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Between-task competition for intentions and actions

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People can switch quickly and flexibly from one task to another, but suffer the effects of between-task competition when they do so: After switching, they tend to be distracted by irrelevant stimulus information and hampered by incorrect actions associated with recently performed tasks. This competition results in performance costs of switching, as well as a bias against switching when there is choice over which task to perform, particularly when switching from a difficult task to an easier one. Two experiments investigated the locus of these between-task competition effects in voluntary task switching. Participants switched between an easy location classification and a harder shape classification, making two responses on each trial: the first to register their task choice, the second to perform the chosen task on a subsequently presented stimulus. The results indicated that participants chose to perform the difficult shape task more often than the easier location task, evidence that between-task competition affects intentions that are expressed independently of task-specific actions. The bias was stronger in participants with faster choice speed, suggesting that these influences are relatively automatic. Moreover, even though participants had unlimited time to choose and prepare a task before stimulus presentation, their subsequent performance was nonetheless sensitive to persisting effects of between-task competition. Altogether these results indicate the pervasive influence of between-task competition, which affects both the expression of global task intentions and the production of task-specific actions.

Keywords: Voluntary action; Task switching; Executive control; Cognitive control; Task asymmetry.

Human intentions and actions are constrained but not determined by the environment: We often act in response to external stimuli but exhibit crucial flexibility in the nature of our responses. This flexibility has been studied experimentally by presenting participants with stimuli affording multiple tasks and asking them to switch between tasks across trials. In most task-switching studies, participants are instructed which task to perform on each trial (Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). However, recent work has extended this approach to include conditions in which participants are given some freedom to choose the task to perform (e.g., Arrington & Logan, 2004, 2005; Liefooghe, Demanet, & Vandierendonck, 2010; Lien & Ruthruff, 2008; Mayr & Bell, 2006; Orr & Weissman, 2011; Yeung, 2010). An attractive feature of these

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voluntary task-switching designs is that participants' choices provide an additional index of the mechanisms that support the observed flexibility of responding, complementing and extending performance cost measures—increases in reaction times (RTs) and error rates on task switch trials—that are the typical focus of instructed switching experiments.

There is now strong evidence that performance in both instructed and voluntary task-switching experiments reflects a complex interaction between current intentions and past experience (Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010). The influence of current intention is evident in participants' ability to perform the instructed or chosen task and is most widely studied in relation to the reduction in switch costs observed when participants are given time to prepare for an upcoming task (Arrington & Logan, 2005; Meiran, 1996): This reduction is typically attributed to a process of reconfiguring the cognitive system in accordance with the new task goal. However, reconfiguration is rarely perfect: A residual cost is observed even after very long preparation intervals (Rogers & Monsell, 1995), and switch costs are sensitive to a range of factors reflecting participants' prior experience. For example, costs are increased if the new task has recently been switched away from (Mayr & Keele, 2000) or if the presented stimulus was earlier associated with a competing task (Waszak, Hommel, & Allport, 2003). These factors also affect participants' task choices in voluntary switching (Arrington, Weaver, & Pauker, 2010; Lien & Ruthruff, 2008), demonstrating in these paradigms the influence of past experience on current behaviour.

The influence of past experience is mediated, at least in part, by increased between-task competition when the task switches, for example because of residual attention to now-irrelevant stimulus information (Yeung, Nystrom, Aronson, & Cohen, 2006) and increased competition among task-relevant and task-irrelevant responses (Allport et al., 1994). One well-studied expression of between-task competition is the pattern of asymmetrical costs and biases observed when participants switch between tasks differing in relative strength. The initially surprising but now often-replicated observation is that switch costs are greater for the stronger task of a pair—for example, being greater for Stroop word reading than colour naming (Allport et al., 1994). These observations have recently been extended to voluntary task-switching paradigms (Liefooghe et al., 2010; Yeung, 2010). Strikingly, but as might be expected given the greater cost of switching to the easier task, participants in these studies exhibit small but consistent biases toward performing a difficult task more often than an easier task. For example, Yeung (2010) asked participants to switch between an easy (spatially compatible) location classification and a more difficult (arbitrarily mapped) shape classification. Although the shape task was performed more slowly, and with greater interference from the location task than vice versa, participants had a greater tendency to repeat this task than the easier location task.

Asymmetries in switch costs and task choice have been explained in terms of the effects of between-task competition. Whereas weaker tasks are subject to between-task interference even when performed repeatedly, stronger tasks are only affected by interference on switch trials—when the task is less effectively established—and are relatively immune to interference when performed repeatedly (Yeung & Monsell, 2003). However, it is unclear at what level these effects of competition are expressed because, in most task-switching studies, participants make a single response on each trial to convey both their task choice (i.e., their high-level intention) and their classification of the particular stimulus presented (i.e., the corresponding action). For example, in Yeung's (2010) study, participants used one hand to respond to locations and the other to respond to shapes, indicating task choice by the hand they used to respond. In this design, it is ambiguous whether the observed bias toward the more difficult task occurs at the level of top-down intentions (i.e., with competition directly influencing task choice), or rather occurs because participants sometimes fail to carry an unbiased intention in the face of competition from alternative task responses primed from previous trials.

The present study aimed to dissociate the influence of between-task competition on participants' intentions and actions. Two experiments extended Yeung's (2010) design to incorporate Arrington and Logan's (2005) *double registration* procedure in which participants make two responses on each trial: the first to register their choice of task, the second to respond to the subsequently presented stimulus. This procedure separates task choice and task performance. Previous research with this approach has shown that voluntary choice can be biased by the presence of distracting cues associated with one of the tasks (Orr & Weissman, 2011) and by the occurrence of Stroop-like response conflict on the previous trial (Orr, Carp, & Weissman, 2012). Of interest here is whether task choices are likewise affected by between-task competition—and hence vary across tasks differing in relative strength—or whether these competition effects are solely observed at the level of task performance—in which case no such biases should be observed.

Experiment 1 used an established procedure in which participants indicated their task choice with one of two keypresses, using different keys to those used to perform the two tasks. Experiment 2 adopted a more exploratory approach in which participants pressed the spacebar to indicate when they had made their task choice, regardless of the task they had chosen, then responded with different hands depending on the chosen task. The rationale for this latter design was that although the standard double registration procedure separates task choice and task performance in time, it nevertheless associates each task choice with a distinct action that might in principle be subject to priming, inhibition, or other task-specific competition effects. As such, if we observed a choice bias in Experiment 1, this bias might still reflect action-specific (rather than truly intentional) competition. Our aim in Experiment 2 was therefore to create a situation in which participants established an intention that was purely internal and not associated with a specific action that might be subject to priming or competition effects. An obvious disadvantage with this modified design is that participants do not need to commit fully to a task choice before pressing the spacebar. On the other hand, this design has the advantage that it prevents participants adopting a strategy of making a very fast and random task choice response, then using this response to determine the task they should perform (rather than vice versa). In fact, as will become apparent below, despite the differing strengths and weaknesses of the methods adopted in Experiments 1 and 2, key findings were consistent across the two experiments.

Of primary interest in both experiments was whether participants' intentions—their task choices—would be sensitive to between-task competition effects and hence replicate the previously observed bias toward performing the more difficult task. We were additionally interested in the time participants took to make their task choice and, subsequently, to perform the chosen task. In particular, the design allowed us to investigate whether effects of between-task competition on task performance—evident as asymmetrical switch costs—would be seen even when participants were given unlimited time to choose tasks prior to stimulus presentation. Finally, although not an initial focus of our design, we observed interesting individual differences in choice behaviour as a function of the speed with which participants made their task choices.

Method

The methods of Experiments 1 and 2 were very similar and so are described together below, while drawing attention to key differences.

Participants

There were 5 male and 10 female participants in Experiment 1, ages 21–31 years, and 6 men and 9 women in Experiment 2, ages 18–32 years. All had normal or corrected-to-normal vision. They were paid for their participation and gave informed consent.

Tasks and stimuli

On each trial, participants were presented with a shape (triangle, square, or circle) in one of three adjacent squares in a stimulus grid. They responded to either the identity of the shape or its location. In the location task, participants responded according to whether the shape appeared in the left, centre, or right location of the grid using a spatially compatible keypress. In the shape task, they responded to the identity of the stimulus with an arbitrarily mapped keypress. These two tasks have previously been shown to differ in relative strength, with the location task performed more quickly and with less interference from irrelevant stimulus features than the shape task, even when the tasks are mapped to different hands for responding (Yeung, 2010). This difference in strength reflects the stimulus–response compatibility of the location task and the fact that bimanual responding usually employs shared spatial response features (Campbell & Proctor, 1993), particularly when stimuli have spatial features (Druey & Hubner, 2008). Thus, stimulus location produces direct and automatic activation of response features, which should lead to fast and accurate responding in the location task, but should interfere with responding in the arbitrarily mapped shape task.

In both experiments, participants were required to choose which task to perform on each trial, while being encouraged to choose the two tasks at random and equally often, "as if flipping a coin that said 'shape' on one side and 'location' on the other". In both experiments, they made their choice prior to stimulus presentation and were cued to do so by presentation of the words "LOCATION/SHAPE" appearing one above the other with large question marks on either side. The crucial difference between experiments lay in the method by which participants registered their task choice. In Experiment 1, participants indicated their task choice during the cue period by pressing the "c" key with their left index finger for the location task and pressing the "d" key with their left middle finger for the shape task. They then responded to the stimulus using their right hand, with left/circle mapped to the index finger, centre/square mapped to the middle finger, and right/triangle to the ring finger. Thus, responses to the imperative stimulus were made with the same hand for both tasks.

In Experiment 2, participants did not signal a specific task at the time of the choice cue, but instead indicated only when they had made their choice (regardless of what that choice was) by pressing the spacebar. They then responded to the imperative stimulus with a different hand according to the chosen task: Half of the participants used their left hand for shape task responses and their right hand for the location task; for the other half of the participants this mapping was reversed. Response keys were similar to those in Experiment 1, with left/circle mapped to the leftmost finger of the responding hand, centre/square mapped to the middle finger, and right/triangle to the rightmost finger.

In both experiments, the stimulus grid remained on the screen throughout the block. The choice cue appeared above the grid at the start of each trial and remained there until the participant made their task choice. The stimulus appeared 300 ms later and remained on the screen until the response, followed by a 500-ms intertrial interval (ITI). At 1-m viewing distance, the stimulus grid was 2.6° high and 7.4° wide, and the presented shape roughly filled one square within the grid. Shape and location varied randomly from trial to trial.

Procedure

In each experiment, participants first practised each task separately, completing two blocks of 45 trials. They then practised switching between the tasks in a block of 54 trials. Following practice, participants completed eight task-switching blocks of 54 trials each. They were given feedback at the end of each block showing their average RT, error rate, number of task choices, and number of task switches and repetitions. In Experiment 2, in which participants indicated having made their choice by pressing the spacebar, it was additionally emphasized that they should make their choice before pressing the spacebar.

Analysis

Data analysis focused on two measures relating to task choice (participants' choices and their choice speed) and two measures relating to task performance (RT and error rate). For analysis, trials were categorized according to task, transition type, and, for task performance only, response congruence. In Experiment 1, the task performed on each trial was determined by the button pressed in response to the choice cue. Trials were scored as errors when the participant responded with the wrong finger to the imperative stimulus according to the task chosen. In Experiment 2, the task performed on a given trial was indicated by the hand that the participant used to respond. Trials were scored as errors when the participant responded with the wrong finger of that hand. Congruency was determined slightly differently in each experiment. In Experiment 1, response congruence was determined according to whether the same response finger would be required given the particular shape and location. In Experiment 2, congruent trials were those where shape and location had the same spatial relationship between responses (e.g., left location and circle both requiring response from the leftmost finger on whichever hand responded; Yeung, 2010).

Analysis of task choice focused on choice proportions, averaging over transition types (switch vs. repeat trials) because, with a fixed number of trials, the number of trials of each task and transition type are not independent measures: Each choice of the location task reduces the possible number of shape task choices by one (and vice versa); similarly each choice to repeat a task reduces the possible number of task switches by one (and vice versa). No trials were excluded from the analysis of choice proportions. Analyses excluding the first trials of each block yielded corresponding results. Choice speed, RTs, and error rates were analysed using repeated measures analyses of variance (ANOVAs), with task and transition type as within-subject factors and experiment and choice speed as between-subject factors. Choice speed was included in our analyses because we were concerned that some participants might respond very quickly to the choice cue without true deliberation, such that critical effects of interest might be absent for these participants. As it turned out, choice speed was more than simply a nuisance variable in our analyses. For simplicity of presentation, the analyses below treat choice speed as a between-subject factor—with participants categorized as fast or slow according to a median split on average choice speed—but corresponding results were observed in analyses using mean choice speed as a continuous covariate. Response congruence was included as an additional within-subject factor in analyses of task performance (RTs and error rates). Analyses of choice speed, RT, and error rate excluded the first trial of each block, trials with response repetitions, trials with reaction times over 3,000 ms, and, for RT analyses, error trials.

Results

We first present analyses of overall task performance (to establish that the tasks differed in difficulty as intended) and of choice speed (to establish that participants used the cue period to make deliberative task choices), before presenting the crucial data of interest: the distribution of participants' task choices. We then present analyses of task-switching performance.

Task difficulty

Consistent with the expected difference in task difficulty, location task responses were faster than shape task responses ($M = 486$ ms vs. 659 ms), $F(1, 26) = 222.07$, $p < .01$, and more accurate ($M = 4.1\%$ errors vs. 10.1% errors), $F(1, 26) = 65.76$, $p < .01$. These differences were consistent across the two experiments: The interaction between task and experiment was not reliable for RTs, $F < 1$, or error rates, $F(1, 26) = 1.63$, $p = .21$. Differences in task strength were also apparent in terms of asymmetrical response congruence effects: Participants were faster, $F(1, 25) = 34.81$, $p < .01$, and more accurate, $F(1, 25) = 91.81$, $p < .01$, when the shape and location of stimuli required congruent responses, and these effects were greater for the shape task than for the location task, reflected in a reliable interaction between task and congruence both for RTs, $F(1, 25) = 22.39$, $p < .01$, and for error rates, $F(1, 25) = 34.63$, $p < .01$. The effect of response congruence did not differ reliably between experiments ($M = 51$ ms in Experiment 1, $M = 44$ ms in

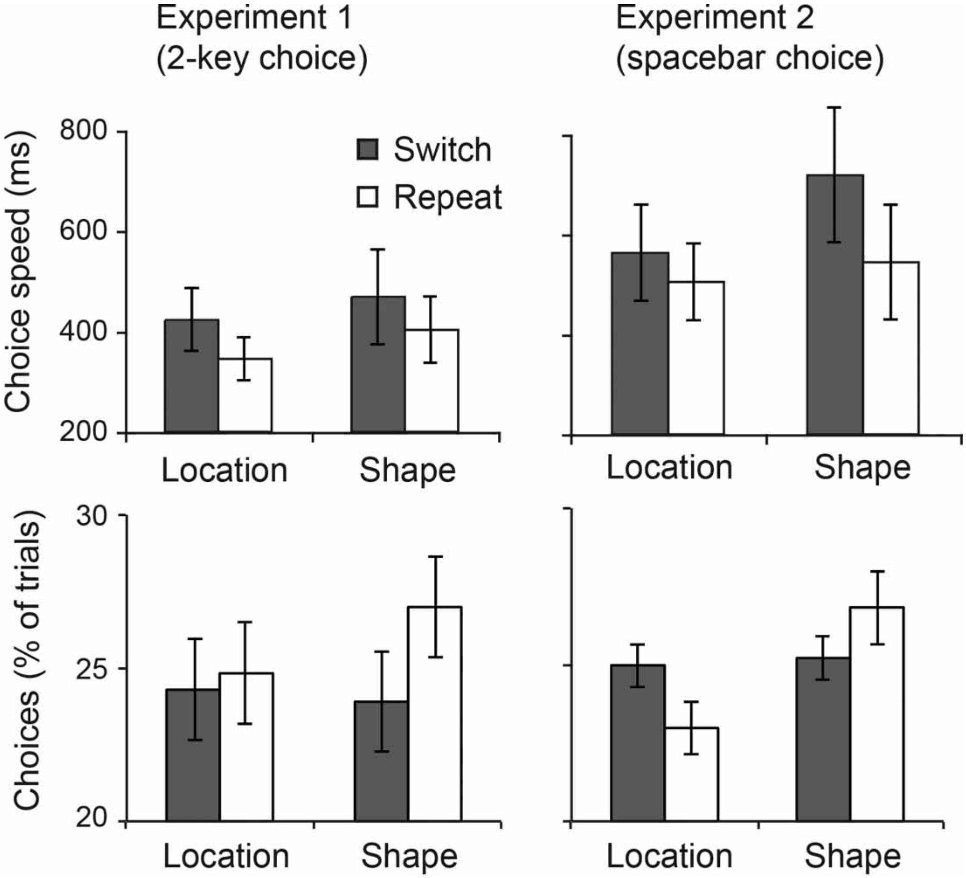

Figure 1. *Task choice in Experiments 1 and 2, showing how choice speed (upper panel) and task choices (lower panel) varied across the two tasks, separately for switch and repeat trials. Results from Experiment 1, in which participants indicated their choice of task with one of two predefined keypresses, are shown on the left. Results from Experiment 2, in which participants pressed the spacebar to indicate when they had made their task choice, are shown on the right. The choice data in the lower panel exclude the first trial of each block, for which a transition type (switch or repeat) is not defined. Error bars indicate standard error of the mean across participants.*

Experiment 2), $F < 1$, despite the separation of task responses between hands in Experiment 2.

Choice speed

In both experiments, participants could take as long as they needed to prepare before indicating that they had chosen which task to perform. Figure 1 (upper panel) presents average choice speed across conditions for each experiment. Participants were overall quicker to choose the location task than the shape task, $F(1, 28) = 7.18$, $p < .05$, an effect that was more marked in participants with slow choice speeds, reflected in a reliable interaction between task and choice speed, $F(1, 26) = 6.81$, $p < .05$ (Table 1). Participants were also quicker to choose to repeat than switch tasks, $F(1, 28) = 7.91$, $p < .01$. There was, however, no significant interaction between task and transition type, $F(1, 28) = 2.26$, $p = .11$.

We were initially concerned that participants in Experiment 2 might be tempted to press the spacebar before making their task choice. However, there was no significant difference in choice speed across experiments, $F(1, 28) = 2.41$, $p = .13$. Indeed, the trend observed was for slightly slower choice speeds in Experiment 2. There were no other

Table 1. *Task choice and task performance in Experiments 1 and 2 as a function of choice speed*

Measure	*Trial type*	*Experiment 1*		*Experiment 2*	
		Fast choosers	*Slow choosers*	*Fast choosers*	*Slow choosers*
Choice speed (ms)	Shape switch	253	714	418	1,063
	Shape repeat	235	596	320	801
	Location switch	277	589	341	816
	Location repeat	215	493	345	688
Task choice (%)	Shape	52.1	50.3	53.2	50.0
	Location	47.9	49.7	46.8	50.0
Task performance	Shape switch	678 (10.8)	714 (11.4)	700 (11.4)	616 (10.6)
	Shape repeat	609 (8.5)	676 (10.9)	677 (8.9)	601 (10.6)
	Location switch	517 (6.3)	561 (7.7)	575 (3.5)	441 (3.6)
	Location repeat	431 (3.3)	491 (4.1)	481 (1.8)	382 (2.7)

Note: Task performance measures give reaction time (RT) in ms, with error percentage in parentheses.

reliable differences in choice speed across experiments, although the three-way interaction between task, transition type, and experiment was marginally reliable, $F(1, 28) = 3.51$, $p = .07$, reflecting a trend towards participants in Experiment 2 being particularly slow when choosing to switch to the more difficult shape task.

Collectively, these results replicate previous observations that participants are quicker to choose to repeat than to switch tasks (Arrington & Logan, 2005; Orr & Weissman, 2011) and extend these findings to show that they are likewise faster to choose to perform the easier task of a pair. Choice times were, if anything, slower in Experiment 2 than in Experiment 1, and task- and transition-related differences were at least as large in this experiment, indicating that participants in Experiment 2 most likely followed instructions to make their voluntary choice prior to pressing the spacebar.

Task choice

Of central interest was whether we would replicate the finding of a bias toward repeating the more difficult task more frequently (Yeung, 2010) in a double-registration design. As shown in Figure 1 (lower panel), this effect was indeed observed, with participants choosing to perform the difficult shape task more often than the easier location task: On average, participants performed the shape task on 51.5% of trials (range = 47.2% to 56.0%), slightly but very consistently above balanced and truly random task choice, $t(29) = 3.75$, $p < .01$. With only two tasks, the overall number of switch trials must necessarily be roughly equivalent (Figure 1, lower panel, grey bars), such that between-task differences were expressed in terms of an increased number of repeat trials for the shape task over the location task (Figure 1, lower panel, white bars).

The task choice data were further analysed using a between-subjects ANOVA with factors of experiment and choice speed. The bias toward the shape task did not differ reliably across the two experiments, $F < 1$. Pairwise comparisons revealed the bias to be present in both Experiment 1, $t(14) = 3.10$, $p < .01$ ($M = 51.3\%$, range = 47.2% to 54.4%), and Experiment 2, $t(14) = 2.46$, $p < .05$ ($M = 51.7\%$, range = 47.7% to 56.0%). In contrast, the task bias differed reliably as a function of choice speed, $F(1, 26) = 13.9$, $p < .01$, reflecting a greater bias toward the shape task in participants who made their choices quickly (52.6%) than in those who made their choices slowly (50.2%), an effect that was similar across the two studies, $F(1, 26) = 1.08$, $p > .3$ (Table 1). This effect of choice speed was somewhat surprising: As mentioned above, we were initially concerned that some participants might make task choice responses very quickly and randomly, for example in Experiment 1 using a

Table 2. *Proportion of task repetitions as a function of whether the location and shape repeated from the previous trial*

		Location changes		*Location repeats*	
Experiment	*Task just performed*	*Shape changes*	*Shape repeats*	*Shape changes*	*Shape repeats*
Experiment 1	Location	.52 (.042)	.50 (.043)	.50 (.039)	.53 (.044)
	Shape	.51 (.028)	.55 (.038)	.51 (.033)	.56 (.035)
Experiment 2	Location	.46 (.034)	.50 (.034)	.47 (.030)	.55 (.028)
	Shape	.52 (.033)	.53 (.026)	.51 (.031)	.56 (.025)

Note: Figures in parentheses indicate standard errors of the means.

strategy of retrospectively following their task choice response to determine the task they would perform (and not vice versa). If so, then choice biases should be particularly marked in participants who were slower to choose. The data suggest otherwise: In both experiments, the choice bias toward the more difficult task was observed for the fastest 8 participants (ts > 3.84, ps $< .01$), and not in the slower 7 (ts < 1).

We performed additional analyses of task choices to assess whether participants in Experiment 2 consistently followed intentions they established during the choice period. Previous research has shown that participants in standard (single-response) voluntary task-switching designs are more likely to repeat tasks when the stimulus repeats (Mayr & Bell, 2006). Such effects might occur in Experiment 2 if participants occasionally overrode their initial intention after stimulus presentation, something that is not possible in Experiment 1 because participants registered a fixed task choice before the stimulus appeared. We therefore analysed the data to see whether stimulus repetition influenced task choice differently across the two experiments, once again including all trials in the analysis (not only those with correct responses during task performance) to avoid any confounding effects of differential error rates across conditions. The analysis (Table 2) revealed no reliable interactions involving experiment and repetition of shape or location, Fs$(1, 26) < 1.80$, ps $> .19$, although a trend was apparent for participants to repeat the task more often if the shape repeated across trials. Given that this trend was weak and of comparable magnitude across the two experiments—yet in Experiment 1 could have arisen only by chance—it suggests that participants in Experiment 2 were little affected by stimulus repetition. As a further exploration of this point, we analysed the Experiment 2 results for interactions between stimulus repetition and choice speed, because biases in task choice discussed above were particularly evident in participants who made their task choices quickly. Again we found no reliable effects, Fs$(1, 13) < 2.47$, ps $> .14$. Thus, there is little persuasive evidence that participants occasionally ignored their initial intention in Experiment 2.

Task-switching performance

RTs and error rates during task performance are shown in Figure 2. Of interest was whether we would observe asymmetrical patterns of switch costs even though participants had unlimited time to establish their task choice prior to stimulus presentation. The asymmetry was indeed observed in the RT data, with a significant interaction between task and transition type, $F(1, 26) = 21.02$, $p < .01$, indicating greater costs when switching to the easier location task than when switching to the harder shape task (for errors, $F < 1$). This RT cost asymmetry was apparent in both experiments, although a marginal interaction between task, transition type, and experiment, $F(1, 26) = 3.56$, $p = .07$, indicated that the RT asymmetry was somewhat greater in Experiment 2. However, a numerically opposite pattern, albeit not reliable, $F(1, 26) = 1.06$, $p = .31$, was observed in the error rate data, rendering the marginal RT effect difficult to interpret. Of more interest, the

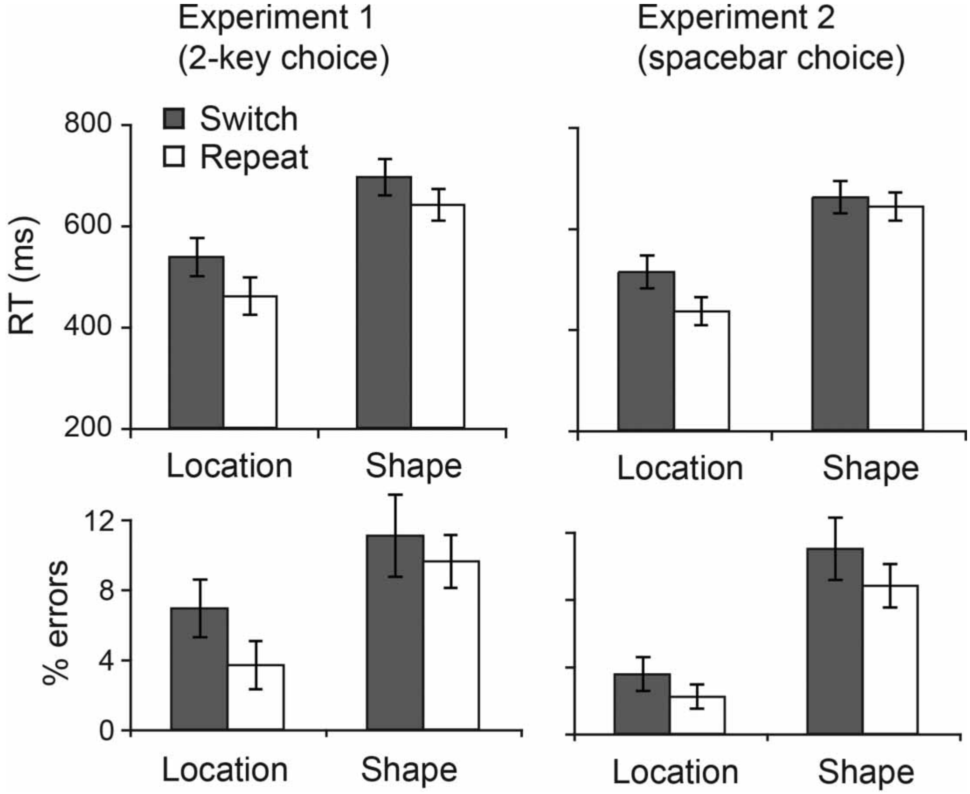

Figure 2. *Task performance in Experiments 1 and 2, showing reaction times (upper panel) and error rates (lower panel), in the two tasks for switch and repeat trials. Error bars indicate standard error of the mean across participants.*

RT switch cost asymmetry did not differ as a function of participants' choice speed—for the three-way interaction between task, transition type, and choice speed, $F < 1$—and was robustly observed when looking only at data from the participants in both experiments who were slowest to register their initial task choices, $F(1, 13) = 23.6$, $p < .01$ (Table 1). Thus, even when participants took longer on average to choose which task to perform ($M = 720$ ms) than to perform the chosen task ($M = 560$ ms), between-task competition continued to influence the efficiency of task performance.

Discussion

This study investigated choice biases in voluntary task switching using experimental designs that separated task choice (intention) from task performance (action). In Experiment 1, participants indicated their task choices with separate response keys prior to performing the chosen task. In Experiment 2, task choices were internal and not associated with distinct actions. The key findings were consistent across the two experiments. First, replicating earlier results from designs confounding intention and action (Liefooghe et al., 2010; Yeung, 2010), a reliable task bias was observed, with participants choosing to perform a difficult shape classification more often than an easier location task. This bias is indicative of the effects of between-task competition, which are enhanced when switching from a more difficult (and therefore more strongly imposed) task set. Second, asymmetrical switch costs found in previous studies were replicated, even though participants had unlimited time to form and express their task choice prior to stimulus presentation. Taken together, these results provide evidence of the pervasive influence of between-task competition on voluntary behaviour at the level of both abstract intentions and executed actions.

We interpret the observed bias in task choice as evidence of the influence of between-task competition: Performing a difficult task requires a strongly imposed task set, which is then difficult to switch away from—even to an easier, more familiar task—resulting in a high cost of switching and a tendency to become "stuck" performing the difficult task (Allport et al., 1994; Yeung, 2010). This conclusion converges with that of a recent study also using the double registration procedure, which found that participants tend to switch tasks less often following trials that elicit high levels of Stroop-like response conflict (Orr et al., 2012): Orr et al. (2012) interpret their results as evidence that detection of response conflict leads to increased activation of the current task, which in turn increases the probability of this task being chosen again on the subsequent trial. Specifically, they adopt the suggestion that voluntary task choice depends in part upon which task sets are most "available" in working memory (Arrington & Logan, 2005), with availability increased when top-down control is applied to enforce a particular task choice. Our results are certainly consistent with this interpretation. In particular, this explanation seems more plausible than an alternative hypothesis that participants' choices are primarily guided by avoidance of cognitive effort, which might suggest that participants avoid switching to the easier location task simply because of the difficulty of this switch. However, as we have noted elsewhere (Yeung, 2010), despite the high switch cost for the location task, switch trials of this task remain markedly easier (i.e., faster and more accurate) than repeat trials of the shape task. Thus, a simple effort-based account should predict a choice preference for the easier task, contrary to the results we observed.

The choice bias we observed toward the more difficult task was small—with participants performing the shape task on 51.5% of trials—but was consistently observed across participants in both experiments. Moreover, the magnitude of the bias probably provides a very conservative estimate of the strength of the underlying effect: First, our instructions to participants emphasized performing the tasks equally often, and we provided feedback about task choices after each block. Second, participants typically exhibit a bias toward easier options, for example preferring to repeat tasks rather than switch (Arrington & Logan, 2005) and to perform the easier task when the effects of between-task competition are minimized (Yeung, 2010). Each of these factors would tend to counteract the shape task bias, yet it was robustly observed across the two experiments.

The size of the bias we observed was also similar to that observed in previous studies using designs that confound task choice and task performance (Yeung, 2010). This comparability suggests that the task bias consistently arises at the level of top-down intentions—with competition directly influencing task choice—rather than because participants sometimes fail to carry an unbiased intention in the face of competition from alternative task responses primed from previous trials. Consistent with this interpretation, in a recent electroencephalography (EEG) study we found that choice biases are reflected in between-task differences in neural markers of intentional preparation in advance of stimulus presentation and task performance (Poljac & Yeung, 2012). The results of Experiment 2 are particularly telling in this regard: In this experiment, participants were not asked to indicate their task choice with any distinct action. Our aim here was to create a situation in which the participants were encouraged to establish an intention that was purely internal. Yet even with this design, the participants exhibited a consistent preference for performing the more difficult task of the pair.

Analysis of participants' choice speed—that is, the time they took to register their initial task choice prior to stimulus onset—revealed two surprising results. First, participants were particularly slow to choose to switch to the more difficult shape task, even though they exhibited an overall bias toward choosing this task. Second, the bias toward choosing the more difficult shape task was greater for participants who made task choices quickly; no reliable choice bias was evident for those who took longer to choose which task to perform. Both findings are indicative of the complexity of factors influencing the formation and expression of task choices.

The hesitancy of participants in choosing to perform the shape task is likely to reflect conflict among at least three factors: a general preference for less effortful options (cf. Kool, McGuire, Rosen, & Botvinick, 2010), a desire to follow experimental instructions to perform the tasks equally often, and between-task competition effects that favour the more difficult task. The resulting dissociation between choice probability (in favour of the shape task) and choice speed (in favour of the location task) is notable because it demonstrates that choice speed is not simply a function of practice or repetition—with more frequent choices inevitably made more quickly (as might be argued, for example, in relation to participants' fast and frequent choice to repeat rather than switch tasks). Instead, our results suggest that choice speed provides a meaningful and distinct index of the mechanisms of task choice, perhaps one that is particularly revealing of participants' overt or strategic preferences (e.g., for avoiding cognitive effort) during intentional task choice and that is less sensitive to biases in between-task competition established on previous trials.

Meanwhile, our observation of individual differences in choice bias as a function of choice speed suggests that participants' intentions and choices reflect similar interactions between current goals and past experience as other aspects of task-switching performance (Kiesel et al., 2010; Vandierendonck et al., 2010): The influence of between-task competition, favouring repetition of the more difficult task, was particularly evident in participants who were fastest to make task choices—suggesting that this influence is relatively automatic. In contrast, participants who made slower choices were more effective in balancing their choices between the two tasks, suggesting a greater top-down, cognitive component to their decision making. These findings are consistent with previous suggestions that task selection is subject to both automatic and deliberative influences (Gotler, Meiran, & Tzelgov, 2003; Koch, 2001; Norman & Shallice, 1986) and that a core function of top-down control is to shield performance from irrelevant information to ensure effective goal-directed behaviour (Dreisbach & Haider, 2008). The present findings extend these suggestions to show that separable influences of automatic and deliberative task control are just as evident in the formation of global intentions as they are in task execution as typically studied.

An open question for future research concerns the nature of top-down control exerted by participants who made slower choices. It could be that there is decay of previous task sets over time and that the control exerted by slow-choosing participants merely consisted of withholding their task choice until this decay progresses sufficiently far to allow unbiased choice responding. Alternatively, the slow choices of these participants may indicate that they adopted a qualitatively different approach to choosing a task—specifically, a more strategic and deliberative approach—than did participants who made fast task choices. There are interesting parallels between this dichotomy and an earlier debate over whether reductions in switch costs with increasing ITI reflect passive decay of the previous task or active preparation for the new one (cf. Allport et al., 1994; Meiran, 1996), a discussion also relevant to observations of decreasing task repetition biases with increasing ITI in voluntary task switching (Arrington & Logan, 2004).

The results of a final analysis perhaps favour an interpretation of our choice results in terms of differing levels of deliberative choice across participants. In this analysis, we divided each participant's task choices according to whether those choices were made faster or slower than their median choice time. If the choice speed effects discussed above simply reflect passive task decay, one would expect to see corresponding effects in a comparison of fast and slow trials for each participant. However, we found no consistent difference in the degree to which the shape-task bias was apparent in this by-trial median split analysis, $F(1, 28) = 1.59$, $p = .22$. Indeed, if anything, the trend was for a greater bias in slower RT trials than in fast RT trials. These results suggest that the effects of choice speed we observed reflect stable strategies adopted by the participants, not simply the passive decay of task activity over time. This interpretation could be tested more directly in future research by varying instructions or incentives across trials to encourage participants to make either fast and automatic or slow and deliberative task choices.

Taken together, the present results add to the emerging picture of a complex relationship between task choice and task performance. On the one hand, there is now clear evidence of dissociable influences on choice and performance. For example, individual differences in biases towards repeating tasks over switching, and towards more difficult tasks over easier ones, correlate very weakly, if at all, with individual differences in switch costs or asymmetries in task strength (Arrington & Yates, 2009; Butler, Arrington, & Weywadt, 2011; Mayr & Bell, 2006; Yeung, 2010), and robust biases in task choice may be observed without corresponding biases in the preparation of specific actions and movements associated with each task (Poljac & Yeung, 2012). The present data provide further evidence of this dissociability: Specifically, whereas participants exhibited particularly large choice costs when switching to the more difficult task, they exhibited particularly large performance costs switching to the easier task. It is nevertheless clear that task choice and task performance are sensitive to similar influences (Lien & Ruthruff, 2008; Orr & Weissman, 2011; Yeung, 2010). Here we have shown that between-task competition, which has been extensively studied in the context of task performance and task switching (Kiesel et al., 2010), likewise exerts important influence over intentional task choice.

In conclusion, the present findings indicate that experimental separation of task choice (intention) and task performance (action) does not cleanly dissociate deliberative and automatic influences on human voluntary action. Our results indicate that task intentions, even when expressed as choices that are independent of task-specific actions, are subject to between-task competition in ways that correspond closely to effects previously observed in analyses of task performance.

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