The contribution of task-choice response selection to the switch cost in voluntary task switching

Baptist Liefooghe

Ghent University

Author Note

This research was supported by grant BOF16/MET_V/002 of Ghent University. The author is indebted to Jan De Houwer, Frederick Verbruggen, Andre Vandierendonck and Helen Tibboel.

Correspondence concerning this article should be addressed to Baptist Liefooghe, Department of Experimental-Clinical and Health Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Ghent (Belgium). E-mail: baptist.liefooghe@ugent.be

Abstract

Mental flexibility not only enables us to switch between tasks but also to select the tasks we want to perform. The latter scenario is central to voluntary task switching, in which participants are free to select on each trial which task to perform. The present study argues that voluntary task switching also includes and additional component, namely task-choice response selection. Task-choice response selection refers to the whole chain of processes involved in the overt report or indication of the task that was selected by emitting an arbitrary response. Task-choice response selection is not required to voluntarily switch between tasks, but serves the measurement of participants' covert task selection. The results of two experiments indicate that the contribution of task-choice response selection to switch performance in voluntary task switching is substantial. It is proposed that task-choice response selection delays the top-down retrieval of task rules in voluntary task switching.

The contribution of task-choice response selection to the switch cost in voluntary task switching

A core function of executive control is mental flexibility, which enables the coordination of different actions or tasks (e.g., Diamond, 2013). A substantial body of knowledge on mental flexibility has been gathered by means of the task-switching paradigm (see Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010 for reviews), in which participants are required to switch between two or more tasks. A common finding is that performance on task switches is inferior (longer reaction times, higher error rates) compared to the performance on task repetitions (i.e., the switch cost). Concerned with the possibility that performance in most task-switching procedures is largely exogenoulsy determined, Arrington and Logan (2004, 2005) introduced the voluntary task switching procedure (VTS), which aimed to reinstate the switch cost as a proxy of executive control involved in mental flexibility.

A common approach in VTS requires participants to "freely" select a task on each trial with the restriction that all possible tasks should be performed an approximate equal number of times in an unpredictable order (e.g., Arrington & Logan, 2004, 2005; Demanet, Verbruggen, Liefooghe, & Vandierendonck, 2010; Liefooghe, Demanet, & Vandierendonck, 2009, 2010). Typically, participants decide to repeat tasks more frequently than would be expected on the basis of chance. The task-repetition bias has been observed many times in voluntary task switching (e.g., Arrington & Logan, 2004, 2005; Arrington & Yates, 2009; Liefooghe, Demanet, & Vandierendonck, 2009, 2010; Mayr & Bell, 2006) and is restricted to the selection of tasks (Vandierendonck, Demanet, Liefooghe, & Verbruggen, 2012). In the literature on the generation of unpredictable or random sequences (e.g., letters, digits, time intervals,. . .), the common observation is an alternation bias, which is a tendency to select more alternations than would be expected on the basis of chance (Lopes, 1982; Lopes & Oden, 1987; Neuringer & Allen, 1986; Rapoport & Budescu, 1992; Treisman & Faulkner, 1987; Wagenaar, 1972). Vandierendonck, Demanet, Liefooghe, and Verbruggen (2012) proposed that the task-repetition bias is entailed by the reluctance to perform task switches, compared to less effortful task repetitions (see also, Rosen & Botvinick, 2007 for a discussion of the “law of least mental effort”). In support of this hypothesis, Vandierendonck et al. (2012) demonstrated the presence of an alternation bias when participants were instructed to randomly switch between a key-press with their left hand and a key-press with their right hand. However, when participants were instructed to randomly switch between two tasks, with each task either being assigned to the left or to the right hand, a task-repetition bias emerged.

Whereas the processes underlying the task-repetition bias, and task selection in general, have been investigated extensively in the past years (see, Arrington, Reiman, & Weaver, 2014 for a review), less attention has been paid to the processes underlying the switch cost in VTS. Because the switch cost in VTS follows the endogenous decision of performing a particular task, Arrington and Logan (2005) proposed that this switch cost may offer a more valid proxy of executive control compared to the switch cost measured in other task-switching procedures. The involvement of executive control was furthermore supported by the observation that the switch cost in VTS is reduced when more preparation time is available before the stimulus onset (Arrington & Logan, 2005; Liefooghe, Demanet, & Vandierendonck, 2009). Such finding suggests that additional top-down control processes are present on task switches compared to task repetitions, which prepare the cognitive system for the new task. If more preparation time is available prior to the stimulus onset, top-down control can be further completed prior to the stimulus onset and the switch cost is reduced. Further inquiry into the nature of this effect, led Demanet and Liefooghe (2014) to conclude that bottom-up control also has a substantial contribution to the switch cost in VTS. Bottom-up control copes with the persisting activation of the task activated on the previous trial, which facilitates task repetitions but interferes with task switches. When the temporal distance between two consecutive trials increases, less persisting activation is present and the switch cost is reduced.

In order to dissociate between top-down and bottom-up control, Demanet and Liefooghe (2014) used a double-registration procedure for VTS (Arrington & Logan, 2005, Experiment 6). Participants chose a task when a probe was presented prior to the stimulus onset and two types of responses were registered: a first response to the probe (*task-choice response*), and a second response to the stimulus (*task-execution response*). Demanet and Liefooghe (2014) varied the Inter-Trial Interval (ITI) as well as the interval between the task-choice response and the stimulus onset (i.e., Response-Stimulus Interval or RSI), with each interval either being 100ms (short) or 1000ms (long). In order to investigate the bottom-up component, the switch cost measured on task-execution responses for trials on which the ITI was short and the RSI was short (short RSI-short ITI) were compared with the switch cost measured on task-execution responses of trials with a long ITI and a short RSI (short RSI-long ITI). Both trial types differ in the amount of time elapsed since the previous trial, whereas the amount of preparation time after having made a task-choice response is short and fixed (see Figure 1). In three experiments, Demanet and Liefooghe (2014) observed that the switch cost was smaller for "short RSI-long ITI"-trials than for "short RSI-short ITI"-trials. Demanet and Liefooghe (2014) also compared the switch cost measured on task-execution responses between "short RSI-long ITI"-trials and "long RSI-short ITI"-trials to investigate the top-down component. Both trial types differ in the amount of time participants receive to prepare for the upcoming task, after having made a task-choice response. However, the time between the stimulus onset on trial n and the task-execution response made on trial n-1 is the same (Figure 1). When using the standard double-registration procedure for VTS, Demanet and Liefooghe (2014; Experiment 1) did observe a smaller switch cost on task-execution responses for "long RSI-short ITI"-trials compared to "short RSI-long ITI"-trials. However, participants in VTS can in principle select and prepare the upcoming task whenever they can. Accordingly, preparation can also take place outside the RSI. In two follow-up experiments, Demanet and Liefooghe (2014; Experiments 2 & 3) constrained participants' preparatory processing to the RSI. In both these experiments, only a bottom-up component was observed, but no top-down component (i.e., no smaller switch costs for “RSI long-ITI short”-trials compared to “RSI short-ITI long”-trials; see also Kleinsorge & Scheil, 2015 for a conceptual replication).

The results of Demanet and Liefooghe (2014) suggest that the switch cost in VTS is mainly related to bottom-up control and to a lesser extent to top-down control. Yet, their findings could be considered as rather trivial by assuming that top-down and bottom-up control are basically only different instances of executive control involved in mental flexibility. In the present study, I will, however, pinpoint to a possibly more pertinent issue by investigating whether a substantial part of the switch cost, as it is commonly measured in VTS, does not reflect processes involved in task switching, but is instead related to *task-choice response selection*. By task-choice response selection, I refer to the whole chain of processes involved in the overt report or indication of the task that was selected by emitting an arbitrary response. Task-choice response selection is not required to voluntarily switch between tasks, but serves the measurement of participants’ covert task selection.

When each task is mapped to a different hand, participants’ task choice is inferred on the basis of the hand used to respond to the stimulus. In the double-registration procedure, the selected task is indicated by using task-choice responses. In both scenarios, the selected task thus needs to be translated to a cue or a response, which is arbitrarily assigned to that task on the basis of instructions. Of course, it could be questioned whether such translation process is actually present: Participants may first randomly select a particular hand or choice response and only subsequently infer the task this hand or response corresponds with. However, this hypothesis seems unlikely in view of the task-repetition bias. If participants would first only engage in random hand selection or random choice-response selection, then an alternation bias would be observed. Alternatively, it could be argued that a task-choice response is selected after a particular task is selected *and prepared*. As such, once a task-choice response is made, the selected task can immediately be applied (i.e., a stimulus can immediately be responded to without additional preparatory processing). Such hypothesis is, however, not in line with performance in the double-registration variant of VTS, which offers separate markers for task choice and task execution. Although performance on task-choice responses has not been extensively investigated, previous reports indicate that task-choice responses in the double-registration procedure are performed relatively fast, and more importantly, are hardly different between task repetitions and task switches (Arrington & Logan, 2005; Demanet & Liefooghe, 2014). In contrast, task-execution responses are significantly slower compared to task-choice responses and reflect a substantial switch cost.

Currently available findings thus suggest that a VTS trial encloses an additional processing step, task-choice response selection, which is engaged after task selection and completed before task execution. The switch cost measured in VTS thus needs to be considered as a function of differences at the level of task selection, task-choice response selection and task execution. On task repetitions, (a) the same task is selected as on the previous trial, (b) the same task-choice response is selected as on the previous trial, and (c) the same task is executed as on the previous trial. On task switches, (a) a different task is selected, (b) a different task-choice response is made and (c) a different task is executed. Task-choice response selection thus results into the same task-choice response on task repetitions, but into a different task-choice response on task switches and the question arises if this difference in task-choice response selection contributes to the switch cost in VTS.

In order to investigate the impact of task-choice response selection, the double-registration variant of VTS was extended by assigning two task-choice responses to each task. Participants were required to switch voluntarily between a letter and a shape task. Each task could be selected by pressing one of two keys of an QWERTY keyboard: the letter-keys "e" and "t" served as task-choice responses for the letter task and the letter-keys "d" and "g" served as task-choice responses for the shape task. Once a task-choice response selection was made, the corresponding task needed to be performed by using a separate set of task-execution responses (i.e., the "1" and the "2" on the numeric key-pad). Three transitions could be derived in this procedure: (a) *complete repetitions* in which the same task is selected on two consecutive trials by using the same task-choice response on trial n-1 and trial n; (b) *task repetitions* in which the same task is selected on two consecutive trials by using a different task-choice response on trial n-1 compared trial n; and (c) *task switches* in which a different task and accordingly a different task-choice response is used on trial n-1 compared to trial n. Both task repetitions and task switches are associated with a switch in task-choice response, but involve different task transitions. The difference between task repetitions and task switches thus indexes the effect of switching from one task to another and offers a proxy of the different top-down and bottom-up processes underlying such transition (e.g., Demanet & Liefooghe, 2014). Complete repetitions and task repetitions involve the same task transition, but a different transition at the level of task-choice response selection. The difference between both thus offers an index of the impact of task-choice response selection.

Experiment 1

The aim of Experiment 1 was to offer an initial estimate of the contribution of task-choice response selection in VTS by using the aforementioned approach. Of main importance, were differences between complete repetitions, task repetitions, and task switches on task-execution responses, as switch costs are mainly present during task execution and not during task choice (Arrington & Logan, 2005; Demanet & Liefooghe, 2014). In order to have a first indication of the strength of the impact of task-choice response selection on task execution, the RSI could either be 0, 300, 600 or 900ms. As discussed in the Introduction, merely increasing the length of the RSI does not permit to draw strong conclusions about the nature of the processes underlying switch performance in VTS. Nevertheless, it remains helpful by showing the extent to which a difference between complete repetitions and task repetitions on task-execution responses is also present for longer RSIs.

Method

Participants. Twenty-Eight students at Ghent University participated for course requirements and credits. All participants had normal or corrected-to-normal vision, were right-handed, and all were naive to the purpose of the experiment.

Materials. Stimuli were the letters A, E, B, or D surrounded either by a circle, an ellipse, a square or a rectangle. Participants were required to classify the letter (consonant or vowel) or the shape (quadrangle or ellipsoid). The set-up of Experiment 1 is outlined in Figure 2. Task-choice responses were made with the left hand on a QWERTY keyboard. Participants chose the letter task by pressing “e” or “t” with the middle finger and the shape task by pressing “d” or “g” with the index finger of the left hand. Based on these four task-choice response keys, complete repetitions, task repetitions, and task switches could be separated. On complete repetitions, participants selected the same task as on the previous trial by pressing the same task-choice response in comparison to the previous trial (e.g., pressing “d” on two consecutive trials). On task repetitions, participants selected the same task by using a different task-choice response that was associated with the same task (e.g., pressing “d” on trial n-1 and pressing “g” on trial n). Finally, on task switches participants selected a different task and thus a different task-choice response in relation to the previous trial (e.g., pressing “e” on trial n-1 and pressing “d” on trial n). Due to the set-up of the task-choice responses (see Figure 2), two types of task switches need to be considered: (a) participants switch towards the alternative task by pressing a task-choice response, which is at the same response side as the previous task-choice response (e.g., pressing “e” on trial n-1 and then “d” on trial n); and (b) participants switch the towards the alternative task by pressing the task-choice response, which is at the opposite response side compared to the previous task-choice response (e.g., “e” on trial n-1 and “g” on trial n).

After each task-choice response, participants moved their middle or index finger back to two rest keys (“r” for the letter task and “f” for the shape task). Participants responded to the stimuli by pressing “1” or “2” on the numeric keypad with the index and middle finger of the right hand. Depending on the selected task, “1” meant “consonant” or “quadrangle” and “2” meant “vowel” or “ellipsoid”.

Procedure. Participants were tested individually by means of a Pentium III personal computer with a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Instructions were presented on screen and paraphrased if necessary. The instructions of Arrington and Logan (2004; 2005) concerning randomness were slightly modified because participants were not only instructed to voluntarily switch between two tasks, but also between the two task-choice responses assigned to each task. More specifically, participants were told to imagine a bag with four different types of candies (i.e., two tasks and two task-choice response associated with each task) and on each trial they had to draw a candy from the bag without watching. Four blocks of 257 test trials followed one block of 50 practice trials with a short break after each block. On each trial, a question mark was presented on the screen center until participants made a task-choice response or a maximum time of 3000ms elapsed. Next, the question mark was removed and a RSI of either 0ms, 300ms, 600ms or 900ms started before the stimulus appeared. The stimulus remained on screen until a task-execution response was made or a maximum response time of 3000ms elapsed. For incorrect responses, the screen turned red for 200ms. The ITI was 500ms.

Results

The practice block and the first trial of each test block were not included in the analysis. Trials on which no task-choice was made within the 3000ms deadline, trials with an incorrect task-execution response, and trials following upon a trial with no task-choice response or an incorrect task-execution response were excluded. This led to the removal of 14.99% of the trials.

Task-choice responses. In a first, step the task-choice portions were investigated. The instructions specified to switch between two tasks and two ways of selecting each task. Accordingly, participants had four possible choices and it was first tested to which extent participants did comply with the instructions. To this end, task-choice proportions were calculated by counting the number of times participants selected each of the four possible scenarios. For each participant, these numbers were then devised by the total number of correct task-choice responses of that participant. Participants selected the shape task by pressing the E-key on .26 (SD= .03) of the trials and by pressing the T-key on .25 (*SD*= .03) of the trials. The letter task was selected by pressing the G-key on .26 (*SD*= .03) of the trials and by pressing the D-key on .23 (*SD*= .03) of the trials. The latter task-choice proportion was significantly below .25, $t(27)= 3.15$, $p< .004$, $r^2= .27$. The other task-choice proportions did not differ significantly from .25. The largest t-value was: $t(27)= 1.27$, $p=$ .217, $r^2= .06$. Participants did thus follow the instructions fairly well. In a next step, the transitions between two consecutive trials were considered. Again four possibilities arise: (a) participants repeat the previous task by pressing the same task-choice response (i.e., complete repetition); (b) participants repeat the previous task by pressing a different task-choice response (i.e., task repetition); (c) participants switch towards the alternative task by pressing a task-choice response, which is at the same response side as the previous task-choice response; and (d) participants switch the towards the alternative task by pressing the task-choice response, which is at the opposite response side compared to the previous task-choice response. Compared to the .25 baseline, participants systematically performed more complete repetitions ($M= .34$; $SD= .17$), $t(27)= 2.68$, $p<.012$, $r^2= .21$, and task repetitions ($M= .28$; $SD= .08$), $t(27)= 2.17$, $p<.039$, $r^2= .15$. In contrast, participants performed significantly less task switches with a response-side repetition ($M=.20$; $SD= .10$), $t(27)= 2.91$, $p< .007$, $r^2= .24$, and task switches with a response-side alternation ($M= .19$; $SD= .10$), $t(27)= 3.32$, $p<.003$, $r^2= .29$.

For reasons of clarity, in the remainder of the analysis I only focus on the theoretically relevant transitions, namely complete repetitions, task repetitions and task switches, thus collapsing across the two types of task switches. RTs were analyzed by means of a one-way ANOVA with Transition Type (complete repetition, task repetition, task switch) as a repeated measures factor. The effect of Transition Type was not significant, $F(2{,}54)= 1.58$, $p= .216$, $MSE= 4739$, $\eta_p{}^2= .06$: complete repetitions ($M= 294$ms; $SD= 198$ms), task repetitions ($M= 325$ms; $SD= 154$ms), and task switches ($M= 317$ms; $SD= 153$ms) were selected equally fast.

Task-execution responses. RTs and the proportion of errors (PEs) were each subjected to a repeated measures ANOVA with Transition Type (complete repetition, task repetition, task switch) and RSI (0ms, 300ms, 600ms, 900ms) as factors. Cell means and corresponding standard deviations are presented in Table 1. The effect of Transition Type was significant, $F(2{,}54)= 81.92$, $p< .001$, $MSE= 12236$, $\eta_p{}^2= .75$. RTs on complete repetitions ($M= 726$ms, $SD= 146$ms) were faster than RTs on task repetitions ($M= 823$ms, $SD= 174$ms), $t(27)= 8.48$, $p<. 001$, $r^2= .72$, which in turn were faster than RTs on task switches ($M= 915$, $SD= 187$), $t(27)= 5.87$, $p< .001$, $r^2= .56$. The main effect of RSI was also significant, $F(3{,}81)= 61.30$, $p< .001$, $MSE= 3232$, $\eta_p{}^2= .69$. RTs decreased as a function of RSI (RSI= 0ms: $M= 893$ms, $SD= 168$; RSI=300ms: $M= 829$ms, $SD= 175$; RSI=600ms: $M= 796$ms, $SD= 180$; RSI=900ms: $M= 788$ms, $SD= 170$). Transition Type and RSI interacted, $F(6{,}162)= 3.36$, $p< .003$, $MSE= 3170$, $\eta_p{}^2= .11$. Further analysis indicated that the difference between complete repetitions and task repetitions did not decrease as a function of RSI, $F(3{,}162)= 1.71$, $p= .208$, $\eta_p{}^2= .03$. In contrast, the difference between task repetitions and task switches became smaller for longer RSIs, $F(3{,}81)= 3.99$, $p< .012$, $\eta_p{}^2= .07$.

For the PEs, the main effect of Transition Type was significant, $F(2{,}54)= 21.99$, $p<.001$, $MSE= .00273$, $\eta_p{}^2= .45$. PEs were higher on task switches ($M= .10$; $SD=.04$) than on task repetitions ($M= .06$; $SD=.04$), $t(27)= 5.59$, $p<.001$, $r^2= .45$. PEs did not differ between task repetitions and complete repetitions ($M= .07$; $SD= .05$), $t(27)= 1.10$, $p= .279$, $r^2= .04$. The main effect of RSI and the two-way interaction were not significant, $F< 1$ and $F(6{,}162)= 1.05$, $p=.393$, $MSE= .001741$, $\eta_p{}^2= .04$, respectively.

Discussion

Complete repetitions and task repetitions were selected more frequently than the .25 baseline, whereas task switches were selected less frequently than the .25 baseline. Task-choice proportions thus indicated the presence of a task-repetition bias as it is commonly observed in VTS. Hence, even though two task-choice responses were assigned to each task, participants still first retrieved a particular task and only subsequently selected a corresponding task-choice response. If the to-be-performed-task would have been inferred only after having randomly selected a choice-key, then an alternation bias should have been observed (Vandierendonck et al., 2012).

Task-choice RTs did not differ as a function of Transition Type. Previous studies reported a switch cost during task choice when the ITI was 100ms (Arrington & Logan, 2005; Experiment 6; Demanet & Liefooghe, 2014). However, for ITIs longer than 100ms, Arrington and Logan (2005; Experiment 6) did not observe a switch cost. For an ITI of 1000ms, Demanet and Liefooghe (2014) observed a reversed switch cost (Experiment 1), no switch cost (Experiment 2), or a smaller switch cost (Experiment 3). The use of a 500ms long ITI may thus have been too long to observe significant differences between complete repetitions, task repetitions and task switches.

Of central importance was switch performance during task execution. Task-execution RTs were significantly faster on complete repetitions than on task repetitions and RTs were significantly faster on task repetitions compared to task switches. The difference between complete repetitions and task repetitions remained present for longer RSIs and accounted for about half of the switch cost in VTS, which is usually indexed as the difference between complete repetitions and task switches. Task-choice response selection thus had a substantial contribution to switch performance in voluntary task switching. In Experiment 2, the nature of this contribution was further investigated.

Experiment 2

Experiment 2 tested the extent by which the effect of task-choice response selection on task execution is related to top-down and/or bottom-up control by using the approach of Demanet and Liefooghe (2014). The lengths of the RSI and ITI were manipulated orthogonally in order to investigate whether the difference between complete repetitions, task repetitions, and task switches could be reduced either on the basis of preparation (i.e., top-down control) or through a decrease in persisting activation (i.e., bottom-up control). Note that Demanet and Liefooghe (2014) did not observe evidence for top-down control when constraining participants' processing to the RSI. Because I was interested in both top-down and bottom-up control, no such constrains were imposed to the participants. Taken together, a conceptual replication of the first experiment of Demanet and Liefooghe (2014) was thus conducted, which now included complete repetitions, task repetitions, and task switches.

Two hypotheses were considered. For your guidance, I again refer to Figure 1. First, the effect of task-choice response selection on task execution reflects bottom-up control, which manages persisting activation emanating from the previous trial. According to this view, task execution is not only impacted by the task that was previously activated, but also by the task-choice response that was used to indicate that task. For task repetitions, a mismatch exists at the level of the task-choice response and interference occurs. Following this hypothesis, the difference between complete and task repetitions should be modulated by the temporal distance between two consecutive trials. A smaller switch cost should be observed on "short RSI-long ITI"-trials than on "short RSI-short ITI"-trials. A second hypothesis relates the difference between complete repetitions and task repetitions to additional top-down processes involved in task repetitions compared to complete repetitions. Such top-down control processes are sensitive to the amount of time available for preparation prior to the stimulus onset and the difference between complete repetitions and task repetitions should become smaller when more opportunity for preparation is present. A such, the difference between both trial types should be smaller for "long RSI-short ITI"-trials compared to "short RSI-long ITI"-trials. Of course, both hypotheses are not mutually exclusive and the effect of task-choice response selection may be related to both top-down and bottom-up control.

The difference between task repetitions and task switches was also of importance. As mentioned before, Demanet & Liefooghe (2014) observed both a top-down and a bottom-up component of the switch cost when varying ITI and RSI orthogonally without constraining participants' preparatory processing. In their study, however, the effect of task-choice response selection was not accounted for and complete repetitions were compared to task switches. The question thus arises whether the top-down and bottom-up component they reported are still present when only considering the difference between task repetitions and task switches, thus taking-out the proportion of variance accounted for by task-choice response selection.

A second purpose of Experiment 2 was to further assess the impact of task-choice response selection during task choice. The timing parameters of Demanet and Liefooghe (2014, Experiment 1) were used and the ITI could either be 100ms (short) or 1000ms (long). As I discussed previously, switch costs were consistently reported for an ITI of 100ms (Arrington & Logan, 2005; Demanet & Liefooghe, 2014). The question was thus whether differences between complete repetitions, task repetitions, and task switches could be observed on the task-choice responses when using an ITI of 100ms.

Method

Twenty-Eight students at Ghent University participated for course requirement and credit. All participants met the criteria of Experiment 1 but none of them participated in Experiment 1. Experiment 2 was identical to Experiment 1, except for the ITI and the RSI, which could now be 100ms or 1000ms. The length of the ITI and RSI varied randomly on a trial-to-trial basis.

Results

One participant had missing cells and was removed from the analyses. The practice block and the first trial of each test block were removed. The same outlier criteria as in Experiment 1 were used. This led to the removal of 12.44% of the trials.

Task-choice responses. For each ITI-length, the task-choice proportions were calculated as in Experiment 1 and compared to a .25 baseline. For the short ITI, participants selected the shape task by pressing the E-key on .25 (SD= .03) of trials, t< 1, and by pressing the T-key on .26 (SD= .03) of the trials, $t(26)$= 1.04, p= .309, r^2= .04. The letter task was selected by pressing the D-key on .22 of the trials (SD= .04), $t(26)$= 4.04, p< .001, r^2= .39, and by pressing the G-key on .28 (SD= .04) of the trials, $t(26)$= 3.62, p< .001, r^2= .33. For the long ITI, participants selected the shape task by pressing the E-key on .25 (SD= .02) of the trials, t<1, and by pressing the T-key on .25 (SD= .03) of the trials, t<1. The letter task was selected by pressing the D-key on .23 (SD= .03) of the trials, $t(26)$=3.19, p<.004, r^2= .28, and by pressing the G-key on .27 (SD= .02) of the trials, $t(26)$= 5.30, p< .001, r^2= .52. Although some bias was present for the letter task, participants complied fairly well with the instructions of the experiment. Next, the different proportions of the four possible transitions are considered. For the short ITI, participants performed .30 (SD= .18) of complete repetitions, $t(26)$= 1.50, p=.145, r^2= .08; .31 (SD= .09) of task repetitions, $t(26)$= 3.36, p< .002, r^2= .30; .21 (SD= .07) of task switches with a response-side repetition, $t(26)$= 3.13, p< .004, r^2= .27, and .18 (SD= .08) of task switches with a response-side alternation, $t(26)$= 4.29, p<.001, r^2= .41. For the long ITI, participants performed .26 (SD= .17) of complete repetitions, t<1; .31 (SD= .09) of task repetitions, $t(26)$= 3.39, p< .002, r^2= .31; .22 (SD= .07) of task switches with a response-side repetition, $t(26)$= 1.86, p< .075, r^2= .12, and .20 (SD= .08) of task switches with a response-side alternation, $t(26)$= 3.14, p< .004, r^2= .28.

RTs were analyzed by means of a repeated measures ANOVA with Transition Type (complete repetition, task repetition, task switch) and ITI (100ms, 1000ms) as factors. The main effect of Transition Type was significant, $F(2,52)= 7.64$, $p< .001$, $MSE= 6341$, $\eta_p^2=$ .23. RTs were faster for complete repetitions ($M=$ 520ms, $SD=$ 107) compared to task repetitions ($M=$ 553ms, $SD=$ 126), $t(26)= 2.18$, $p< .038$, $r^2= .15$. RTs did not differ between task repetitions and task switches ($M=$ 558ms, $SD=$ 124), $t<1$. The main effect of ITI was also significant, $F(1,26)= 80.05$, $p< .001$, $MSE= 48969$, $\eta_p^2= .76$. RTs were longer for the short ITI ($M=$ 682ms, $SD=$ 172) than for the long ITI ($M=$ 387ms, $SD=$ 119). Both factors interacted, $F(2,52)= 4.69$, $p< .013$, $MSE= 4795$, $\eta_p^2= .15$. For the short ITI, the difference between complete repetitions and task repetitions was significant, $t(26)= 2.64$, $p<$ .014, $r^2= .21$. For the long ITI, this difference was not significant, $t< 1$. The difference between task repetitions and task switches was neither significant for the short ITI, $t(26)=$ 1.50, $p= .145$, $r^2= .08$, nor for the long ITI, $t< 1$.

Task-execution responses. RTs and PEs were subjected to a 3 (Transition Type: complete repetition, task repetition, task switch) by 4 (Interval Combination: short RSI-short RPI, short RSI-long RPI, long RSI-short RPI, long RSI-long RPI) repeated measures ANOVA. Cell means and corresponding standard deviations are presented in Table 2. The main effect of Transition Type was significant, $F(2,52)= 72.07$, $p<.001$, $MSE= 11502$, $\eta_p^2= .73$. RTs on complete repetitions ($M=$ 737, $SD=$ 114) were faster than RTs on task repetitions ($M=$ 829, $SD=$ 157), $t(26)= 7.16$, $p<.001$, $r^2= .66$, which were in turn faster than RTs on task switches ($M=$ 912, $SE=$ 183), $t(26)= 5.70$, $p< .001$, $r^2= .56$. The main effect of Interval Combination, $F(3,78)= 26.38$, $p<.001$, $MSE= 5206$, $\eta_p^2= .50$, as well as the two-way interaction between Interval Combination and Transition Type, $F(6,156)=$ 10.59, $p< .001$, $MSE= 1770$, $\eta_p^2= .28$, were significant.

The two-way interaction was further analyzed in order to assess the extent by which the difference between complete repetitions, task repetitions, and task switches is related to top-down control, bottom-control or both. In order to investigate top-down control, the effect of Transition Type on “short RSI-long ITI”-trials was compared with the effect of Transition Type measured on “long RSI-short ITI”-trials. The effect of Transition Type was different for both interval combinations, $F(2{,}156)= 3.19$, $p< .042$, $\eta_p{}^2= .04$. The difference between complete repetitions and task repetitions (68ms) was smaller for "long RSI-short ITI"-trials compared to "short RSI-long ITI"-trials (97ms), $F(1{,}156)= 4.42$, $p< .021$, $\eta_p{}^2=$ .03. In contrast, the difference between task repetitions and task switches did not differ between both interval combinations, $F< 1$. For the bottom-up control component, the effect of Transition Type measured on "short RSI-short ITI"-trials was compared to the effect of Transition Type measured on "short RSI-long ITI"-trials. The effect of Transition Type differed between both interval combinations, $F(2{,}156)= 11.11$, $p< .001$, $\eta_p{}^2= .12$. The difference between complete repetitions and task repetitions did not differ between "short RSI-short ITI"-trials and "short RSI-long ITI"-trials, F<1. The difference between task repetitions and task switches was significantly reduced for "short RSI-long ITI"-trials compared to "short RSI-short ITI"-trials, $F(1{,}156)= 18.15$, $p< .001$, $\eta_p{}^2= .10$.

For the PEs, the main effect of Transition Type was significant, $F(2{,}52)= 16.00$, $p<$ .001, $MSE= .001358$, $\eta_p{}^2= .38$. PEs were higher on task switches ($M= .08$; SD=.04) than on task repetitions ($M= .06$; SD=.04), $t(26)= 4.95$, $p< .001$, $r^2= .48$. PEs did not differ between task repetitions and complete repetitions ($M= .05$; $SD= .04$), t<1. The main effect of Interval Combination was not significant, F<1. The two-way interaction between Interval Combination and Transition Type was on the verge of significance, $F(6{,}156)= 2.12$, $p= .055$, $MSE= .001478$, $\eta_p{}^2= .08$. However, further analysis indicated that the effect of Transition Type neither differed between "short RSI-long ITI"-trials and "long RSI-short ITI"-trials, F<1, nor between "short RSI-long ITI"-trials and "short RSI-short ITI"-trials, $F(2{,}156)=$ 2.49, $p= .084$.

Discussion

For the short ITI, task-choice proportions were significantly larger than .25 for task repetitions and numerically larger than .25 for complete repetitions. For task switches, task-choice proportions were significantly below the .25 baseline. For the long ITI, task-choice proportions were significantly larger than .25 for task repetitions and numerically larger than .25 for complete repetitions. For task switches, task-choice proportions were significantly below the .25 baseline for response-side alternations and numerically below the baseline for response-side repetitions. Overall, a task-repetition bias was thus observed.

For the short ITI, task-choice RTs on complete repetitions were significantly faster compared to task repetitions and task switches. The latter two transitions did not differ. For the long ITI, the effect of Transition Type was not significant. The small switch cost on task choice that has been previously reported for a short ITI (Arrington & Logan, 2005; Demanet & Liefooghe, 2014), thus seems to be mainly related to the difference between task-choice response repetition (complete repetition) and task-choice response alternation (task repetition and task switches), rather than to a difference between task repetitions and task switches.

Again, performance during task execution was of main importance. Complete repetitions were faster than task repetitions, which in turn were faster than task switches. The findings of Experiment 1 were thus replicated. Furthermore, the difference between complete repetitions and task repetitions was smaller for “long RSI-short ITI”-trials than on “short RSI-long ITI”-trials and did not vary between “short RSI-long ITI”-trials and “short RSI-short ITI”-trials. This pattern of results suggests that the impact of task-choice response selection on task execution relates to top-down control processes, which are more involved in task repetitions compared to complete repetitions.

Another crucial finding relates to the difference in task-execution RTs between task repetitions and task switches. This difference was smaller on “short RSI-long ITI”-trials than on “short RSI-short ITI”-trials. However, the difference between task repetitions and task switches did not vary between “short RSI-long ITI”-trials and “long RSI-short ITI”-trials. This pattern of results is in line with the second and the third experiment of Demanet and Liefooghe (2014, see also, Kleinsorge & Scheil, 2015), who observed a bottom-up component, but not a top-down component of the switch cost. Experiment 2 thus offers an important addition to the conclusions of Demanet and Liefooghe (2014), namely that the small top-down component they observed in their first experiment is in fact related to top-down processes entailed by task-choice response selection and is not related to the actual switch between one task to another task.

General Discussion

The present study continued upon our previous work (Demanet & Liefooghe, 2014) by further exploring the different component processes underlying the switch cost measured in VTS. Whereas we previously claimed that the switch cost in VTS is best considered as a mixture of top-down and bottom-up control, the present study adds that a substantial part of the switch cost in VTS is related to task-choice response selection. Task-choice response selection was defined as the processing step underlying the translation of a selected task into an arbitrary response, which serves the overt report of the selected task. Importantly, the operation of task-choice response selection differs between task repetitions and task switches. In order to measure the contribution of task-choice response selection to the switch cost in VTS, two task-choice responses were assigned to each task in a double-registration procedure for VTS (Arrington & Logan, 2005; Demanet & Liefooghe, 2014). The impact of task-choice response selection was indexed as the difference between complete repetitions in which all events repeat on two consecutive trials and task repetitions in which the same task is selected twice in a row by using a different task-choice response. On task switches a different task was selected compared to the previous trial. The results of two experiments can be summarized as follows. First, complete repetitions and task repetitions were selected more frequently than task switches. A task-repetition bias was thus observed, which indicates that task-choice responses were made on the basis of a selected task and not vice versa. Second, only for an ITI of 100ms complete repetitions were selected significantly faster compared to task repetitions and task switches. This finding suggests that the so-called switch cost during task choice (Arrington & Logan, 2005; Demanet & Liefooghe, 2014), is mainly related to task-choice response selection. Third, and of core interest for the present study, task execution was substantially faster on complete repetitions compared to task repetitions, whereas task repetitions were substantially faster than task switches. Task-choice response selection thus contributed significantly to the switch cost in VTS. The results of Experiment 2, furthermore, suggested that the impact of task-choice response selection is mainly related to the induction of additional top-down control processes. In contrast, the difference between task repetitions and task switches (i.e., the *task*-switch cost) was not related to the operation of top-down control and was mainly a function of bottom-up control (see also Demanet & Liefooghe, 2014; Kleinsorge & Scheil, 2015).

As I argued in the Introduction, a VTS trial most likely consists of three processing demands: (a) task selection; (b) task-choice response selection; and (c) task execution. The present results indicate that task-choice response selection delays task execution, beyond its own length. More precisely, whereas the difference between complete repetitions and the other two transitions was negligible on task-choice responses, substantial differences were observed on task-execution responses. The delay or cost induced by task-choice response selection decreases when more time is available between the task-choice response and the stimulus onset (i.e., top-down control). This pattern of results could suggest that additional retrieval processes are triggered when task-choice response selection is completed. Similar suggestions have been made in the context of cued task switching. In cued task switching, bi-dimensional stimuli are used on which two choice-reaction tasks can be performed. For instance, colored shapes on which a color or a shape judgment can be applied. On each trial, a task cue (e.g., the letter X cueing the color task or the letter Y cueing the shape task) is presented, which indicates the task to perform on that trial. Importantly, the sequence in which the tasks are presented is unpredictable for the participants and they can only rely on the task cue in order to know which task to perform. Logan and Bundesen (2003, 2004; see also Mayr & Kliegl, 2003; Schneider & Logan, 2005) pointed out that when only one cue is used per task, a task switch always coincides with a cue switch. In order to disentangle cue switches and task switches, Logan and Bundesen (2003) assigned two cues per task (e.g., X and W cueing a color task; Y and Z cueing a shape task). When doing so, three types of transition can be derived: (a) cue repetitions on which cue and task are repeated in comparison to the previous trial (e.g., trial n-1: X -> color task; trial n: X -> color task); (b) cue switches on which the task is repeated but not the cue (e.g., trial n-1: X -> color task; trial n: W -> color task); and (c) task switches on which both the cue and the task switch (e.g., trial n-1: X -> color task; trial n: Y -> shape task). The difference between cue repetitions and cue switches indexes the effect of cue-related processing (i.e., cue-switch cost). The difference between cue switches and task switches indexes the effect of task-switch related processing (i.e., task-switch cost). When non-transparent or semantically task-unrelated cues are used (e.g., the letter X cueing a color task), substantial cue-switch and task-switch effects have been reported (e.g., Logan & Schneider, 2006; Mayr & Kliegl, 2003). In addition, Mayr and Kliegl (2003, Experiment 2) observed that cue-switch effects decreased when more preparation time was provided, whereas task-switch effects did not vary as a function of preparation. In other words, the cue-switch effect was related to top-down control, but not the task-switch effect. Mayr and Kliegl (2003) related this pattern of results to the operation of two sets of processes in task switching. First, the cue-switch effect is supposedly based on the cue-based retrieval of task rules (i.e., stimulus-response mappings) from long-term memory (see also Mayr & Kliegl, 2000; Meiran, 1996; Rogers & Monsell, 1995 for similar proposals). Each time a task-cue is encoded, the corresponding task rules are retrieved. For cue repetitions, such retrieval is facilitated as a result of cue priming, which is absent on cue switches. Furthermore, the longer the time interval between the task-cue and the target stimulus, the further task-rule retrieval is completed. This results in a decrease of the cue-switch effect when more preparation time is available (i.e., top-down control). Second, the task-switch effect reflects interference during the application of the relevant task rule on the target stimulus. Such interference can be caused by the persisting activation of the task executed on the previous trial (e.g., Allport et al., 1994; Meiran, 1996) as well as by the stimulus-based retrieval of previously learnt stimulus-task and stimulus-response associations (e.g., Waszak, Hommel, & Allport, 2003, 2004; Wylie & Allport, 2000). Interference is higher on task switches compared to task repetitions (and cue repetitions), eliciting a task-switch effect. Because the task-switch effect is induced during task application, it is insensitive to the amount of available preparation time.

The results of Mayr and Kliegl (2003, Experiment 2) are highly similar to the results obtained in Experiment 2. The difference between complete repetitions and task repetitions could be reduced through preparation, whereas the difference between task repetitions and task switches could not. As such, it can be hypothesized that the cost task-choice response selection induces on task execution in VTS, relates to the retrieval of task rules, which can be initiated prior to the stimulus onset. As it is the case for a non-transparent cue in cued task switching, a task-choice response thus triggers the retrieval of the corresponding task rules from long-term memory. This retrieval step is facilitated on complete repetitions compared to task repetitions, because in the former case the task-choice response is repeated across two consecutive trials. As in cued task switching, the difference between task repetitions and task switches did not vary as a function of preparation and is most likely related to bottom-up or interference control during the application of the relevant task rule. Yet, whereas the results of Experiment 2 indicated that the difference between task repetitions and task switches decreases for a longer temporal distance between two consecutive trials (i.e., a bottom-up component), Mayr and Kliegl (2003, Experiment 2) did not observe such effect. Possibly, the task-switch cost in VTS is more related to bottom-up control dealing with the previously activated task settings (see also, Demanet & Liefooghe, 2014), whereas the task-switch cost in cued task switching is more related to the stimulus-based retrieval of associations, which is known to be insensitive to neither top-down nor bottom-up control (i.e., the residual switch cost, Meiran, Chorev, & Sapir, 2000).

The results of the present study thus advocate a strong commonality between VTS and cued task switching with non-transparent cues. In a similar vein, Masson and Carruthers

(2014) performed a close comparison between VTS and cued task switching with non-transparent cues and concluded that both types of switching are based on the same task-reconfiguration processes. However, the rationale of the present study should not be neglected, namely that task-choice response selection is an additional processing demand, which is not essential to VTS. One is perfectly capable of deciding to perform a particular task or to switch between tasks, without indicating or signaling what she or he is intending to do. Most likely, in the absence of task-choice response selection, task rules are retrieved immediately after a particular task is covertly selected. Task-choice response selection thus delays the retrieval of task rules until after the task-choice response made. This sequence of processing may be induced by cognitive constrains in performing task-choice response selection and task-rule retrieval in parallel (see, Rohrer & Pashler, 2003 for an illustration of the bottleneck between response selection and long-term memory retrieval) or by the strategic scheduling of different processing steps (e.g., Meyer & Kieras, 1997). Within the latter perspective, it is conceivable that changing the priority by which participants process the different demands on a trial in VTS (e.g., by stressing speed instructions) could modulate the contribution of task-choice response selection to switch performance in VTS. In a similar vein, it is important to again emphasize that Demanet and Liefooghe (2014) did not observe a top-down component of the switch cost when constraining participants' preparatory activity. Accordingly, it is very likely that applying similar manipulations in the current context would also eliminate the top-down component following task-choice response selection, which would suggest that, under such conditions, the retrieval of task rules does not immediately follow upon the completion of task-choice response selection.

A premise of the current study is that participants first select a task and subsequently proceed with task-choice response selection on the basis of the selected task. The difference between complete repetitions and task repetitions is then considered as a proxy of the operation of task-choice response selection, which was defined as the translation of a task choice into an arbitrary response. It could, however, be argued that participants did not conceive the procedure along these lines. In line with instructions provided concerning randomness (see, p. 10) , the goal of the procedure could have been interpreted as switching between four tasks with each task being assigned to one task-choice response (i.e., the letter-task with task-choice response “e”, the letter-task with task-choice response “t”, the shape-task with task-choice response “d”, the shape-task witch task-choice response “g”). Within the latter view the difference between complete repetitions and task repetitions does not only reflect task-choice response selection, but also task selection proper, because the selection of a different task-choice response, always coincides with the decision to perform a “different” task. Such alternative account does, however, not fit with the task-choice proportions observed in both experiments. In both experiments, task repetitions (i.e., selecting the same task with a different task-choice response) were selected above the .25 baseline. In contrast, task switches were selected below the .25 baseline. This pattern of results indicates that a task-repetition bias was present for task repetitions, which suggests that task repetitions were conceptualized as the selection of the same task as on the previous trial, which was overtly indicated by using a different task-choice response. The difference between complete repetitions and task repetitions thus most likely reflected the operation of task-choice response selection and not of task selection proper.

The present study indicates that task-choice response selection induces a substantial cost on task execution in VTS. Most likely, task-choice response selection delays the retrieval of task rules, until a particular task-choice response is made. It could be argued that the cost of task-choice response selection reported in the present study is in part modulated by the two-choice-responses-per-task procedure that was used and the different experimental parameters it was associated with (e.g., speed instructions, opportunity to prepare,. . .). A similar concern was raised about the generality of the findings obtained in the two-cues-per-task variant of cued task switching (e.g., Altmann, 2006; Forstmann, Brass, & Koch, 2007; but see Schneider & Logan, 2011 for a reply) and future research will be needed to investigate these issues. Nevertheless, to my knowledge, task-choice response selection is part of all currently used VTS procedures. Accordingly, the question remains whether these procedures offer a proxy of mental flexibility or of task-choice response selection.

References

Arrington, C.M. (2008). The effect of stimulus availability on task choice in voluntary task-switching. *Memory & Cognition, 36,* 991-997.

Arrington, C.M., & Logan, G.D. (2004). Episodic and semantic components of the compound-stimulus strategy in the explicit task-cuing procedure. *Memory & Cognition, 32,* 965-978.

Arrington, C.M., & Logan, G.D. (2004). The cost of a voluntary task switch. *Psychological Science, 15,* 610-615.

Arrington, C.M., & Logan, G.D. (2005). Voluntary task-switching: Chasing the elusive homunculus. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 683-702.

Arrington, C.M., & Rhodes, K.M. (2010). Perceptual asymmetries influence task choice: The effect of lateralized presentation of hierarchical stimuli. *Laterality, 15,* 501-513.

Arrington, C.M., & Yates, M.M. (2009). The role of attentional networks in voluntary task switching.* Psychonomic Bulletin & Review, 16,* 660-665.

Arrington, C. M., Reiman, K.M., & Weaver, S. M. (2014). *Voluntary Task Switching.* In J. Grange, & G. Houghton (Eds.), Task Switching and Cognitive Control. (pp. 117-136). Oxford University Press.

Arrington, C.M., Weaver, S.M., & Pauker, R.L. (2010). Stimulus priming in task choice during voluntary task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36,* 1060-1067.

Arrington, C.M., Logan, G.D., & Schneider, D.W. (2007). Separating cue encoding from target processing in the explicit task-cuing procedure: Are there "true" task switch effects? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 484-502.

Demanet, J. & Liefooghe, B. (2014). Component processes in voluntary task switching. *Quarterly Journal of Experimental Psychology, 67,* 843-860.

Demanet, J., De Baene, W., Arrington, K., & Brass, M. (2013). Biasing free choice: The role of the rostral cingulate zone in intentional control. *NeuroImage, 72,* 207-213.

Demanet, J., Verbruggen, F., Liefooghe, B., & Vandierendonck, A. (2010). Voluntary task-switching under load: Contribution of top-down and bottom-up factors in goal-directed behavior. *Psychonomic Bulletin & Review, 17,* 387-393.

Demanet, J., Liefooghe, B. , & Verbruggen, F. (2011). Valence, arousal and cognitive control: A voluntary task switching study. *Frontiers in Psychology,* 2:336.

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology, 64,* 135-168.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Phillip, A., & Koch, I. (2010). Control and interference in task-switching-A review. *Psychological Bulletin, 136,* 849-874.

Liefooghe, B., Demanet, J., & Vandierendonck, A. (2009). Is advance reconfiguration in voluntary task switching affected by the design employed? *Quarterly Journal of Experimental Psychology, 65,* 850-857.

Liefooghe, B., Demanet, J., & Vandierendonck, A. (2010). Persisting activation in voluntary task switching: It all depends on the instructions. *Psychonomic Bulletin & Review, 17,* 381-386.

Logan, G.D., & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance, 29,* 575-599.

Logan, G.D., & Bundesen, C. (2004). Very clever homunculus: Compound stimulus strategies for the explicit task-cuing procedure. *Psychonomic Bulletin & Review, 11,* 832-840.

Logan, G.D., & Schneider, D.W. (2006). Interpreting instructional cues in task switching procedures: The role of mediator retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 347-363.

Lopes, L.L. (1982). Doing the impossible: A note on induction and the experience of randomness. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 626-636.

Lopes, L.L., & Oden, G.C. (1987). Distinguishing between random and nonrandom events. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 392-400.

Masson, M.E., & Carruthers, S. (2014). Control processes in voluntary and explicitly cued task switching. *Quarterly Journal of Experimental Psychology, 67,* 1944-1958.

Mayr, U., & Bell, T. (2006). On how to be unpredictable: Evidence from the voluntary task-switching paradigm. *Psychological Science, 9,* 774-780.

Mayr, U., & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1124-1140.

Mayr, U., & Kliegl, R. (2003). Differential effects of cue changes and task changes on task-set selection costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 362-372.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1423-1442.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task-switching. *Cognitive Psychology, 41,* 211-253.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Monsell, S. & Mizon, G.A. (2006) Can the task-cueing paradigm measure an "endogenous" task-set reconfiguration process? J*ournal of Experimental Psychology: Human Perception and Performance, 32,* 493-516.

Monsell, S. (2003). Task-switching. *Trends in Cognitive Sciences, 7,* 134-140.

Neuringer & Allen. (1986). Can people behave "randomly": The role of feedback. *Journal of Experimental Psychology: General, 115,* 62-75.

Orr, J.M., & Weissman, D.H. (2011). Succumbing to bottom-up biases on task choice predicts increased switch costs in the voluntary task-switching paradigm. *Frontiers in Psychology,* 2:31.

Orr, J.M., Carp, J., & Weissman, D.H. (2012). The influence of response conflict on voluntary task switching: A novel test of the conflict monitoring model. *Psychological Research, 76,* 60-73.

Rapoport, A., & Budescu, D.V. (1992). Generation of random series in two-person strictly competitive games. *Journal of Experimental Psychology: General, 121,* 352-363.

Rapoport, A., & Budescu, D.V. (1997). Randomization in individual choice behavior. *Psychological Review, 104,* 603-617.

Schneider, D.W., & Logan, G.D. (2005).Modeling task switching without switching tasks: A short-term priming account of explicitly cued performance. *Journal of Experimental Psychology: General, 134,* 343-367.

Sohn, M.H., & Anderson, J.R. (2001).Task preparation and task repetition: Two-component model of task-switching. *Journal of Experimental Psychology: General, 130,* 764-778.

Sohn, M.H., & Anderson, J.R. (2003). Stimulus-related priming during task switching. *Memory & Cognition, 31,* 775-780.

Stevens, M., Lammertyn, J., Verbruggen F., & Vandierendonck A. (2006). Tscope: A C library for programming cognitive experiments on the MS Windows platform.* Behavior Research Methods, 38,* 280-286.

Treisman, M., & Faulkner, A. (1987). Generation of random sequences by human subjects: Cognitive operations or psychophysical process? *Journal of Experimental Psychology: General, 116,* 337-355.

Vandamme, K., Szmalec, A., Liefooghe, B. , & Vandierendonck, A. (2010). Are voluntary switches corrected repetitions? *Psychophysiology, 47,* 1176-1181.

Vandierendonck, A., Demanet, J., Liefooghe, B. , & Verbruggen, F. (2012). A chain-retrieval model for voluntary task switching. *Cognitive Psychology, 65,* 241-283.

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task-switching: Interplay of reconfiguration and interference. *Psychological Bulletin, 136,* 601-626.

Wagenaar, W.A. (1972). Generation of random sequences by human subjects: A critical review of the literature. *Psychological Bulletin, 77,* 65-72.

Weaver, S.M., & Arrington, C.M. (2010). What's on your mind: The influence of the contents of working memory on choice. *Quarterly Journal of Experimental Psychology, 63,* 726-737.

Yeung, N. (2010). Bottom-up influences on voluntary task-switching: The elusive homunculus escapes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36,* 348-362.

Tables

Table 1. Task-execution RTs and PEs of Experiment 1 as a function of Transition Type and IIT. Corresponding standard deviations are printed between brackets.

	Transition Type	ITI= 0ms	ITI= 300ms	ITI= 600ms	ITI= 900ms
RTs	task switch	1005 (166)	930 (202)	874 (215)	851 (186)
	task repetition	876 (175)	838 (177)	782 (177)	799 (195)
	complete repetition	786 (169)	716 (146)	707 (161)	696 (128)
PEs	task switch	.102 (.055)	.103 (.058)	.094 (.054)	.113 (.088)
	task repetition	.062 (.056)	.060 (.043)	.058 (.052)	.058 (.052)
	complete repetition	.067 (.049)	.062 (.054)	.079 (.073)	.060 (.061)

Table 2. Task-execution RTs and PEs of Experiment 2 as a function of Transition Type and Interval Combination. Corresponding standard deviations are printed between brackets.

	Transition Type	short RSI- long ITI	long RSI - short ITI	short RSI - short ITI	long RSI - long ITI
RTs	task switch	957 (190)	851 (173)	975 (203)	861 (173)
	task repetition	882 (181)	779 (134)	832 (175)	787 (134)
	complete repetition	784 (132)	711 (123)	735 (110)	698 (123)
PEs	task switch	.074 (.051)	.079 (.055)	.087 (.054)	.069 (.045)
	task repetition	.056 (.057)	.057 (.050)	.054 (.039)	.048 (.051)
	complete repetition	.056 (.047)	.053 (.055)	.036 (.037)	.068 (.057)

Figure Captions

Figure 1. Illustration of the different time intervals used by Demanet and Liefooghe (2014) to estimate top-down and bottom-up control in VTS. The Inter-Trial Interval (*ITI*) lasts from the task-execution responses on trial n-1 ($TER_{n\text{-}1}$) to the probe indicating the onset of trial n (P_n). The Response-Stimulus Interval (*RSI*) starts after the task-choice response on trial n (TCR_n) and ends with with the onset of the stimulus on trial n (S_n).

Figure 2. Example of the sequence of events on two consecutive trials and the alignment of the task-choice and task-execution responses.

Figures

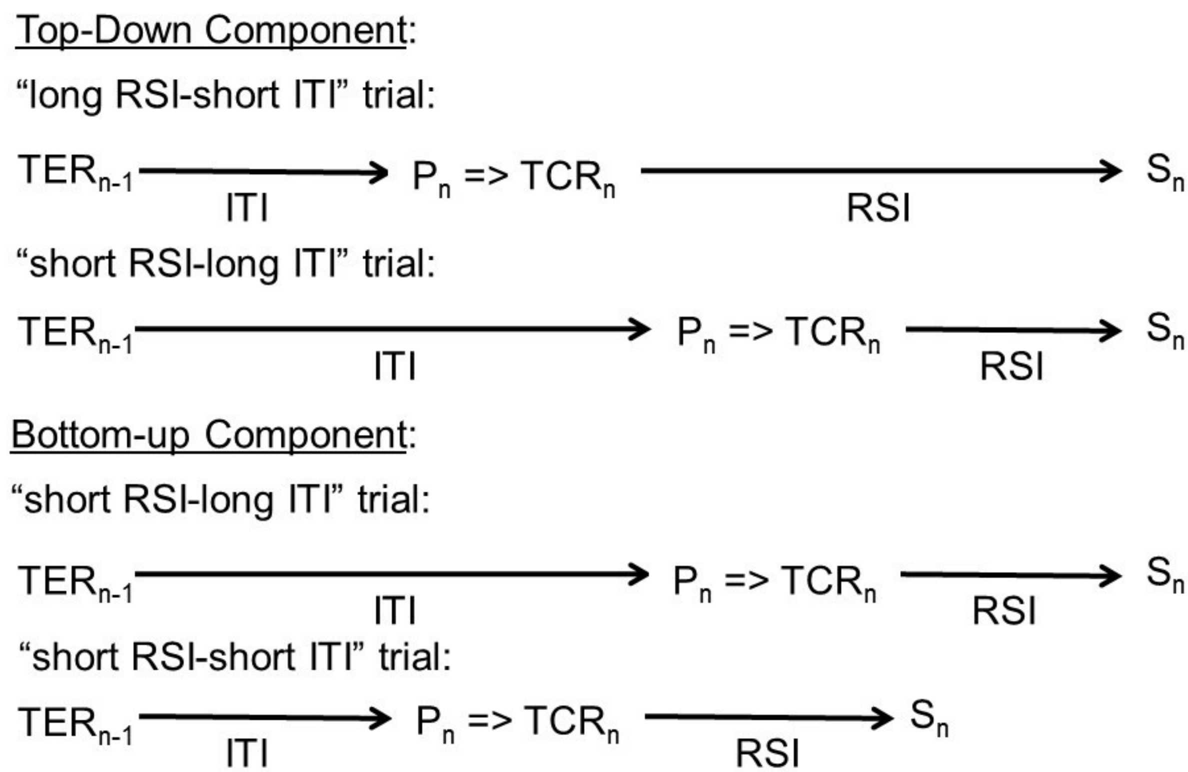

Figure 1

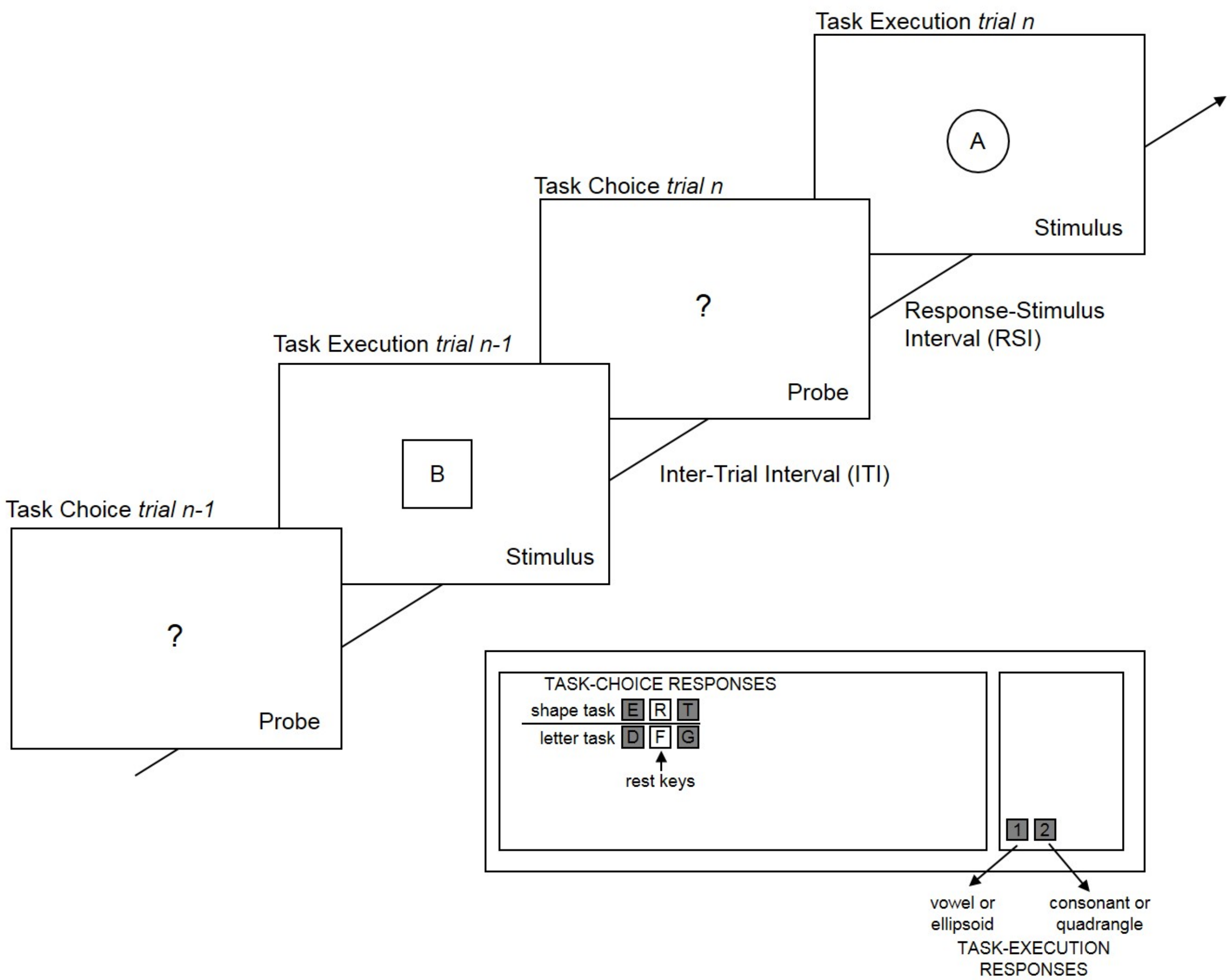
Task Execution *trial n*
A
Stimulus
Task Choice *trial n*
?
Probe
Response-Stimulus Interval (RSI)
Task Execution *trial n-1*
B
Stimulus
Inter-Trial Interval (ITI)
Task Choice *trial n-1*
?
Probe
TASK-CHOICE RESPONSES
shape task E R T
letter task D F G
rest keys
1 2
vowel or ellipsoid
consonant or quadrangle
TASK-EXECUTION RESPONSES

Figure 2