



The costs of crossing paths and switching tasks between audition and vision

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ABSTRACT

Switching from one functional or cognitive operation to another is thought to rely on executive/control processes. The efficacy of these processes may depend on the extent of overlap between neural circuitry mediating the different tasks; more effective task preparation (and by extension smaller switch costs) is achieved when this overlap is small. We investigated the performance costs associated with switching tasks and/or switching sensory modalities. Participants discriminated either the identity or spatial location of objects that were presented either visually or acoustically. Switch costs between tasks were significantly smaller when the sensory modality of the task switched versus when it repeated. This was the case irrespective of whether the pre-trial cue informed participants only of the upcoming task, but not sensory modality (Experiment 1) or whether the pre-trial cue was informative about both the upcoming task and sensory modality (Experiment 2). In addition, in both experiments switch costs between the senses were positively correlated when the sensory modality of the task repeated across trials and not when it switched. The collective evidence supports the independence of control processes mediating task switching and modality switching and also the hypothesis that switch costs reflect competitive interference between neural circuits.

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1. Introduction

The activities of daily life require an ability to flexibly switch from one functional or cognitive operation to another. Sometimes, such switches can be triggered by environmental stimuli (e.g., a knock at the door or the ringing of a telephone) and will draw one's attention, interrupt current activities, and result in a clear set of consequent behaviors (e.g., opening the door or picking up the telephone). Other situations are more ambiguous and are thought to require the involvement of control or executive processes to guide behavior (Monsell, 1996; Norman & Shallice, 1986). For example, when arriving home after work, one must decide whether to sit and watch TV, make dinner, or tidy up the house. All of these are valid actions upon returning home, but the choice of which will depend on what one's currently relevant goals or plans are.

In an experimental setting, control processes can be investigated using task-switching paradigms. Task switching refers to the ability to perform a given task after having just performed a different task. In a cued task-switching paradigm, like the one used here, participants are presented with stimuli that afford two (or more) tasks and are instructed by cues as to which task is relevant on each trial. Sequences are arranged such that on a given trial participants are either repeating the same task that they just performed on the preceding trial or are switching to perform a different task (termed repeat and switch trials, respectively). Performance on switch and repeat trials is then compared, and participants are typically slower and more error prone on switch trials than on repeat trials—a difference in performance commonly termed 'switch cost'.

Switch costs have been thought of as an index of the operation of control processes (Jersild, 1927; Meiran, 1996; Nicholson, Karay-anidis, Poboka, Heathcote, & Michie, 2005; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001; Spector & Biederman, 1976), though the precise interpretation of which neural operations are being performed remains debated. Some propose that the switch cost follows from a necessity to reconfigure brain networks, i.e.,

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to activate cognitive or attention control structures, (e.g., pre-frontal cortices, the anterior cingulate, parietal cortices, etc.) necessary for switching to the new task (Rogers & Monsell, 1995; Rubinstein et al., 2001). Some part of this reconfiguration is thought to occur during the preparation interval between presentation of the cue stimulus and imperative stimulus (e.g. Wylie, Murray, Javitt, & Foxe, 2008). Others interpret switch costs as due in part to the coding of the cue stimulus itself (Logan & Bundesen, 2003), though more recent studies would suggest that encoding of a new cue does not account for the full switch cost (Brass & von Cramon, 2004). In addition to these propositions, previous studies from Wylie and colleagues provide evidence that a substantial portion of the switch cost arises from interference (competition) with persisting, task-related activity of the previous trial, i.e. with activity in neural circuits that were associated with the no longer relevant task and/or with processing stimulus features for this task (Allport & Wylie, 1999; Allport & Wylie, 2001; Wylie & Allport, 2000; Wylie, Javitt, & Foxe, 2003a; Wylie, Javitt, & Foxe, 2003b; Wylie, Javitt, & Foxe, 2004a; Wylie, Javitt, & Foxe, 2004b; Wylie, Javitt, & Foxe, 2006).

In addition to costs associated with switching tasks, variation in the sensory modality in which a task is performed has been shown to result in modality switch effects, wherein participants are typically slower and more error prone on modality switch trials than on modality repeat trials despite the task remaining constant (e.g. Gondan, Lange, Rösler, & Röder, 2004; Spence, Nicholls, & Driver, 2001; though see also Duncan, Martens, & Ward, 1997). At present, the commonality between the mechanisms mediating the costs associated with task switching and modality switching remain understudied. To the best of our knowledge only one study has to date been conducted. Hunt and Kingstone (2004) investigated whether task switching and modality switching rely on independent control mechanisms, in which case the effect of switching both task and modality on the same trial would be expected to be additive when compared to the effect of switching either task or modality alone. In addition to obtaining both an effect of task switching and modality switching, Hunt & Kingstone also obtained a sub-additive effect of simultaneously switching both the sensory modality and task (though this was indeed greater than the effect of switching either alone). From such findings, they proposed that control processes mediating these kinds of switches are separable, yet linked. More generally, they concluded that control processes do not operate in full independence of the modality in which a task is being performed. Rather, the processes of task switching and modality switching are subject to their respective processing bottlenecks, which are at least partially distinct from any common bottleneck operating when both task and modality are switched (see also Duncan et al., 1997; Jolicoeur, 1999).

A parallel issue when considering switch costs is the ability of participants to prepare for the switch. The effects of increasing the preparation time, prior to a switch of task, have been extensively studied (e.g. Gade & Koch, 2007; Meiran, 1996; Rogers & Monsell, 1995; Wylie et al., 2008). One consistent finding is that switch costs decrease as the amount of time subjects have to prepare for a forthcoming switch increases, through typically not to zero. In the study by Hunt and Kingstone (2004), there was a long preparation interval (~2500 ms) on every trial. Plus, repetitions and switches of task were fully predictable across trials. While it might be that these attributes of the paradigm afforded maximal opportunity to engage in preparatory processes prior to each switch of task, it could also be that this interval was overly long for participants to have been maximally prepared when the stimulus was presented. Because few task-switching studies use preparatory intervals longer than 1000 ms, it is difficult to know whether switch costs begin to increase when preparatory intervals become exceedingly long. One possibility is that maximal preparation is achieved within the first second and then wanes. One of the

aims of the current experiments was to determine the effects of switching task and modality using a preparatory interval that can be more easily interpreted relative to the existing literature (Experiment 1). Second, while Hunt and Kingstone (2004) provided participants with a very long interval to prepare for each task, the sensory modality of the stimulus (visual or auditory) was completely random, only becoming evident upon stimulus presentation. Thus, they were allowed no time to prepare for the forthcoming sensory modality. It is therefore not entirely clear whether the cost associated with switching task and that associated with switching modality should be directly comparable. Our second aim was to manipulate subjects' foreknowledge of the sensory modality of the forthcoming stimulus to investigate subjects' ability to prepare for a switch of sensory modality.

Our third aim was to better understand the relationship between task switching and modality switching. Hunt and Kingstone (2004) showed that the interaction between these variables was sub-additive, but important questions remain. Here, we use correlational analyses to investigate this issue. We reasoned that the switch costs elicited by switching between two visual tasks or between two auditory tasks (i.e., within-modality switches of task) should be positively correlated with one another. This follows an underlying premise in the task-switching literature that the switch cost measures a cognitive process that is not dependent upon the specific tasks that are used. The array of tasks that have been used to study switch costs is very large, yet the switch costs that have been elicited have been thought to reflect the operation of a common cognitive process. Some have interpreted this cost as the time taken to reconfigure the system for the new task (e.g., Meiran, 1996; Rogers & Monsell, 1995; Rubinstein et al., 2001), others as more reflective of interference or competition between alternative stimulus-response mappings (e.g., Allport, Styles, & Hsieh, 1994; Wylie et al., 2004b). Regardless of the interpretation, if this assumption is valid, one would expect that if a given participant exhibited a large switch cost when switching between tasks A and B, that participant would also show a large switch cost when switching between tasks C and D. That is, switch costs should positively correlate. While this framework leads to strong predictions about the correlations between within-modality switch costs (i.e., when the sensory modality repeats), we were less sure about the correlations of across-modality switch costs (i.e., when the sensory modality switches). If switching task is dependent upon a process of reconfiguration, one might expect positive correlations between across-modality switches for much the same reasons as one would expect positive correlations between within-modality switches. However, if it is competition that is largely responsible for the switch cost, one might not expect across-modality switch costs to correlate. This is because the segregation of the two modalities should result in less competition between tasks, and therefore this putative competitive process should account for less of the RT on switch trials when subjects switch from one modality to another.

The present study further examined the proposition that switch costs will diminish when effective preparation of the appropriate neural circuits is possible and/or when these neural circuits are distinct either anatomically or functionally (Wylie et al., 2006) by examining task switching between functional subdivisions within a sensory modality and/or between sensory modalities. More specifically, we investigated the ability to switch between tasks requiring the categorization of a given object (the 'what' task), and the localization of where it was presented in space (the 'where' task). In addition, on any given trial these stimuli were presented either visually or acoustically. Experiment 1 cued participants as to the task, but not the sensory modality of the stimulus, whereas Experiment 2 cued participants as to both the upcoming task and sensory modality. Multiple lines of evidence support the existence of partially segregated functional and anatomic pathways for pro-

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