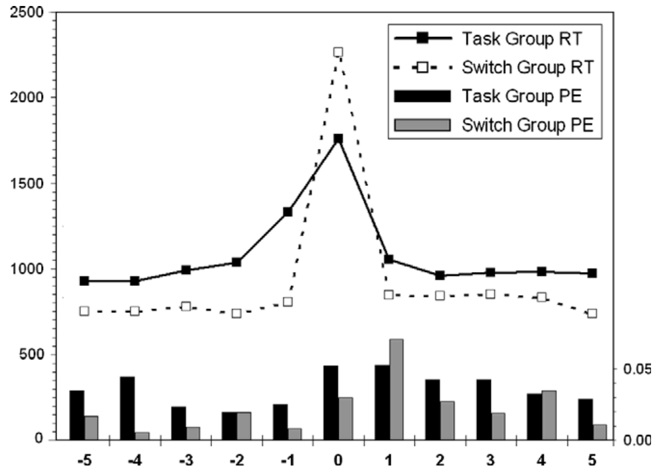

Fig. 3. Serial position effects for Experiment 2. Position "0" denotes a switch trial, positions 1–5 are post-switch trials, and positions (−1)–(−5) are pre-switch trials. Note that position 5 includes all the positions beyond 5 and position (−5) include all the positions before (−5).

pre-switch trials. An ANOVA was conducted on the RT data with positions (−5 to −1) as a within-subject variable and Group as a between-subject variable. Main effects were found for Position, $F(4,68) = 6.45$, $MSe = 26{,}346.48$, $\eta_p^2 = .28$, and for Group, $F(1,17) = 7.11$, $MSe = 257.367.45$, $\eta_p^2 = .29$. The two-way interaction was also significant, $F(4,68) = 3.88$, $MSe = 26{,}346.48$, $\eta_p^2 = .19$. The simple effect of position in the Switch Group was non-significant, $F < 1$. In contrast, the effect of position was significant in the Task Group, $F(4,36) = 6.56$, $MSe = 42{,}682.57$, $\eta_p^2 = .42$. As in Experiment 1, a series of Helmert contrasts were applied in order to examine at which point before the task-switch a decrease in performance can be observed. The first contrast, comparing position −1 and positions −2 to −5, was significant, $F(1,9) = 6.90$, $MSe = 150{,}028.91$, $\eta_p^2 = .43$. The second contrast, comparing position −2 and positions −3 to −5, was marginally significant, $F(1,9) = 4.37$, $MSe = 12{,}831.08$, $\eta_p^2 = .33$, $p = .07$. The third contrast, comparing position −3 and positions −4 to −5, was also significant, $F(1,9) = 8.77$, $MSe = 3171.91$, $\eta_p^2 = .49$. The fourth contrast, comparing positions −4 and −5, was clearly non-significant, $F < 1$. Accordingly, a gradual decrease in the performance was observed four trials before a switch in the Task Group, but not in the Switch Group. This difference might be related to preparatory processes that begin to take place before the actual switching, and interfere with task performance. Such processes include a decision about the task that will be selected, a decision that is unnecessary in the Switch Group, in which gradual decrease in performance before a switch was not observed. The findings, both regarding a difference between the groups and regarding the point in which a performance decrement can be observed before a switch takes place, stand at odds with the results of Experiment 1. At this point, we can only speculate about the reasons for these differences. These include the difference in the number of tasks involved and in their difficulty that might have caused more marked effects in Experiment 2.

We now turn to look at the after effects of switching. As in Experiment 1, we conducted an ANOVA with positions (1–5) as a within-subject variable, and Group as a between-subject variable. The main effect of position was significant, $F(4,68) = 2.80$, $MSe = 7728.46$, $\eta_p^2 = .14$. The main effect of Group was non-significant, $F(1,17) = 2.83$, $MSe = 235{,}857.48$, $\eta_p^2 = .14$, $p = .11$, as well as the two-way interaction, $F(4,68) = 1.58$, $MSe = 7728.46$, $\eta_p^2 = .08$, $p = .19$. Helmert contrasts were used in order to determine the scope of post-switch influence. The first contrast, comparing position 1 and positions 2–5, was nearly significant, $F(1,17) = 4.27$,

$MSe = 11{,}134.11$, $\eta_p^2 = .20$, $p = .05$. The second contrast, comparing position 2 and positions 3–5, was already non-significant, $F < 1$. Accordingly, the costs of switching diminished after the post-switch trial.

Finally, we turn to evaluate the local benefits of switching, by comparing pre-switch and post-switch trials. As in Experiment 1, the responses in the trial after a switch were quicker than those in the trial before the switch, all that in the Task Group only. This difference was nearly significant, $F(1,9) = 4.62$, $MSe = 83{,}357.17$, $\eta_p^2 = .34$, $p = .06$. In the Switch Group, as in Experiment 1, this difference was in the opposite direction and non-significant ($F < 1$). The longer-term benefits of switching, however, are different in both groups. In the Task Group, a difference of 53 ms is found between the five pre-switch positions and the five post-switch positions, $F(1,9) = 6.50$, $MSe = 10{,}860.51$, $\eta_p^2 = .42$. However, this difference only stems from positions −1 and 1. When these were removed from the analysis, no difference is found between positions −5 to −2 and positions 2–5, $F < 1$. In the Switch Group, however, the five post-switch positions were slower by 57 ms than the pre-switch positions, $F(1,8) = 10.53$, $MSe = 6916.17$, $\eta_p^2 = .57$. A difference of 61 ms was observed even when positions −1 and 1 were removed from the analysis, $F(1,8) = 8.86$, $MSe = 7448.08$, $\eta_p^2 = .53$. Accordingly, the negative after effects of switching in the Switch Group are long lasting.

4. General discussion

The goal of the present study was to examine whether participants would choose to switch tasks even if such switching is not required, and is even disadvantageous in terms of performance. To this end, we looked at actual switch behavior (see Baumeister, Vohs, & Funder, 2007), in situations that did not necessitate any switch at all. The results clearly showed that the vast majority of the participants chose to switch tasks despite the observed switch costs. This was even seen under conditions in which the choice to switch tasks was associated with task uncertainty or when the switched-to task was clearly more difficult. Importantly, we did not observe any long-term performance advantage after switching, when comparing pre- and post-switch trials.

When telling people of our findings, we sometimes heard that they are not very surprising. It might be argued, for example, that although no current theory of task switching or cognitive control explicitly predicts spontaneous switching, the phenomenon reported here could be expected on the basis of common sense. Accordingly, it is not surprising that participants switch when having the opportunity to do so, making the present findings trivial. However, we argue that such a view reflects hindsight bias (Fischhoff, 1975), the phenomenon of increasing the subjective likelihood of and event after knowing that it actually occurred. The fact that no one has shown this phenomenon before and that those who studied "voluntary switching" always took precautions to ensure that participants would switch tasks suggests that this phenomenon has not been predicted.

The current work shows that current theorizing wrongly predicts that spontaneous switching would be rare. It was not meant to study the processes underlying spontaneous switching in detail. Nonetheless, it would be interesting to speculate what could be the reason for spontaneous task switches? We suggest two, not necessarily mutually exclusive, classes of answers, one is bottom-up in nature and the other is top-down (see also Haggard, 2008). The "bottom-up" approach explains spontaneous switches as resulting from random fluctuations in the inner world. Accordingly, switching is hard to avoid due to the inherent noise in the psychological and the physiological systems (see Faisal, Selen, & Wolpert, 2008, for review). Examples for such effects whose products reach processing levels as high as conscious experience are the popping-out of irrelevant and involuntary memories (e.g. Kvavilashvili & Mandler, 2004), and changing percepts of multistable visual phenomena (e.g. Leopold & Logothetis, 1999). The behavioral and phenomenal effects of the noisy internal environment can be maladaptive to goal-oriented behavior, such as in the case of attentional lapses (e.g. Weissman, Roberts, Visscher, & Woldorff, 2006) and mind wandering (Smallwood & Schooler, 2006). Internal noise is a core assumption in many cognitive models, including models of task switching. In this literature, random fluctuations in the representation of the tasks or the control parameters that govern its manifestation can lead to selecting the wrong, inappropriate task (e.g. Altmann & Gray, 2008; Meiran, Kessler, & Adi-Japha, 2008). However, taking a broader perspective, random fluctuations are critically important for flexible behavior, as they prevent the system from being attracted to a permanent state. The internal fluctuations that may give rise to spontaneous switching can be also accompanied by external variation in the environment. A relevant example is Mayr and Bell's (2006) study, which show that task switches in the voluntary task-switching paradigm (Arrington & Logan, 2004) are more frequent when in stimulus changes as compared to stimulus repetitions.

In contrast, the top-down approach regards spontaneous switching as an adaptive behavior, which is deliberately chosen rather than just "happens". Switching can be beneficial in several ways. First, switching can be used to maintain a desired level of alertness, to refrain from boredom (Jersild, 1927). The same factors that make task switching difficult, such as adopting a new task set and overcoming proactive interference, may contribute to a subjective feeling of arousal and interest. Using switching to refrain from boredom is a special case of a larger principle, of keeping the optimal balance between exploration and exploitation of the environment (e.g. Cohen, McClure, & Yu, 2007). Many situations require us to choose how to invest our effort: whether to try to make the best out of the present situation (exploitation), or to shift to seek other possibilities (exploration). Choosing between these two poles requires weighing short-term vs. long-term utilities. In the context of our paradigm, switching between the tasks is an act of exploration, since it increases the information obtained about the task space and the subjective utilities of each task (and also of repetition and switching).

It should be noted that the top-down and the bottom-up approaches should be regarded as complementary, rather than competitive. First, it might be that switches are caused by several mechanisms that act independently. Moreover, even if switching is dictated by high-level intentions, the exact time in which it occurs, and the distributional properties of switches and repetitions in time, may depend on bottom-up fluctuations.

The implications of the present results extend beyond the scope of the task-switching paradigm *per se*, and they relate to the much broader questions of optimality and causality in behavior, and of control and free will. Recently, Haggard (2008) described human volition as a hierarchical set of decisions, made in different levels of abstraction. One of these decisions, termed task (or goal) selection, refers to selecting the appropriate or desired task among several alternative. Task selection was required in the previous studies that used the voluntary task-switching paradigm (Arrington & Logan, 2004, 2005; Mayr & Bell, 2006), as well as in Forstmann et al. (2006), and the Task Group of our current study. However, both the Task Group and the Switch group of our study faced a higher-level decision, termed by Haggard as "early 'whether decision'". This is the decision to change the course of present behavior. The decision to perform a voluntary change of the system's current state is a necessary condition for a task decision that should be made subsequently. The spontaneous switching phenomenon provided an opportunity to examine these 'whether decisions'. Understanding the causes of spontaneous switch behavior might get us closer to a future understanding of human volition.

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