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Modality and task switching interactions using bi-modal and bivalent stimuli ☆

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ABSTRACT

Investigations of concurrent task and modality switching effects have to date been studied under conditions of uni-modal stimulus presentation. As such, it is difficult to directly compare resultant task and modality switching effects, as the stimuli afford both tasks on each trial, but only one modality. The current study investigated task and modality switching using bi-modal and bivalent stimulus presentation under various cue conditions: no cue, either task or modality (single cue) or task and modality (double cue), with participants responding to either the identity or the position of an audio–visual stimulus at each trial. In line with previous research, task and modality switching effects showed sub-additive patterns, with switching costs decreasing as pre-stimulus cue information increased. The current data also showed that modality switching costs were more malleable than task switching costs as the former were eliminated when full and single cue information was provided, as well as when participants responded to the more efficiently processed task (position relative to identity). Conversely, task switching costs were only eliminated in the full cue condition, but were present for both tasks and both modalities despite a similar asymmetry in efficiency (vision relative to audition). The data further show that the specific task-modality combination being responded to impacted on combined task- and modality switching effects, with those combinations leading to either the greatest or lowest costs contributing most heavily to sub-additivity.

1. Introduction

Substantial yet separate literatures have been developed regarding the neural and cognitive implications of task switching (e.g., Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010) and modality switching (e.g., Spence, Nicholls, & Driver, 2001). To our knowledge there have only been two studies that have considered the predictions of combined task and modality switching on the basis of the data from task switching alone and modality switching alone (Hunt & Kingstone, 2004; Murray, De Santis, Thut, & Wylie, 2009). The value of a joint analysis is the ability to evaluate how both forms of switching interact with one another and the extent to which both effects are expressions of the same neural mechanisms.

The first putative neural mechanism associated with both task and modality switching refers to frontal and prefrontal cortex activation and an executive attentional bottleneck (Hunt & Kingstone, 2004). According to the logic of Wylie, Sumowski, and Murray (2011), if a single mechanism is responsible for the coordination of both task switching and modality switching, then this should lead to larger costs in the face of combined switching (i.e., task and modality) relative to single switching (i.e., task or modality). Thus to address the role of fronto-cortical executive control, the processing efficiency associated with joint task and modality switch (TSMS) is deemed to be of critical value, relative to cases where task switches but modality repeats (TSMR) and where task repeats and modality switches (TRMS). Both studies that have examined combined task and modality switching to date have revealed sub-additive (also described as under-additive) effects (Hunt & Kingstone, 2004; Murray et al., 2009), in that the cost associated with combined modality and task switching (TSMS) was less than that predicted by the sum of the cost associated with task switch alone and the cost associated with modality switch alone (although the combined cost was still larger than a single switch in the study by Hunt and Kingstone (2004)). The observation of sub-additive costs for combined modality and task switching has been interpreted as an ambiguous independent-but-interdependent relationship between the coordination of modality and task switching. Discussed in terms of fronto-cortical executive control, Hunt and Kingstone (2004, p. 327) state these processes "... are separable because the switching cost for task and modalities are under-additive. They are linked because switching both task and modalities produced a cost that was greater than either switch alone."

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In the light of the minimized and, in one case, absent switching costs found in their study, Murray et al. (2009) also discuss the possibility that separate control mechanisms may exist for task switching and modality switching, but argued that a more parsimonious account of the data was available via the consideration of interference across trials resulting from the anatomical relationships between modalities and tasks. Under this context then, the second putative neural mechanism associated with switching effects concerns the degree of interference between the variously activated task and modality pathways. Here, the concern revolves around the benefits accrued from the repeated activation of a particular neural pathway that represents a particular conjunction of task and modality if processing requirements are repeated across trial, and the costs accrued from persisting, and no longer task-relevant activity from neural pathways associated with specific tasks and modalities when processing requirements change across trial. The idea that interference (Kiesel et al., 2010) may arise from active but incompatible brain regions from the previous trial echoes the central ideas of so-called episodic accounts of processing (e.g., Hommel, 2004; Huang, Holcombe, & Pashler, 2004; Kruger & Shapiro, 1981; Pashler & Baylis, 1991). Although expressed in a variety of ways, the underlying idea here is that switching effects arise when the specific neural pathways used to complete a previous trial cannot be reused on the current trial. The issue as to whether these episodic effects are ultimately due to neural interference on switch trials or neural facilitation on repeat trials (or some mixture of the two) is likely to rest on neurological data (see Gotts, Chow, & Martin, 2012; Grill-Spector, Henson, & Martin, 2006, for relevant discussions) but at least part of the effects associated with switching may be attributable to lingering activity in neural pathways between past and current processing. Typical predictions state that if there are no constraints associated with moving between the different neural task pathways (e.g., those associated with position (*where*) and identity (*what*)), then responding to task switch (TS) trials should be equivalent to task repeat (TR) trials. Similarly, if there are no constraints associated with moving between different neural modality pathways (e.g., those associated with vision and audition), then responding to modality switch (MS) trials should be equivalent to modality repeat (MR) trials. Task switching effects are observed if TS trials are different from TR trials and modality switching effects are observed if MS trials are different from MR trials. In both cases, switch trials usually lead to a reduction in processing efficiency relative to repeat trials, expressed as an increase in reaction time and/or an increase in error rate. In this regard, the dual consideration of auditory and visual position and identity (as per Murray et al., 2009) is particularly appropriate as there is evidence that both modalities run according to separate ventral identity (or *what*) and dorsal position (or *where*) pathways (for vision see Ungerleider & Mishkin, 1982; for audition see Arnott, Binns, Grady, & Alain, 2004). Thus, not only does the processing of auditory information follow a distinct route from that of visual information but the processing of identity follows a distinct route from that of position. According to Murray et al. (2009), this anatomical separation between modalities and between tasks should reduce the extent to which the benefits and costs associated with neural pathway interference contribute to the data, relative to more interactive routes.

Our study was motivated by previous observations and the potential utility that examining combined task and modality switching offered in terms of revealing the contributions of fronto-cortical executive control and/or neural pathway interference. As echoed by Wylie et al. (2011, p. 539): "... tasks performed in different sensory modalities will recruit spatially distinct brain networks, making it easier to tease apart those regions/networks specifically involved in control processes. By also including switching within and between sensory modalities, there is the added benefit of being able to assay the specificity of control processes to the modality and/or the task in hand." Both Hunt and Kingstone (2004) and Murray et al. (2009) chose to make more fine-grained distinctions regarding the nature of modality switching (comparing visual and auditory repetition or switch) relative to the nature of task switching (collapsing across task to consider repetition or switch only). Although this allowed for an evaluation of the neural asymmetries associated with visual and auditory processing (particularly relevant in the Murray et al., 2009 paper), the literature is currently silent regarding the presence of similar neural asymmetries across ventral and dorsal pathways and the switching between position and identity, or indeed any potential interaction between specific combinations of modalities and tasks. As a result of the previous emphasis on the impact of modality switching on task-switching without an examination of the reverse effects, a number of design features are apparent in the previous literature that preclude a clear assessment of combined task- and modality-switching. In moving forward with the current research, we deemed it necessary to consider: differences in the predictability of task and modality switching, differences in the time available for task and modality switching preparation, and, the use of uni-modal but bivalent stimuli.

In the study by Hunt and Kingstone (2004), participants responded to either visual or auditory digits in terms of one of two tasks: whether the digit was odd or even or, whether the digit was greater or less than five. Task switching was more predictable than modality switching, on the basis that the former was based on an alternating-run procedure (Rogers & Monsell, 1995) using lateralized cueing, whereas the latter was random at each trial (Hunt & Kingstone, 2004, p. 326). Thus the regularity of task switching in contrast to modality switching provides a partial account of why task switching may have led to a numerically smaller cost relative to modality switching alone in their study. Similar methodological decisions were made in the Murray et al. (2009, Experiment 1) study, where pre-stimulus cues informed participants as to the upcoming task (left/right lateralization in the case of *where*; man-made/living in the case of *what*) but not the upcoming modality (subsequently addressed in their Experiment 2). This feature did not translate into smaller task switching costs relative to modality switching however, revealing that other factors may be in play. A secondary concern related to these differences in predictability was the time allocated for switch preparation. A common observation is that with extended preparation time switching costs may be reduced (e.g., Lukas, Philipp, & Koch, 2010; although perhaps never completely eliminated, Kiesel et al., 2010, p. 855; Rogers & Monsell, 1995). In Murray et al. (2009, Experiment 1), task switching preparation could have been initiated earlier than modality switching, given that the cue related to the upcoming task was presented 1150 ms prior to the onset of the uni-modal stimulus. In contrast, participants would only have been aware of a modality switch following presentation of the uni-modal stimulus. Similarly, in Hunt and Kingstone (2004), task switching preparation could have been initiated earlier than modality switching, given that task switching was predictable but modality switching was not with the latter, again, only indexed when the uni-modal stimulus was presented. A final contribution to differential weighting between task switching and modality switching may have been due to the use of uni-modal rather than bi-modal stimuli for representing variation in auditory and visual numerical judgments (Hunt & Kingstone, 2004) or *what*/*where* processing (Murray et al., 2009). As acknowledged by Murray et al. (2009, p. 49) "target stimuli were always bivalent with respect to the to-be-performed task and were univalent with respect to the stimulated sensory modality." Thus, task status was more ambiguous than modality status and may once again have been differentially weighted relative to modality switching. To give task and modality switching an