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The role of phonological loop resources in task choice and task performance

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THE ROLE OF PHONOLOGICAL LOOP RESOURCES
IN
TASK CHOICE AND TASK PERFORMANCE

by

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DISSERTATION

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DEDICATION

First and foremost, this dissertation is dedicated to my wonderful husband, Jon Thomas Minerich. Your care and compassion is boundless; *uden dig der intet*. This is also dedicated to my parents who fostered my inquisitive nature and tolerated its backlash, thank you. As for the ragtag bunch of misfits and scoundrels that I endearingly call my family and friends, thank you for holding my hand all these years.

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ABSTRACT

Individuals can use verbal resources of the phonological loop to support goal-directed behavior. Resources of the phonological loop are known to support goal-directed behavior via the maintenance and retrieval of stimulus-response maps (S-R), but it is also possible that these resources control behavior more broadly by contributing to the choice of what task to perform, i.e. task choice or task selection. To evaluate the role of phonological resources in task choice a unique variant of task switching was used, voluntary task switching (VTS). VTS provides the traditional metrics of task performance as well as a metric of task choice, the probability of switching tasks. In four experiments, task choice and task performance were measured as a function of the response to stimulus interval (RSI), the type of stimulus (a stimulus repetition or a stimulus change) and the availability of phonological loop resources. Individuals performed articulatory suppression to disrupt resources of the phonological loop, i.e., individuals repeated the word 'the' aloud in time with a metronome. Decreased switching was found at short

RSIs, when stimuli repeated, and when individuals performed concurrent articulatory suppression. The expected interaction of RSI and Load for the task choice measure was inconsistent and incompatible with the view that individuals rehearse previous task choices to guide current task choice in VTS. These data suggest that resources of the phonological loop contribute to processes of goal-activation as well as basic task-level processing. These results support models of task switching that distinguish between goal and task-level representations. Critically, this work suggests that traditional task-switching environments underestimate the impact of phonological interference on goal-directed behavior.

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1 Introduction

Cognitive control is useful for navigating complex environments that offer no explicit cues for guiding behavior. Our environment provides a number of explicit cues that directly communicate what action we should take (e.g., green light/go, red light/stop, but it is also filled with ambiguity (e.g., a yellow/amber light). In ambiguous situations, we use cognitive control to determine our course of action (Norman & Shallice, 1986). Despite the importance of cognitive control in determining our course of action, our understanding of this process is far from complete. Some theories stress that cognitive control processes of working memory "govern" the execution of endogenously driven, or top-down, behavior (Carver & Scheier, 2011; Schmeichel & Baumeister, 2004; Posner & Rothbart, 2000). Other theories cite evidence of goal-directed behavior that can occur without the need for an explicit intention and emphasize the role of bottom-up, or environmentally driven, contributions to goal-directed behavior (Bargh, 1994; Nisbett & Wilson, 1977). Generally speaking, however, most researchers agree that complex behavior involves some combination of top-down and bottom-up influences. It is unclear, however, what phonological processes are necessary for guiding behavior and under what conditions these resources are the most useful. This is an increasingly important question as the complexities of our daily lives present task environments that place heavy demands on our ability to successfully multitask.

1.1 Experimenter Instructed Task Switching (EITS)

Task switching has become a common psychological paradigm for measuring processes of cognitive control related to goal-directed behavior. Task-switching is a general term for a broad range of tasks environments, but the common feature of these paradigms involves the comparison of single task performance to performance when more than one task must be executed. Jersild (1927) was the first to systematically observe behavior in environments that required individuals to perform more than one task at a time. Using a variety of tasks, Jersild measured how quickly individuals could perform one task and compared this to the time needed to switch between tasks. As one might expect, the amount of time needed to perform more than one task was greater than the time needed to perform a single task; the term *shift effect* was coined to describe this pattern. The magnitude of the shift effect varied across the studies, but his general finding was consistent; individuals were slower and less accurate when they were required to switch between tasks (e.g., alternate between addition and subtraction), compared to when individuals performed only one task (e.g., simple addition). His design become known as the *list design* because individuals worked down lists of stimuli and the participant's overall reaction time and accuracy were compared across the single-task lists and dual-task lists.

The consistency of the shift effect observed in the list design led Jersild to conclude that a special "switching" process was necessary for managing dual-task performance. Moreover, Jersild concluded that the difficulty of the tasks determined the extent to which this special process was necessary. The more demanding the tasks the more "effort" one would need to switch between tasks and that "effort" resulted in exaggerated shift effects. The special switching process reflected Jersild's endorsement of an endogenous system responsible for establishing new task sets, but his acknowledgement that the demands of a task influence the switching process reflects his view that elements of the task environment can affect the cost associated with multitasking performance.

The original work of Jersild (1927) was invaluable because it introduced task-switching as a method for systematically studying costs associated with multitasking. His work provided a foundation for researchers to use similar methods and techniques to understand the origins of costs associated with task-switching. At the time, Jersild did not have sophisticated techniques to measure switch effects precisely. If the switch effect was not measured precisely, then Jersild's work may have exaggerated the true magnitude of these multitask costs. Moreover, because Jersild did not control the presentation of each stimulus in his lists, it was possible that individuals adopted a strategy that allowed them to execute a response while simultaneously initiating perceptual processes of the next stimulus. To address these concerns, Spector and Biederman (1976) used Jersild's list design, but required an experimenter to precisely record the onset of the first stimulus and completion of the final response for the list. Additionally, these researchers presented the task stimuli one at a time to prevent individuals from adopting strategies of stimulus pre-processing that might adulterate the true cost of switching.

Despite greater experimental control Spector and Biederman (1976) continued to observe a cost associated with task switching. These researchers concluded that Jersild's (1927) original interpretation was reliable; alternating between tasks produced a reliable increase in the time needed to complete the tasks as well as decrease in the accuracy of task performance.

1.2 Theoretical Explanations of Switch Costs

The persistence of switch costs across diverse task environments encouraged researchers to theorize regarding the cause of these costs. As mentioned above, Jersild (1927) assumed there was a top-down process that controlled task-switching and that switch effects reflected the processing of this switching mechanism. He did agree, however, that the relevance of this switching mechanism depended on factors of the task environment (e.g., practice with a given task. Jersild's position highlights a debate that continues to this day; to what extent does the environment contribute to task-switching and to what extend is task-switching controlled endogenously?

Bottom-up theories explain that the cost associated with task-switching is best investigated by examining the role of interference from residual and automatically-activated features of the tasks themselves. These theories suggest that switch costs arise because of interference experienced as the cognitive system moves from one set of task rules to another set of task rules (e.g., Allport, Styles & Hsieh, 1994; Allport & Wylie 1999; Yeung, 2010). In a demonstration of the importance of bottom-up contributions to costs associated with switching, Allport, Styles and Hsieh (1994) concluded that switch costs resulted from aspects of the tasks (e.g., the S-R maps and the degree of practice), and that these features could account for the bulk of the costs associated with switching. These researchers also suggested that activation of a task-set, like the activation of other memory traces, was subject to decay. They proposed that this decay would interfere with the performance of the new task until that activation fell below a threshold. Allport and Wylie (1999) coined the term *task-set inertia* to refer to this interference between a recently abandoned task set and a new task set. With this view switch costs reflect the degree of decay from the previously executed task rather than a "switching" process itself.

Rogers and Monsell (1995) disagreed with the Allport et al. (1994) claim that task-set inertia could sufficiently account for switch costs. They argued that the idea of task-set inertia would predict a slow decline in switch costs as the interval between one task response and a new task response increased, i.e. as the interference from the previous task-set abates. However, contrary to the slow decay of task activation predicted by task-set inertia, the bulk of switch costs typically followed the first trial of a switch, not thereafter, as task-set inertia would predict.

Complicating matters further, Rogers and Monsell (1995) pointed out that some methods of task switching, such as the list method developed by Jersild (1927), incidentally confounded the complexity of the task environment. For example, the list design measured costs associated with switching by comparing performance on blocks of alternating tasks to performance on blocks that only require one task to be performed. In the former condition individuals are required to maintain more than one set of task rules across the block of trials, while single task performance only requires the maintenance of one set of task rules across blocks.

In an effort to understand costs related to the switch itself rather than the complexity of the task environment, Rogers and Monsell (1995) developed a new procedure to measure switching effects on a trial-by-trial basis. This new paradigm was termed the *alternating- runs* paradigm. The alternating-runs paradigm required individuals to both repeat and switch tasks within a block [e.g., performing task A twice (AA) followed by two B tasks (BB), resulting in a task sequence, AABB]. In the alternating-runs paradigm individual trial-to-trial switch costs could be calculated by subtracting the time taken to respond with a repeated task on a new stimulus, i.e., the reaction time of the second trial in an A-A task sequence, from the time needed to respond with a new task, i.e., the second trial reaction time in a A-B sequence. This design controlled for the demands of task complexity because task S-R maintenance requirements were the same across both repeat and switch trials.

These researches coined a new term for the specific trial-to-trial switch-related performance declines, *switch costs*. This term was adopted to refer to the specific cost associated with moving from one task to another rather than the additional costs resulting from the demands of performing more than one task at a time. Rogers and Monsell (1995) demonstrated that a number of manipulations designed to support top-down control could reduce the costs associated with switching tasks. Factors such as task expectancy, compatible S-R maps, and the time to prepare for a task all reduced switch costs. All of these this led Rogers and Monsell to conclude that top-down features of the task-switching environment are equally important in determining switch costs. Importantly, these researchers argued that task-switching involves top-down control processes, such as task set reconfiguration, to activate a particular task set according to internal goals and motivations.

Meiran (1996) was another proponent of the idea that switch costs were the result of an endogenous “switching” system, but like Allport and colleagues, he also appreciated the role of bottom-up influences over task performance. Meiran used a random task cuing environment to investigate his claim. In the random task cuing environment, a cue is presented prior to the stimulus presentation (e.g., HIGH/LOW). The cue indicates what task the participant should execute on the next stimulus (e.g., *judge a digit as higher or lower than 5*). Like the alternating-runs paradigm, trial-to-trial switch costs can be measured while also equating the task complexity by requiring individuals to maintain both task sets across the experimental block. However, unlike the alternating-runs paradigm, this technique allowed Meiran to control the amount of time between a task cue and the next stimulus, i.e., the cue to stimulus interval. This was an important modification because it allowed for control over the recency of the previous task set while also controlling for the amount of time an individual had to prepare the new task prior to the next stimulus presentation. He found that switch costs declined as individuals had more time to prepare for a task, presumably via a reconfiguration process that was initiated when the task cue was presented. Meiran (2000a) also noted that these preparation effects, or *foreperiod effects*, represent the role of task expectancy in the selection of task sets without the need to rely on an exogenous cue (Meiran, 2000b; Meiran & Daichman, 2005). Meiran's view suggested that individuals do carry the potential to prepare responses in anticipation of the target although they cannot select a response until they are presented with the target stimulus. This distinction suggests a process of task choice, or task selection, as well as a process of S-R retrieval, supporting the general view that both top-down and bottom-up factors affect the costs associated with task switching.

Using statistical modeling techniques, Logan and Bundesen (2003) came to a similar conclusion when they tested three basic models of switch costs in a cued task-switching paradigm. One model included a "switching" mechanism that was governed by exogenous mechanisms. Another model included a "switching" mechanism that was governed by endogenous mechanisms. The final model included parameters for both endogenous and exogenous mechanisms. Across all studies, models that included an exogenous parameter outperformed the models that only included an endogenous parameter. However, the model that included both endogenous and exogenous parameters provided the overall best fit, but was less parsimonious.

Like Rogers and Monsell (1995) before them, Logan and Bundesen (2003) concluded that the composition of switch costs depends, in part, on the task-switching environment. For example, switch costs associated with list designs used by Jersild (1927) and Spector and Biederman (1976) allow for *global* switch costs measures. Global switch costs appear to capture cognitive processes that are more generally required for multitasking, such as maintaining multiple task sets. Alternatively, the alternating-runs paradigm of Rogers and Monsell and the cued-task switching paradigm used by Meiran (1996) and Allport and colleagues allow for comparison of *local* switch costs. Local switch costs appear to capture cognitive processes related specifically to switching between tasks. These differences in local and global switch costs are likely to reflect varying degrees of exogenous and endogenous control.

Similarly, while the list paradigm can be constructed to include task related cues similar to the cued task switching environment, the alternating-runs paradigm was specifically designed to be performed without the need to refer to an external cue. In the former case, it is possible that switch costs are not a pure measure top-down reconfiguration of the new task set because individuals can rely on the environment to activate the relevant task set. The cue could lead to the activation of the currently relevant response without the need to access S-R maps, in effect eliminating the need for self-cuing. This would reduce the amount of time needed to encode the new cue in the case of a cue repetition, but increase the amount of time needed to encode a new cue in the case of a cue switch, resulting in a switch cost that are linked to factors in the environment. In the latter case, however, endogenous factors might contribute to performance more so because elements in the environment cannot cue the relevant task set, a point also made by Logan and Bundesen (2003). They pointed out that processes of cue encoding are necessary in the random cued task-switching paradigm, but unnecessary in other paradigms. Admittedly, this could have led to the advantage of the exogenous model in their work because individuals were required to use the environment to determine which task to perform.

1.3 Voluntary Task Switching (VTS)

In an effort to design a task-switching environment that would support controlled task choice rather than deferment to the environment, Arrington and Logan (2004) developed a new type of task-switching paradigm referred to as *voluntary task switching* (VTS). VTS was designed to evoke an active task choice on every trial by instructing participants to switch between tasks "as if flipping a coin" determined which task they should perform on each trial (Arrington & Logan, 2004; Arrington & Logan, 2005). Unlike EITS that explicitly controls task choice, VTS provides limited guidance from the experimenter regarding task choice. The requirement to choose tasks in VTS not only differentiates it EITS, but also provides a measure of task choice, the *probability of switching* [p(sw)]. This metric reflects the proportion of times an individual chooses to switch to a new task rather than repeat tasks. Task choice in VTS is interesting because, unlike other tasks that ask participants to be random, individuals show a bias towards repetitiveness (Arrington & Logan, 2004; Arrington & Logan, 2005).

Theories of randomness propose that random choice is driven by the use of a representativeness heuristic (Rapoport & Budescu, 1992). The representativeness heuristic is thought to guide “random” selection via a comparison process. The comparison process evaluates possible outputs in light of one’s mental representation of “randomness”. The output that is selected is the one that best fits the individual’s representation of “random” in lieu of the ongoing sequence. The comparison process requires the maintenance of the on-going sequence and is constrained by the capacity of short-term memory to rehearse the previously executed sequence. Generally, human representation of randomness demonstrates a significant bias towards switching, p(sw) >.50, a pattern that is not found in VTS. In VTS individuals switch less often than expected by chance, a pattern that has been attributed to a task choice process that involves the use of two decision making heuristics: a representativeness heuristic and an availability heuristic (Arrington & Logan, 2005).

According to Arrington and Logan (2004), the representativeness heuristic and availability heuristic work in competition to guide task choice. Specifically, “The representativeness heuristic operates by evaluating the *n* previous trials held in STM and choosing the element that makes the series most representative of the subjects’ idea of a random sequence”. When the representativeness heuristic is used to guide task choice, then individuals are biased to switch tasks. However, the availability heuristic is not based on a comparison of a representation, but instead is based on how quickly a representation comes to mind (Kahneman, Slovic & Tversky, 1982). The most recently executed task is the task that comes to mind most easily, so the use of the availability heuristic biases an individual to repeat what they have just done. According to the heuristic view, task choice occurs on every trial, but the information that is used to guide the choice varies. At short preparatory intervals individuals guide task choice by referencing what most readily available, i.e., the task that was most recently performed. At longer preparatory intervals the availability of the most recent task set is weaker and choice behavior is guided more by the representation of randomness.

Arrington and Logan (2005) found a linear relationship between RSI and task choice supporting the view that individuals tend toward randomness when given sufficient time to bring the representativeness heuristic online. The longer the RSI the more likely an individual was to switch tasks. These researchers concluded that increasing the time between an individual's response and the presentation of the next stimulus, i.e., RSI, promotes increased probability of switching because it allows for more central-executive-demanding processing to guide behavior. When there is insufficient time to base task choice on the time-consuming representativeness heuristic, task selection is based on the task set that is most readily active, i.e., the task most recently executed.

1.4 Phonological Loop Contributions to Task Switching

An important intersection of behavioral control and task switching is seen with the proposed role of phonological loop resources (Baddeley, 2001). As Goschke (2000) points out, verbal goal representation appears to be the preferred representation for behavioral intentions that cannot be executed automatically. Similarly, researchers of human development note the significant role of language in behavioral control (Luria, 1959; Vygotsky, 1962) and task switching researchers have explored this topic in a variety of task switching methodologies coupled with *articulatory suppression*. Articulatory suppression is a common technique for manipulating the availability of the phonological loop resources. Articulatory suppression requires that an individual repeat a word aloud at a certain pace (e.g., repeating the word 'the' in time with a metronome). This manipulation effectively interferences with the use of phonological resources such as rehearsal, but does not appear to load the central executive component of working memory. So, while articulatory suppression interferes with verbal maintenance, it does not require active processing that reflects a defining feature of executive control.

Baddeley, Chincotta and Adlam (2001) capitalized on the fact that taxing elements of the central executive require maintenance with simultaneous processing, but interfering with subsystems of working memory, i.e., the visuospatial sketchpad and the phonological loop, involves simple disruption of maintenance without taxing higher-order executive control (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005 Hitch & Baddeley, 1974). Thus, by selectively taxing systems of working memory, i.e., the central executive, the visuospatial sketch pad and the phonological loop, they were able to observe how the phonological loop subsystem of working memory contributed to switching performance. In seven experiments, they found a variety of secondary load tasks differentially affected performance on task switching using the list paradigm. They noted that secondary articulatory suppression tasks reliably slowed performance on alternating lists, but as the difficulty of the secondary articulatory suppression task increased so too did reaction times on the blocked lists. This effect was not seen for non-verbal secondary tasks or tasks thought to tax the central executive. Unlike the pattern seen for simple articulatory suppression, taxing the central executive impaired performance on both blocked and alternating lists. They concluded that phonological loop resources contributed to elements of switching such as maintaining the switching "program" which was especially important when the environment did not offer explicit cues to indicate the currently relevant task.

Emerson and Miyake (2003) replicated and extended Baddeley, Chincotta, and Adlam (2001) when they measured switch costs in the list-paradigm with simple articulatory suppression or simple foot-tapping. They observed that both articulatory suppression and foot-tapping slowed overall completion of the alternating lists, i.e., lists that required the participant to alternate between addition and subtraction suggesting that some switch costs were the result of general multitasking requirements. However, they noted that articulatory suppression increased the time needed to complete alternating lists over and above the time needed to complete alternating lists while simultaneously performing foot-tapping. This difference suggests that articulatory resources were uniquely valuable for switching. The authors went further, arguing that phonological loop resources were not only valuable for switching, but were important for general self-cuing and preparing for an upcoming task.

To test their ideas that phonological loop resources are important for self-cuing and task preparation, Emerson and Miyake (2003) manipulated factors of the tasks that should have affected general cognitive processes, i.e., task difficulty in Experiment 3 and number of tasks in Experiment 4, as well as factors of the task environment that are known to be sensitive to the availability of the phonological loop systems, i.e. the presence or absence of cues in Experiment 2. As expected, they found that manipulating factors that should have affected general cognitive resources resulted in overall decrements in performance for both blocked and alternating lists. Importantly, they found that the use of a cue did differentially affect overall performance when performing a concurrent task, but that this decrement was more pronounced with concurrent articulatory suppression. Emerson and Miyake (2003) interpreted their patterns of switch costs as evidence that phonological processes support switching because articulation is important for retrieving task goals rather than the retrieval of specific S-R codes.

One admitted limitation of Emerson and Miyake (2003) was the use of the list method. Thus, in an effort to replicate and extend this work, Miyake, Emerson, Padilla and Ahn (2004) measured performance in a randomly cued task-switching environment with cues that either identified the relevant task, i.e., *COLOR*, or cues that were less direct, i.e., *C*, at short and long cue-to-stimulus intervals. Manipulating the cue-to-stimulus interval allowed them to understand the role of preparation in the random task switching environment. At short intervals, individuals do not have much time to prepare the task before the stimulus appears and their response times presumably capture some task-switching processing. However, at long intervals individuals presumably have sufficient time to prepare a task and reaction times should not reflect task-switching processing. Compared to other secondary tasks, articulatory suppression resulted in significant switch costs when the cue indirectly identified the task, i.e., *C*, suggesting phonological loop resources are important for retrieval of the task. Because the effects of the type of cue, i.e., direct or indirect, also interacted with the cue-to-stimulus interval, these researchers argued that phonological resources were especially valuable for retrieving the task goal when the environment could not automatically trigger the relevant task set.

Although the work of Emerson, Miyake and colleagues concluded that phonological loop resources were vital for triggering task sets, Liefooghe, Vandierendonck, Muyllaert, Verbruggen and Vanneste (2005) pointed out that task sets can consist of task goals as well as the stimulus-response maps needed to execute the task. In this view, they noted that the pattern of switch costs given secondary articulatory suppression could be the result of retrieving task goals or S-R maps. To test their hypothesis, these researchers used the alternating-runs task-switching paradigm in their Experiment 1 and noted that articulatory suppression affected switch costs by increasing reaction times for repeat trials. Their second experiment extended this finding, demonstrating differential switch costs with and without concurrent articulatory suppression using direct and indirect cues in a cued-task switching procedure. Specifically they found that concurrent articulatory suppression effected switch costs, but most obviously for repeat trials when the cue did not directly trigger the relevant task settings. This finding demonstrated that articulatory suppression interfered with cue processing that, in turn, affected repeat task performance because the cue was not available to help retrieve the relevant S-R maps. In their final experiment, Liefooghe, et al. (2005) found that the effects of non-verbal secondary task manipulations, i.e., foot-tapping and matrix foot-tapping, did not match those seen in Experiment 2.

Like previous work in task switching, however, interpreting the contribution of phonological loop resources is complicated by the type of task switching used in a particular study. Factors such as cue encoding are most clearly relevant in a cued task-switching environment. In this case, articulatory suppression seems vitally important in cue encoding and the successful use of the cue to retrieve the relevant task goal. However, task switching in environments such as the alternating-runs paradigm do not require cue-encoding, but show similar effects on switch costs when performed with concurrent articulatory suppression. Moreover, as Bryck and Mayr (2005) pointed out, increased errors seen in alternation trials compared to blocked trials in the list-paradigm can lead to post-error slowing that can inflate the effect of articulatory suppression on the observed switch costs. To address this concern, these researchers observed task-switching performance under conditions of concurrent secondary articulatory suppression or foot-tapping in three experiments, but they removed trials following errors when analyzing the data to control for post-error slowing.

Across all three experiments, Bryck and Mayr (2005) demonstrated a significant effect of articulatory suppression on switch costs, albeit less so than reported when these trials were not excluded (e.g., Baddeley et al. 2001 and Emerson and Miyake, 2003). Thus, switch reaction times were still longer than repeat reaction times when performing concurrent articulatory suppression, but the magnitude of the switch costs was weaker than those observed in previous studies that did not remove trials following errors. The second and third experiments, however, were most influential for their proposition that phonological loop resources can be used for cue encoding, but may also be used in task sequence maintenance. They manipulated the extent to which the environment could be relied on to assist in task set sequencing, i.e., bivalent stimuli compared to univalent stimuli and spatial cues that did not indicate the task to be performed but rather where the individual was in their task sequence. As expected, articulatory suppression increased switch reaction times when the environment did not offer support for guiding task selection. This finding was important because it highlighted the versatile role of phonological loop resources in task performance as well as task selection and maintenance.

Saeki and Saito (2009) continued with the ideas of Bryck and Mayr (2005) designing task-switching environments that integrate both task cues and what they describe as *transition cues* into a single task-switching environment. Unlike task cues, transitions cues do not indicate the task that should be executed, but instead indicate if the participant should stay on task or switch tasks. In this way transition cues do not offer task relevant information, but require individuals to maintain a task sequence that must be referenced in order to know what task is currently relevant. These researchers observed task-switching performance with concurrent articulatory suppression when individuals were given a combination of task cues and transition cues. Compared to a foot-tapping control, articulatory suppression affected reaction times when transition cues were presented suggesting that articulatory suppression interfered with processes related to task sequence recall.

Taken together, data undoubtedly support a role for phonological loop resources in task switching. In cued-task-switching environments, phonological loop resources appear vital to linking ambiguous cues to their respective task sets. The literature also supports a role for phonological loop resources when the task environment requires that an individual must keep track of their previous task sequence in order to determine the current relevant task set. This suggests that phonological loop resources are used, as needed, to support goal-directed behavior. When the environment supplies cues for behavior, phonological loop resources are used when those cues do not directly activate the relevant behavior. When the environment requires that an individual reference what they have done, then phonological loop resources are important for the maintenance of previous task sets. In the former case, phonological loop resources contribute task switching by assisting the cognitive processes of task-retrieval. In the latter, phonological loop resources contribute to task switching by maintaining the previous task set as an internal cue to assist the cognitive processes of task-retrieval. The studies converge to suggest that phonological loop resources are directly linked to task-retrieval.

1.5 Phonological Loop Resources and Voluntary Task Switching

Although the role of phonological loop resources in task switching has been investigated in EITS environment, to date, no study has directly investigated the role of phonological loop resources in the VTS environment. This is an important question, in part, because many of our daily tasks are not easily cued by our environment and demand high levels of endogenous control for task activation and execution. In EITS environments, there is no ambiguity and task selection is guided by the environment (e.g., cued task switching), or by an imposed task sequence (e.g., alternating-runs paradigm). In contrast, many real-world task environments require that tasks be selected from a range of other potentially equally important tasks. Although the VTS environment is admittedly less cluttered than real-world multitasking environments, VTS offers a measure of task choice that is not found in other task-switching environments.

It is possible that VTS uses phonological loop resources much in the same way one might expect individuals to use phonological loop resources in an alternating-runs paradigm, i.e., to maintain a task sequence. If this is the case, then it will support the view that individuals do attempt to maintain a sequence of previous task choices in an effort to guide current task choice. This would then support the proposition that, like other randomness measures, VTS relies on processes related to the representativeness heuristic.

Demanet, Verbruggen, Liefooghe, and Vandierendonck (2010) offer some insight into the potential for phonological loop resources in task choice. In a study designed to investigate top-down, inhibitory, control over task choice, Demanet et al. (2010) observed the effects of a secondary working memory task on task choice using the VTS environment. The working memory task required individuals to remember a series of consonants while simultaneously performing VTS with magnitude and parity judgments. They also manipulated the influence of bottom-up environmental factors. In the first experiment they did this by repeating the VTS stimulus on 25 percent of the trials. The second experiment involved the manipulation of repetition of response-irrelevant shape on each trial rather than repeating the stimulus itself. The third experiment required individuals to judge stimuli as *living/non-living* or as *larger/ smaller than a basketball* as the VTS tasks while performing with and without a concurrent secondary memory load. Across all three experiments Demanet et al. observed that the secondary working memory task decreased probability of switching.

Additionally, Demanet et al. (2010) hypothesized that the task associated with a particular stimulus in training would have a bottom-up influence on task choice when the same stimulus was presented in a post-training VTS procedure and that that this effect would be exaggerated when individuals were required to perform a concurrent working memory load. In the first experiment, Demanet et al. observed that stimulus repetition decreased the probability of switching, but only when the choice task was performed under the concurrent memory load. The second experiment was similar in that participants were more likely to repeat a task when performing the concurrent memory task and were more likely to repeat a task when the irrelevant shape repeated, but these variables did not interact as they did in Experiment 1. Finally, also as expected, individuals were more likely to choose the task that was associated with a particular stimulus during the single task exposure when given free choice in a VTS block. Counter to expectations, this effect did not differ when individuals performed a secondary working memory task suggesting that stimulus-task associations could not account for the interaction seen in Experiment 1.

Demanet et al. (2010) interpreted the pattern of effects as evidence that central executive resources are vital to the “voluntary” component of task choice. More specifically, they concluded that the central executive controls trial-to-trial response priming perhaps through inhibition of the previously selected task. The intention of their manipulation was to load central executive processes, but the verbal nature of the secondary tasks suggest an alternative interpretation. The manipulation used by Demanet et al. is similar to manipulations used in early research investigating short-term verbal rehearsal and the phonological loop (Baddeley, 2003). Because Demanet et al. required the maintenance of words or numbers, and it is quite possible that the results reflect the role of phonological processing in behavioral control rather than an inhibitory system or other central executive process.

1.6 The Present Research

Like Demanet et al. (2010), the present proposal was designed to investigate control processes used in VTS. However, unlike Demanet et al., the primary purpose of this study was to understand how systems of the phonological loop contribute to VTS performance. To this end, task choice was measured as a function of three independent variables: RSI, the stimulus type, and concurrent task load that was either verbal or nonverbal.

The variable of stimulus type provides a bottom-up processing manipulation because it strongly biases the use of bottom-up information to guide task choice. RSI was a top-down processing manipulation that varied the amount of time available for task preparation and, arguably, the time available to use a representativeness heuristic to guide task choice. This variable is uniquely important because there is evidence to support the view that time has a substantial effect on the influence of phonological processes in task switching (Miyake et al., 2004). Finally, the variable of concurrent task load, i.e., no load, concurrent articulatory suppression or concurrent foot-tapping, enabled the investigation of articulatory processes of the phonological loop that may be involved in directing behavior but are not thought to tax central executive processes of working memory.

Given the work suggesting that task sequence maintenance may rely on phonological loop processes (Bryck & Mayr, 2005; Saeki & Saito, 2009), it is possible that the same verbal rehearsal processes are used in VTS to support task choice via the use of the representativeness heuristic. If the use of the representativeness heuristic supports random behavior in VTS, then one would expect that interfering with the cognitive processes that support task sequence maintenance should affect random task choice. Specifically, if individuals cannot use the phonological loop to maintain a series of their previously chosen tasks because of articulatory suppression, then the use representativeness heuristic should be rendered ineffective. Without the ability to use a representativeness heuristic to guide random task choice, one would predict that task choice will be guided by features of the environment as well as carry-over from the previous task set..

If VTS is like other task switching environments then one might expect that phonological loop resources maintain the previously chosen task to help guide performance on the current trial. Because there is no cue in VTS phonological loop resources are not used for cue encoding, but it is possible that phonological resources are used in VTS not to maintain a series of previous tasks, but merely the most recently executed task set. This then influences the choice to switch tasks by biasing repetition via the availability heuristic. With respect to preparation, when performing articulatory suppression the influence of availability should interfere with the use of this heuristic at short RSIs. This suggests that interfering with the use of the availability heuristic will lead to switching that is *more* random.

Furthermore, if articulatory suppression interacts with stimulus repetitions in a way similar to that observed by Demanet et al. (2010) it would suggest that the disruption of inhibitory processes, or some other central executive mechanism, is not responsible for their observed pattern of results. This would in turn suggest that systems of verbal short term memory are vital to complex behavior by supporting task choice and multitasking behavior.

Regarding switch costs, manipulations of load should not affect switch costs because switch costs generally thought to reflect endogenous reconfiguration needed to switch task sets. Additionally switch costs should decrease as the RSI increases, a finding that is widely observed in the traditional task-switching literature. Finally, for task performance metrics load and RSI should not interact because the load manipulation should not act on processes of reconfiguration linked to executive control.

2 Experiment 1a

The first experiment manipulated the availability of verbal rehearsal resources as well as the time to prepare a task set, i.e., the RSI, in an effort to understand verbal contributions to task choice performance in the VTS procedure. Participants were required to repeat the word 'the' aloud in time with a metronome at a rate of 1 Hz. Experiment 1a also included an additional manipulation of performance pressure, i.e., stereotype threat, that required testing only females (mid-way through the VTS trials, half of the [female] participants were told they would complete a final math task that was designed to examine if women are bad at all forms of math or only certain types of math; see Beilock, Rydell & McConnell, 2007). However, at the end of the experiment the control and stereotype threat groups reported equivalent subjective experiences of performance pressure and there was no significant effect of the pressure manipulation. Therefore the results for Experiment 1a are reported without the variable of performance pressure.

2.1 Method

2.1.1 Participants

Eighty-three participants (all females, Age: *M* = 19.3, *SD* = 2.2 years; Education: *M* = 13, *SD* = 1.3 years) were recruited from an undergraduate introduction to psychology course at the University of New Mexico. Eight individuals were excluded from the data analysis: one was unable to complete the task in the allotted time, one reported a current diagnosis of anxiety/depression, one was excluded because of current treatment with psychotropic medication, two were excluded because their accuracy on non-articulatory suppression VTS trials was less than 85% and three switched tasks more than 95% of the time in either of the conditions. Only females were tested in this experiment because we included a between subject manipulation of stereotype threat. This variable did not enter into any interactions.

2.1.2 Apparatus and Materials

A Dell Dimensions computer running E-Prime software presented the VTS procedure (Schneider, Eschmann, & Zuccolotto, 2002). Stimuli were digits 1-4 and 6-9 presented in white Courier New font, 7x5 mm, presented on a black background via a 17-inch CRT monitor. The stimuli were randomly selected on each trial resulting in a stimulus repetition rate of approximately 11%. A plus sign was also presented in white in the center of the screen and the digit appeared just above it. Responses were made on a Psychological Software Tools, Inc. serial response box that has five buttons arrayed linearly. The demographic questionnaire contained questions about age, sex, current medications, and the importance of math performance to the individual (see Appendix A).

2.1.3 Procedures

Participants began the experiment by completing a demographic sheet. Participants were then positioned in front of the computer and told that the purpose of the experiment was to understand single task performance in a multitasking environment. They were told that the two tasks were both number judgments, determining if a digit is higher or lower than five or determining if the digit is odd or even. They were told to perform each of the tasks equally often and in a random order as if they were “flipping a coin" (Arrington & Logan, 2005). Participants then performed 32 practice VTS trials while the experimenter observed and provided additional instruction if needed.

Each trial began with the fixation symbol, a plus sign, in the middle of the screen, followed by the presentation of a randomly selected digit. Following a response, the next stimulus was displayed after a randomly chosen RSI (100, 500, 900 or 1300 ms). Responses were made with the index or middle fingers of the left or right hand by pressing one of five possible keys on a serial response box. Responses for the same task were always mapped to the same hand, but the assignment of keys to responses and hands to tasks was counterbalanced across participants. Because of a programming mistake, two levels of the response mappings were repeated and 2 levels were not included.

The task began with 2 blocks (32 trials each) of single task practice, one for each task (high/low and odd/even). Following single task practice, participants were introduced to the voluntary task-switching procedures. They were told that the procedures of the task would remain the same, a digit would appear just above a fixation in the middle of the screen, but in this case they would need to make a choice to perform either the high/low task or the odd/even task. They were additionally told that they should perform each of the tasks equally often and in a random order (Arrington & Logan, 2004). Individuals were instructed to avoid strictly alternating between tasks, performing the tasks in a predetermined pattern, or counting the number of times each task was performed. Prior to each experimental block they were reminded to perform the task equally often and in a random order.

Prior to the experimental blocks, participants performed one VTS practice block of 32 trials as the experimenter observed. If the experimenter observed that the participant continued to perform the same task on approximately 5-6 consecutive practice trials, then the experimenter stopped the participant and reminded them that they should perform the tasks equally often and in a random order as though they were flipping a coin to determine what task to perform. Participants were also stopped and given the same additional instruction if they strictly alternated between tasks on the beginning practice trials.

Participants completed 7 experimental blocks of VTS with no current task and 7 experimental blocks of the VTS procedure with an additional articulatory suppression task. Each block consisted of 64 trials. The articulatory suppression task required individuals to repeat the word ‘the’ in time with a metronome set to 1Hz for Experiment 1a.

2.2 Results

2.2.1 Data Coding

Each experimental trial for each subject was coded for accuracy by comparing the participant’s response to the two possible correct responses for the presented stimulus, i.e., if the stimulus was the digit ‘2’, the trial was considered accurate if the participant responded *even* or *lower than 5*. Each trial was then identified according to the task indicated by the correct response, i.e., if the trial stimulus was ‘2’ and the response was *even*, the task was coded as *parity*. This then allowed each trial to be identified as a repetition trial, i.e., the task executed on the current trial was the same task executed on the previous trial, or as a switch trial, i.e., if the task executed on the current trial was different from the task executed on the previous trial.

2.2.2 Data Trimming

Trials with reaction times longer than 3000ms or less than 150ms were excluded from the probability of switching [p(sw)], reaction time, and accuracy analyses. Error trials, trials following errors and trials that began each block were excluded from p(sw) and reaction time analyses. Overall 12.9% of trials were excluded.

2.2.3 Task Choice

Probability of Switching

P(sw) was calculated as a function of load (concurrent articulatory suppression or no concurrent load), a variable RSI (100ms, 500ms, 900ms, 1300ms) and stimulus type (the stimulus repeated or the stimulus changed) and submitted to a load by RSI by stimulus Type within subjects ANOVA.

The overall mean probability of switching was lower than traditionally observed in the literature (*M*=.27, *SE* =.02). In part, this difference was due to the inclusion of the articulatory suppression manipulation. Individuals switched tasks a mere 23.7% while performing articulatory suppression, but switched tasks 29.2% of the time in the no load condition. There was the expected a main effect of load, F (1, 74) = 21.5, $p < .001$, $\eta_p^2 = .225$, demonstrating that concurrent articulatory suppression significantly reduced the probability that an individual would switch tasks.

There was also a main effect of RSI, F (3, 222) = 29.7, $p < .001$, $\eta_p^2 = .287$, demonstrating an increase in switching as individuals have more time between a response and the presentation of the next stimulus. The significant linear contrast reflected a steady trend for increased switching as individuals has more time to prepare. This trend was confirmed when paired samples t-tests showed that the p(sw) was greater at 500ms compared to the 100ms RSI, $t(74) = -3.2$, $p = .002$, at 900ms compared to 500ms RSI, $t(74) = -4.2$, $p < .001$, and 1300ms compared to 900ms RSI, $t(74) = -2.8$, $p = .007$, adjusted $\alpha = .02$ (see Figure 1).

Finally, there was a main effect of the stimulus type, $F(1, 74) = 37.2$, $p < .001$, $\eta_p^2 = .334$. If a stimulus repeated individuals were significantly more likely to repeat tasks compared to situations where the stimulus changed.

As you can see in Table 1, the expected interaction of RSI and Load was not significant, $F = 1.6$, and no other interactions were significant, all *Fs* < 1.5. This suggests that task choice was affected independently by the type of concurrent load, the time to prepare a task and the repetition of a stimulus.

To be confident that our failure to find an interaction between load and RSI was not the result of the statistical analysis we used, we conducted a linear contrast of p(sw) across the four RSIs. For each individual, a p(sw) slope was calculated for each of the load conditions. The slopes were then analyzed in a 2 (load) by 2 (stimulus type) ANOVA. This contrast found no significant effects or interactions, all *F's* < 0.25. Critically, there was no effect of load, $F = 0.01$.

2.2.4 Task Performance

Unlike measures of task choice, measures of task performance include the additional variable of transition type. Task transition type has two levels: trials that were preceded by the same task, i.e., task repeated, and trials that were preceded by a different task, i.e., task switched. We included the transition variable for the reaction time and accuracy data analysis, but did not include the type of stimulus in these analyses to avoid losing too much of the sample to missing data points.

Additionally, because of the low probability of switching seen in the sample, only a subsample of individuals were included in the reaction time and accuracy analyses for Experiment 1a. Specifically, to ensure the reliability of reaction time and accuracy measures, individuals must have switched at least 10% of the time to be included in the analysis of task performance.

2.2.4.1 Reaction Time

Reaction times were analyzed in a 2 (load: concurrent articulatory suppression or no concurrent load) by 4 (variable RSI: 100ms, 500ms, 900ms or 1300ms) by 2 (transition: task repeated or task switched) within subjects ANOVA.

Overall, participants took 867 ms to execute an action. As expected, individuals were faster to act when the task repeated (M = 787 ms, SE = 18) compared to when the task switched (M = 948 ms, SE = 23), F (1, 60) = 173.2, $p < .001$, $\eta_p^2 = .743$, demonstrating a significant switch cost.

Reaction times decreased significantly as the preparatory interval increased, F (3, 180) = 32.8, $p < .001$, $\eta_p^2 = .353$. This effect, however, interacted with task transition, F (3, 180) = 40.6, $p < .001$, $\eta_p^2 = .404$ (see Figure 2). Switch reaction times benefited most clearly from the increasing RSI compared to the repeat reaction times, but the switch costs continued to be significant at the longest RSI.

Interestingly, there was no main effect of load, F = 1.3, on reaction time. Individuals responded at similar speeds with and without concurrent articulatory suppression. Concurrent load, however, did interact with the type of task transition, F (1, 60) = 22.2, $p < .001$, $\eta_p^2 = .270$. Reaction times suggest the interaction was driven by faster switch trial reaction times under articulatory suppression compared to switch reaction times without concurrent articulatory suppression (see Figure 3). In post-hoc follow-up tests of the interaction the trend was not significant, $t(60) = 2.2$, $p = .03$ with a Bonferroni adjusted alpha of α=.008.

As you can see in Table 2, RSI did not interact with load, $F = 2.1$, and there was no three-way interaction, $F < 1.0$. This suggests that concurrent articulatory suppression did not interfere with preparatory processes to affect reaction times, supporting the view that phonological loop resources are not used in VTS to prepare a task set in the way they are used to prepare a task set in EITS.

Accuracy

Accuracy was analyzed in a 2 (load: concurrent articulatory suppression or no concurrent load) by 4 (variable RSI: 100ms, 500ms, 900ms or 1300ms) by 2 (task transition: task repeated or task switched) within subjects ANOVA. For a summary of the data please see Table 3.

As expected, individuals were more accurate when they repeated tasks (M= 98.7%) compared to trials when they switched tasks (M=87.8%), F (1, 60) = 204.2, $p <$ .001, η_p^2= .773. Additionally, individuals were more accurate as the amount of time available for an individual to prepare increased, F (3, 180) = 2.8, p = .04, η_p^2= .044. Unlike the reaction time data there was a main effect of load, individuals were significantly less accurate when they maintained a concurrent articulatory suppression load (M = 90.9%) compared to the no load condition (M = 95.5%), F (1, 60) = 51.2, $p <$ .001, η_p^2= .46.

All main effects were qualified by a three-way interaction of load, RSI and the type of transition, F (3, 180) = 5.4, p = .001, η_p^2= .083. When the task repeated accuracy remained fairly high and fairly stable across all preparation intervals regardless of the articulatory suppression load. When individuals switched tasks, however, overall accuracy declined, but was especially poor when individuals switched tasks under articulatory suppression at the longer RSI intervals (the 100ms RSI compared to the 500, 900, and 1300ms RSIs)[1].

3 Experiment 1b

Although the pattern of results did not differ when the data analysis included the between subject variable of stereotype threat, it was not clear how this variable might have affected the general pattern of performance. Thus, to ensure that the additional performance pressure manipulation in Experiment 1a was not influencing the articulatory suppression effects that were observed, Experiment 1b was conducted. Furthermore, there were two distinct differences in this data compared to the data observed by Demanet et al. (2010). One, there was not the observed stimulus type by load interaction for the p(sw) metric. Also, Demanet et al. observed slower reaction times with their concurrent load compared to a no load condition.

In addition to excluding the stereotype threat manipulation, we used a slightly faster tempo for the articulatory suppression manipulation. In the original work linking task-switching and phonological loop processing, Baddeley, Chincotta and Adlam (2001) used a suppression rate of 2 Hz. Therefore, we used a suppression rate of 2 Hz for this version of Experiment 1 to ensure that the pattern of effects, and lack of them, observed

[1] All analyses [p(sw), reaction time and accuracy] were repeated with the inclusion of threat as a between subjects variable. This did not change the pattern of results for any of the dependent variables. Additionally, there were no significant main effects of threat and this variable did not enter into any significant interactions, all *F's*

in Experiment 1a were not due to a weak manipulation of the availability of articulatory resources.

3.1 Method

3.1.2 Participants

Thirty-two participants recruited from a college general psychology course (22 females, Age: *M*=21.6 years, *SD*=3.1; Education: *M*=13.9 years, *SD*=1.5) were included in the data analysis. Two individuals were excluded: one individual because of childhood diagnoses of ADHD and another because of switching more than 95% of trials in the silent control condition.

3.1.3 Apparatus, Materials and Procedures

The apparatus and materials were the same as Experiment 1a. The methods and procedures were identical to Experiment 1 with two exceptions. First, individuals were required to repeat the word "the" aloud in time with a metronome set to 2Hz rather than 1Hz. Second, the stereotype threat manipulation was not included.

3.2 Results

3.2.1 Data Coding and Trimming

Data coding was identical to Experiment 1a as was data processing. Data trimming resulted in the loss of 11.5% percent of trials. As in Experiment 1a, for the reaction time and accuracy analyses, the variable of task transition was included, but resulted in too few trials per conditions to include the variable of stimulus type.

3.2.2 Task Choice

Probability of Switching

P(sw) was submitted to a 2 (load: concurrent articulatory suppression load or no concurrent load) by 4 (variable RSI: 100ms, 500ms, 900ms, 1300ms) by 2 (stimulus type: stimulus repeated or stimulus changed) within subjects ANOVA. Data for this experiment are described in Table 1. Interestingly, in this experiment individuals switched 40.9% of the time, compared to the 26.5% switching seen in Experiment 1a.

The results of Experiment 1b replicated the significant main effect of RSI, F (3, 93) = 5.1, p =.003, η_p^2 = .140, as individuals had more time to prepare they were more likely to switch tasks. There was also a main effect of load, F (1, 31) = 15.3, $p < .001$, η_p^2 = .331 and a main effect of stimulus type, F (1, 31) = 15.6, $p < .001$, η_p^2= .335. Unlike Experiment 1a, however, the effect of load and stimulus type interacted, F (1, 31) = 4.3, p =.05, η_p^2 = .123. Individuals were less likely to switch while maintaining a concurrent articulatory suppression load and this was most pronounced when the stimulus repeated compared to when the stimulus changed (see Figure 4). No other interactions were significant, all *Fs* < 2.0. As with Experiment 1a, the linear contrast was conducted to assess if the effect of load on switch probability increased with greater preparation time. P(sw) slopes were analyzed in a 2 (load) by 2 (stimulus type) ANOVA. Like Experiment 1a, there were no main effects or interactions, all *F*'s < 0.31, confirming that longer RSI intervals did not make maintaining a series of previous task choices to guide current task selection more likely.

3.2.3 Task Performance

3.2.3.1 Reaction Time

Reaction times were analyzed in a 2 (load: concurrent articulatory suppression or no concurrent load) by 4 (variable RSI: 100ms, 500ms, 900ms or 1300ms) by 2 (task transition: task repeated or task switched) within subjects ANOVA. Again, note that this analysis is slightly different from the probability of switch analysis because it includes the variable of trial transition and does not include the variable of stimulus type. The reaction time data are presented in Table 2.

Overall, participants took 854ms to execute an action in the VTS procedure. There was a marginally significant effect of load on reaction time, replicating the trend observed in Experiment 1a. Once again, reaction times were faster when performing VTS with a concurrent articulatory suppression load (*M*= 860ms, *SE* = 35) compared to performing the task alone (*M* = 821ms, *SE* = 33), F (1, 31) = 3.8, p =.06, η_p^2 = .110. That said, load did enter into an interaction with the type of transition, F (1, 31) = 5.8, p = .022, η_p^2 = .158. Once again, the interaction of load and task transition demonstrated that individuals were faster to switch when they were maintaining a concurrent articulatory suppression load compared to no concurrent load (see Figure 3).

There was a main effect of preparatory interval, F (3, 93) = 27.7, $p < .001$, η_p^2 = .472, but unlike Experiment 1a there was an interaction with load, F (3, 93) = 5.14, p = .002, η_p^2 = .142, in addition to the interaction with task transition, F (3, 93) = 16.7, $p <$ .001, η_p^2 = .350. Despite the fact that individuals were faster to respond when performing articulatory suppression, individuals were unable to capitalize on an increased preparatory interval when they performed concurrent articulatory suppression. Similarly, as you can see in Table 3, task switches benefited by an increasing preparatory interval although, in this case, switching consistently took longer to execute compared to repeating a task.

Like Experiment 1a, the three-way interaction was not significant for reaction time, $F = 0.08$.

3.2.3.2 Accuracy

Accuracy was analyzed in a 2 (load: concurrent articulatory suppression or no concurrent load) by 4 (variable RSI: 100ms, 500ms, 900ms or 1300ms) by 2 (task transition: task repeated or task switched) within subjects ANOVA. The data for this variable is presented in Table 4.

Replicating Experiment 1a there was a significant main effect of load, F (1, 31) = 15.3, $p < .001$, $\eta_p^2 = .330$, and a main effect of transition type, F (1, 31) = 61.8, $p < .001$, $\eta_p^2 = .666$, but these variables also entered into a significant interaction, F (1, 31) = 22.7, $p < .001$, $\eta_p^2 = .422$, (see Figure 5). Individuals were significantly less accurate when switching tasks, but this effect was more pronounced when individuals switched tasks while performing concurrent articulatory suppression.

Unlike Experiment 1a there was no main effect of RSI on accuracy, $F = 1.3$, however this variable interacted with the type of transition, F (3, 93) = 2.8, $p = .05$, $\eta_p^2 = .082$. Overall accuracy was lower when individuals switched tasks, however, like Experiment 1a, individuals tended to be more accurate at the shortest RSI compared to the longer RSI intervals. This trend was not significant, however, in post-hoc follow-ups. The 3-way interaction, however, was not significant, $F = 1.15$.

3.3 Discussion of Experiment 1

Across both Experiment 1a and Experiment 1b task switching was less likely when individuals maintained a concurrent articulatory suppression load that filled the phonological loop. Similarly, when the time available to prepare a task choice was reduced, individuals were less likely to switch. Interestingly these two factors did not interact, suggesting that phonological resources are important for the choice to switch, but not in the way predicted by the representativeness heuristic.

These findings also suggest that the phonological loop may play a primary role in task choice, even modulating the likelihood that choice is guided by bottom-up processes if switching rates are high enough (Experiment 1b and high switchers in Experiment 1a, see Appendix B).

Another surprising result from these experiments was that switch trial reaction times under articulatory suppression were *faster* than in the no load condition and repeat trial reaction times were comparable in the two load conditions. One possible interpretation of this finding is that phonological processes might actually slow performance on switch trials leading to an increase in switch costs. While this is a potentially interesting conclusion, perhaps it is more likely that the speed up in switch reaction times reflect a speed/accuracy trade off. Individuals performed less accurately overall when maintaining a concurrent articulatory suppression load, but accuracy declined even more when they performed concurrent articulatory suppression *and* switched tasks.

Compared to previously established literature this work demonstrates that VTS is affected by articulatory suppression, but in a way that is as unique as this paradigm.

Switch costs decreased when performing concurrent articulatory suppression, but this decrease was driven by decreased switch reaction times rather than increased repeat reaction times. Individuals may be able to perform switches more quickly, but do so in part because they do not successfully reconfigure the new task set leading to increased errors. However, it is also possible that unpredictable RSIs could have encouraged individuals to try and engage in alternative strategies for task-set preparation. For example, individuals might attempt to prepare new task sets more quickly because they could not predict when information in the environment will become available. Because information in the environment can affect task choice, it is possible that individuals attempt to prepare switches more quickly in an effort to insulate their choice from the information in the environment.

4 Experiment 2

Experiment 2 sought to examine whether the lack of an interaction between load and RSI found for the p(sw) in Experiment 1a and Experiment 1b was the result of unpredictable preparation intervals. Using language to represent and maintain sequences of task choices is serial and may be difficult to do if an individual cannot predict when the next stimulus will be presented (Emerson and Miyake, 2003). If individuals could not predict the presentation of the stimulus they may have chosen to rely on other strategies to guide task selection. With increased predictability individuals can adjust their performance accordingly and, in this case, may be encouraged to use rehearsal as a strategy for guiding task performance.

Thus, the goal of the second experiment is to examine if phonological processes will play more of a role in task preparation when a predictable interval is available to prepare for a task choice. Another goal of Experiment 2 was to determine if the reaction time effects seen in Experiment 1a and Experiment 1b would replicate when individuals were able to predict the amount of time they would have for task reconfiguration.

4.1 Method

4.1.1 Participants

In Experiment 2, 37 individuals (25 females) were included in the analysis (Age: *M*=19.6, *SD*=3.0; Education: *M*=2.8, *SD*=1.3). One individual was excluded because of a reported diagnosis of depression and another individual was excluded because they were older than 30 years of age.

4.1.2 Apparatus & Materials

Apparatus and materials were identical to Experiment 1b.

4.1.3 Procedures

Similar to Experiment 1b, individuals were asked to perform a voluntary task choice procedure while performing a concurrent articulatory suppression, i.e., repeating the word "the" aloud in time with a metronome set to 2Hz, or no concurrent load.

Experiment 2 was distinct from Experiment 1a and Experiment 1b because RSIs were fixed across blocks of trials with a consistent RSI throughout each block. All four levels of the RSI were used, i.e., 100ms, 500ms, 900ms and 1300ms.

Individuals began by practicing each task individually with a variable RSI. Individuals were then introduced to the VTS procedure and given practice with the procedure with fixed RSIs. Participants performed 2 blocks of 16 trials each at each RSI interval. Each block of practice trials was preceded by information about the length of the RSI.

Participants were randomly assigned to begin the experimental procedure with the concurrent articulatory suppression load or the no load control. Within each suppression condition, individuals performed 8 VTS blocks of 56 trials each, 2 blocks for each level of the RSI. The order of each RSI block was randomly determined such that one block from each RSI condition was performed in the first 4 blocks and the second block was performed in the final 4 blocks of that load condition. As with the practice, individuals were told before each block how long they would have to prepare between their response and the presentation of the next stimulus.

4.2 Results

4.2.1 Data Coding and Trimming

Data coding was identical to Experiment 1a. Additionally, data processing excluded trials with reaction times less than 150ms or greater than 3000ms (1.4% of trials), as well as errors and trials following errors (an additional 15.6% of trials). For the reaction time and accuracy analyses, the variable of stimulus type was not included. Instead, the factor of task transition was evaluated in place of the stimulus type variable.

4.2.2 Task Choice

Probability of Switching

For the fixed RSI design, the switching probabilities were submitted to a 2 (concurrent load: articulatory suppression or no load) x 2 (stimulus type: stimulus repeated or stimulus changed) x 4 (fixed RSI: 100ms, 500ms, 900ms, 1300ms) within subjects ANOVA.

Overall individuals switched 24.7% of the time, *SE* = .02, in Experiment 2. Like Experiment 1a and Experiment 1b, p(sw) was significantly affected by load, F (1, 36) =

16.8, $p < .001$, $\eta_p^2 = .318$. As you can see in Table 5, individuals were less likely to switch while performing articulatory suppression (M = 22.4%, SE=.02) compared to the no load condition (M = 27.0%, SE = .02).

Additionally, the stimulus type affected p(sw) demonstrating that stimulus repetitions decreased the probability of switching, F (1, 36) = 52.4, $p < .001$, $\eta_p^2 = .539$. When the stimulus repeated individuals switched on 19.7% of trials (SE=.02), and when the stimulus changed they switched on 29.6% of trials (SE = .02). Replicating Experiment 1a, and Experiment 1b, the effect of RSI reached significance, F (3, 108) = 29.2, $p <$ .001, $\eta_p^2 = .448$. Unlike Experiment 1a and Experiment 1b, however, in Experiment 2 load interacted with RSI when RSI was fixed, F (3, 108) = 2.95, p = .04, $\eta_p^2 = .076$ (see Figure 6). P(sw) demonstrated a linear increase under no load conditions, however when individuals performed concurrent articulatory suppression, there was a significant increase in the p(sw) when the 500ms RSI interval was compared to the 900ms RSI. The p(sw) at the 500ms RSI interval, however, was not significantly different from the 100ms RSI and the p(sw) at the 900ms RSI interval was not significantly different from the p(sw) at the 1300ms RSI. No other interactions were significant, all Fs < 1.41. The linear contrast was also conducted on this data set. The slopes of p(sw) across the four RSI intervals were calculated for each condition and submitted to a 2x2 ANOVA. In this case, neither stimulus type nor load affected the change in the probability of switching with longer RSIs, all F's < 2.4. There was a marginally significant load by stimulus type interaction, F(1, 36) = 3.6, p = .07, $\eta_p^2 = .091$. Post hoc comparisons showed that the differences in p(sw) slope were driven by the no load condition. In the no load condition, when the stimulus repeated individuals were more likely to switch as they had more time to prepare for the stimulus. This benefit, however, was noticeably less for stimulus changes, $t(36) = 1.9$, $p = .057$. This supports the view that information from the stimulus influences task choice at short RSIs perhaps by priming the most recently executed task.

4.2.3 Task Performance

4.2.4.1 Reaction Time

Reaction times were analyzed in a 2 (load: concurrent articulatory suppression or no load) x 2 (task transition: task repeated or task switched) x 4 (fixed RSI: 100ms, 500ms, 900ms, 1300ms) within subjects design. The reaction time data for Experiment 2 are presented in Table 6.

Unlike Experiment 1a and Experiment 1b, individuals were significantly faster to respond when there was no concurrent load (M = 770ms, SE = 25) compared to a concurrent articulatory suppression (M = 827, SE = 23), F (1, 36) = 7.3, p = .01, η_p^2 =.17. Unlike Experiment 1a, but as seen in Experiment 1b, load interacted with RSI, F (3, 108) = 7.3, $p < .001$, η_p^2 =.17. However, the pattern of this interaction was not the same for Experiment 1b and Experiment 2. In Experiment 1b, when the RSI intervals were unpredictable, articulatory suppression appeared to have the greatest effect at the shortest RSI leading to speeded reaction times when performing concurrent articulatory suppression. In Experiment 2, however, articulatory suppression appeared to have its greatest effect at the longest RSIs when that interval was predictable (see Figure 7).

Replicating Experiment 1a and Experiment 1b, task repetitions (M = 712ms, SE =17) were executed significantly faster compared to task switches (M = 886ms, SE = 29), F (1, 36) = 79.7, p = .01, η_p^2 = .69, and this effect interacted with RSI, F (3, 108) = 30.0,

p < .001, η_p^2 =.453 (see Figure 8). Switch reaction times got faster as RSI increased. That said, switch costs remained significant at even the longest RSI (1300ms).

Neither the load by task transition, F = 0.2, or the 3-way interaction, F = 0.17, were significant.

4.2.4.2 Accuracy

Individual accuracy was analyzed in a 2 (concurrent load: concurrent articulatory suppression or no concurrent load) x 2 (task transition: task repeated or task switched) x 4 (fixed RSI: 100ms, 500ms, 900ms, 1300ms) within subjects design. Accuracy data for Experiment 2 can be seen in Table 7.

Individuals were significantly more accurate if they repeated tasks (M = 98.7%, SE= .002) compared to switching tasks (M=83.8%, SE = .013), F (1, 36) = 151.3, p < .001, η_p^2=.808, replicating Experiment 1a and Experiment 1b. Additionally, individuals were more accurate when they performed the VTS without a concurrent articulatory suppression load, (M = 92.9%, SE = .007), compared to performing VTS with concurrent articulatory suppression (M = 89.6%, SE = .009), F (1, 36) = 30.0, p < .001, η_p^2= .454. Finally, the main effect of RSI was also significant F (3, 108) = 12.0, p < .001, η_p^2= .248, again replicating Experiment 1a and Experiment 1b.

Like Experiment 1a and unlike Experiment 1b, there was a 3-way interaction of task transition, load and fixed RSI, F (3, 108) = 4.2, p = .008, η_p^2= .104. Once again, accuracy was fairly stable when individuals repeated tasks regardless of the concurrent load, however when individuals switched tasks accuracy declined especially when individuals performed the articulatory suppression load. Moreover, the decline in accuracy under load was most obvious in the 500ms RSI condition compared to the other

RSI conditions. This stands in contrast to the 3-way interaction seen in Experiment 1a for accuracy, that appeared to be driven by improved accuracy at the 100ms RSI interval. It is interesting to note that this 3-way interaction is not found in p(sw) measures or reaction time measures.

4.3 Discussion of Experiment 2

While probability of switching rates were more like Experiment 1a than the higher levels seen in Experiment 1b, the pattern of effects seen in Experiment 2 were similar to those seen in Experiment 1a and Experiment 1b. As expected RSI, stimulus type and load all affected task choice, however, with the fixed RSI design, load significantly interacted with RSI to affect choice behavior. Interestingly, and contrary to the prediction, the effect was not linear. This suggests that predictable RSI might have evoked the use of phonological loop resources to help guide task choice, but not in the way one would expect if individuals were maintaining a series of previously executed task selections, i.e., to support the use of a representativeness heuristic.

The justification for using predictable RSIs in Experiment 2 was based on the idea that the unpredictable RSI intervals used in Experiment 1a and Experiment 1b might have discouraged the use of phonological loop resources to help maintain a series of previous task choices, i.e., to support the use of a representativeness heuristic, which would then explain why there was no interaction between RSI and load (Emerson & Miyake, 2003). However, as you can see in Figure 6, when participants performed concurrent articulatory suppression demonstrated distinctly lower levels of switching at short RSI intervals, i.e., 100 and 500ms, compared to longer RSI intervals, i.e., 900 and 1300ms. This suggests that individuals do use phonological loop resources to guide switching, but the resources do not appear to support task choice via the maintenance of increasingly long series of previous task selections.

Similarly, Experiment 2 also demonstrated that predictable RSIs affect the way phonological loop resources are used to support task performance in VTS compared to the way these resources are used with an unpredictable RSI. With predictable RSIs the counterintuitive finding of speeded switch reaction times in Experiment 1a and 1b was not found. When individuals could predict when the next stimulus was going to appear they were more successful at instantiating a new task set regardless of whether a concurrent articulatory suppression task was being performed. It is possible that predictable RSIs encouraged individuals to delay the preparation of a task choice until the stimulus appeared in an effort to use stimulus information to assist their task switching performance.

The pattern of effects on task performance further suggests that experimental designs that used fixed RSIs discourage the use of central executive processes of task choice. Interestingly, this possibility is supported by the interaction of load and RSI for the p(sw) seen in Experiment 2 that was not seen in earlier experiments. This conclusions, however, is speculative without the inclusion of a secondary task that does not load phonological loop resources. Experiment 3 was designed to include an additional load condition, foot-tapping, to confirm that the effects of phonological loop on task choice and task performance are unique.

5 Experiment 3

The primary goal of Experiment 3 was to address the extent to which the effects observed in the previous experiments are specific to the role of phonological processing or merely reflect a general effect of simultaneously performing multiple tasks. If the effects of load on switch probability and switch cost measures are due to the dual-task demands rather than verbal short-term memory processes, then a secondary task such as foot tapping should interfere with performance much in the same way that an articulatory suppression load affects performance. However, if verbal resources play a unique role in directing and executing task switches then switch probability should be relatively similar for concurrent foot-tapping and no concurrent load. A secondary goal of Experiment 3 is to replicate the pattern of effects seen at long and short RSIs that are fixed.

It was predicted that the effect of concurrent articulatory suppression on p(sw) would replicate. Additionally, if concurrent foot-tapping does not reduce p(sw) then the proposed role of phonological resources in guiding task choice will be supported. On the other hand, if concurrent foot-tapping reduces p(sw) in the same way as concurrent articulatory suppression, it will suggest that task choice is primarily reliant on processes used to coordinate dual-tasks that are not specific to phonological short-term memory. Based on the finding with concurrent articulatory suppression it is predicted that a foot-tapping control should have little or no effect on reaction time performance.

5.1 Method

5.1.1 Participants

In Experiment 3, 49 participants (26 females) were included in the analysis and 4 people were excluded (Age: M = 20 years, SD = 2.4; Education: M = 13.1 years, SD = 1.4). One person who did not understand the task instructions was excluded. Another participant was excluded because the experimenter did not feel that the participant understood the task instructions. A third participant was excluded for reporting being diagnosed as dyslexic. Finally, the fourth person was excluded because they switched 99% of the time when they performed the VTS task with no secondary load.

5.1.2 Apparatus & Materials

Apparatus and materials were identical to Experiment 2 with the exception that only the short and long RSIs were included (500ms and 1300ms, respectively) and each block included 64 trials each. Additionally, a third concurrent load condition was included. Individuals were asked to tap their foot in time with a metronome set to 2Hz. Finally, following each block, individuals were given feedback about their accuracy.

5.1.3 Procedures

Participants performed VTS while performing one of three concurrent tasks conditions: articulatory suppression, foot tapping and no concurrent load. Participants completed 4 blocks of trials, in each secondary load condition with 64 trials in each block. Response to stimulus interval was fixed at 2 levels: 500ms and 1300ms. The order of the concurrent task load conditions and the order of RSI blocks were counterbalanced by participants.

5.2 Results

5.2.1 Data Coding and Trimming

Data coding was identical to Experiment 1a. Data trimming followed the same procedures described in Experiment 1a. For the reaction time and accuracy analyses, the variable of stimulus type was not included. Instead, the factor of task transition was evaluated in place of the stimulus type variable. Data trimming resulted in the loss of 11.7% percent of trials.

5.2.2 Task Choice

Probability of Switching

P(sw) was analyzed in a 3 (load: no concurrent load, concurrent articulatory suppression or concurrent foot-tapping) by 2 (fixed RSI: 500ms or 1300ms) by 2 (stimulus type: stimulus repeated or stimulus changed) within subjects ANOVA. The p(sw) data can be found in Table 8.

There was a main effect of concurrent load, F (2, 96) = 14.0, $p < .001$, $\eta_p^2 = .226$, a main effect of RSI, F (1, 48) = 34.0, $p <.001$, $\eta_p^2 = .414$, as well as a main effect of stimulus type, F (1, 48) = 108.8, $p < .001$, $\eta_p^2 = .694$. These effects, however, were qualified by a marginally significant 3-way interaction between fixed RSI, stimulus type and load, F (2, 96) = 2.82, $p = .06$, $\eta_p^2 = .056$ (see Figure 9).

To explore the unique contribution of phonological loop resources to task choice and task performance, it was vital to explore the pattern of effects while individuals performed concurrent articulatory suppression to that of concurrent foot-tapping. This comparison can demonstrate that the observed patterns of effects with concurrent articulatory suppression are the result of phonological loop processing rather than general interference resulting from performing more than one task at a time.

When the no load condition was compared to the articulatory suppression condition, all main effects were significant at p <.001, but no interactions reached significance, all Fs < 0.80. This replicates the findings for p(sw) seen in Experiment 1a and Experiment 2 supporting the view that task choice declines when individuals perform articulatory suppression, but not in the way predicted by the representativeness heuristic. Moreover, this pattern was different for the foot-tapping condition compared to no load condition. In this case, there was a 3-way interaction of fixed RSI, stimulus type and load, F (1, 48) = 6.52, p = .01, η_p^2 = .120.

To follow-up the significant 3-way interaction, the articulatory suppression condition was compared to the foot-tapping condition. This comparison is relevant because it distinguishes between processes of task choice that rely on phonological loop resources and those that rely on general multitasking. When the articulatory suppression secondary task was compared to the foot-tapping secondary task all main effects continue to reach significance. The main effect of RSI replicates the finding in Experiment 1a, Experiment 1b, and Experiment 2 that p(sw) increases as the preparation interval increases. Similarly, there was a main effect of stimulus type that showed a decrease in p(sw) when the stimulus repeated, an effect that was also seen in Experiment 1a, Experiment 1b, and Experiment 2.

Interestingly, this effect of stimulus type interacted with load, F (1, 48) = 4.56, p = .04, η_p^2 = .087. Follow-ups showed that when the stimulus repeated, p(sw) was not different for the articulatory suppression condition compared to the foot-tapping condition, $t(48) = -.973$. However, when the stimulus changed, this pattern changed and the p(sw) was significantly lower for articulatory suppression compared to foot-tapping. This suggests that general multitasking resources are utilized in VTS when the stimulus repeats, but when the stimulus changes, resources related to the phonological loop affect the choice to switch tasks, $t(48) = -4.04$.

As with the previous studies, we calculated the change in p(sw) across the 500ms and 1300ms RSI. We then submitted this difference score to a 2 (load) x 2 (stimulus type) ANOVA. Once again, no main effects were present and there were no interactions, all *F*'s < 1.9.

5.2.3 Task Performance

5.2.3.1 Reaction Time

A 3 (load: no load, concurrent articulatory suppression or foot-tapping) by 2 (fixed RSI: 500ms or 1300ms) by 2 (task transition: task repeated or task switched) ANOVA was conducted with reaction times. This reaction time data is presented in Table 9.

There was a main effect of load, $F\ (2, 96) = 8.59$, $p < .001$, $\eta_p^2 = .152$, and a main effect of transition type, $F\ (1, 48) = 65.7$, $p < .001$, $\eta_p^2 = .578$. These effects, however, were qualified by a significant 3-way interaction, $F\ (2, 96) = 3.4$, $p = .04$, $\eta_p^2 = .066$.

To follow-up the significant three-way interaction, the load conditions were compared to the no load conditions to determine how the different types of loads would be affected. Comparing reaction times under concurrent articulatory suppression to no load showed a main effect of load, $F\ (1, 48) = 9.6$, $p = .003$, $\eta_p^2 = .167$, as well as a main effect of RSI, $F\ (1, 48) = 4.3$, $p = .04$, $\eta_p^2 = .082$, and a main effect of transition type, *F*

(1, 48) = 76.5, $p < .001$, $\eta_p^2 = .615$. Additionally, RSI interacted with load, F (1, 48) = 11.1, $p = .002$, $\eta_p^2 = .188$, as well as the type of transition, F (1, 48) = 12.0, $p = .001$, $\eta_p^2 = .201$. Reaction times were slower when individuals performed concurrent articulatory suppression compared to the no load condition, but this difference was only significant at the 1300ms RSI interval. Individuals were also faster to repeat tasks regardless of the RSI interval, however there was a trend for repeat reaction times to be slower at the 1300ms RSI. This trend, however, was not significant in post-hoc follow-up tests (see Figure 10).

When foot-tapping was compared to the no load condition there was no main effect for RSI ($F = 0.3$), however there remained a significant main effect of transition type, F (1, 48) = 49.5, $p < .001$, $\eta_p^2 = .508$, as well as a main effect of load, F (1, 48) = 14.9, $p < .001$, $\eta_p^2 = .237$. Unlike the no load condition compared to the articulatory suppression condition, reaction times for foot-tapping compared to no load did enter into a 3-way interaction, F (1, 48) = 5.1, $p = .03$, $\eta_p^2 = .028$. At long RSIs, when individuals performed concurrent foot-tapping, reaction times were similar regardless of switching tasks or repeating them. This was not the case at the shorter, 500ms, RSI where there was a distinct cost for switching tasks compared to repeating tasks. Foot-tapping, unlike both the no load condition and concurrent articulatory suppression load, showed a significant decrease in switch costs across RSIs. The reduction in switch costs was driven by an increase in repeat reaction times as well as a slight speed up for switch reaction times at long RSIs. It is possible that general interference of executing multiple motor actions can account for this finding; foot-tapping might result in S-R level interference that slows repeat reaction times at long RSIs, but benefits switch reaction times (see Figure 10).

5.2.3.2 Accuracy

A 3 (load: no load, concurrent articulatory suppression or foot-tapping) by 2 (fixed RSI: 500ms or 1300ms) by 2 (task transition: task repeated or task switched) ANOVA was conducted for accuracy. The data are presented in Table 10.

There was a significant effect of RSI, F (1, 48) = 32.0, $p < .001$, $\eta_p^2 = .400$, demonstrating that individuals were more accurate as they had more time to prepare, an effect that interacted with the type of task transition, F (1, 48) = 23.7, $p < .001$, $\eta_p^2 = .330$. Specifically, as individuals had more time to prepare they were able to switch tasks with higher accuracy. There was also a significant effect of concurrent load, F (2, 96) = 103.7, $p < .001$, $\eta_p^2 = .684$, but this interacted with transition type, F (2, 96) = 15.6, $p < .001$, $\eta_p^2 = .245$. Task repetitions were similarly accurate across all load conditions, however when individuals switched tasks accuracy was worst for the articulatory suppression condition, followed by the foot-tapping and no load condition. No other interactions were significant, all Fs < .815.

5.3 Discussion of Experiment 3

Experiment 3 demonstrates the unique contribution of the phonological loop to task choice and task performance, but also supports the view proposed by Demanet et al. (2010) that p(sw) is sensitive to manipulations of central executive processing. Both articulatory suppression and foot-tapping affected task choice, but when the stimulus changed the p(sw) under articulatory suppression continued to be lower compared to the foot-tapping condition. This is important because it suggests that task choice and task performance are sensitive to more passive systems of working memory in addition to more active systems of the central executive.

One could argue that our articulatory suppression manipulation may have inadvertently taxed the central executive in the same way that the manipulation used by Demanet et al. may have filled the phonological loop. After all, performing more than one task at a time is known to tap more general resources of the central executive. However, if this were the case, then the same pattern of effects should have been seen for articulatory suppression and foot-tapping in Experiment 3.

6 General Discussion

The goal of this work was to assess the role of the phonological loop, a subsystem of working memory, in task choice and task performance during a voluntary task switching procedure. Across all four experiments both task choice and task performance were affected by the availability of phonological loop resources as well as the time available to prepare a response and the type of stimulus. To begin, we will review the role of phonological loop resources in task choice followed by a review of the task performance effects. We will then consider this work in light of models of task switching that separate goal level representation and task level representation, focusing on Logan and Gordon's (2001) model of executive control of visual attention in dual-task situations (ECTVA). Conclusions will discuss the practical implications of these data, address limitations of the current study and discuss future directions.

6.1 Task Choice

With respect to task choice, articulatory suppression decreased the p(sw) in all four experiments. Critically, compared to a no load condition, articulatory suppression decreased the p(sw) regardless of the stimulus type while a nonverbal concurrent foot-tapping task affected p(sw) when the stimulus repeated but not when the stimulus changed. This suggests that the control involved in task choice is unique when the stimulus changes compared to a stimulus repetition. When the stimulus repeats, general working memory resources are vital for biasing a task switch perhaps by supporting the inhibition of episodic priming (Demanet et al., 2010; Mayr & Bell, 2006). However, when this form of control is not needed because the stimulus does not prime the previous episode, resources of the phonological loop are still important for biasing a task switch. This supports the view proposed by Miyake et al. (2004) that phonological loop resources serve as a self-cuing process that is important for instantiating new task sets when cues in the environment do not explicitly support task retrieval.

Across the four experiments the interaction of load and RSI for p(sw) was inconsistent and incompatible with the view that phonological loop resources are used in VTS to support a representativeness heuristic that depends on verbal rehearsal. Only in Experiment 2 did load and RSI interact to demonstrate a distinct stepwise function across short (100ms and 500ms) and long RSIs (900ms and 1300ms) for the p(sw) when individuals performed articulatory suppression. Compared to the no load condition, articulatory suppression significantly affected p(sw) at an RSI interval of 500ms, and marginally so at the 1300ms RSI (post-Bonferroni adjustment, p = .008), but was non-significant at 100ms and 900ms RSIs. If phonological loop resources were being used to guide task choice via the maintenance of previous task sequences, then one would expect a significant effect of articulatory suppression that either suppressed switching at all RSIs equally or increased incrementally for each of the RSIs as the task set decayed.

Replicating previous work, all four experiments demonstrated significant changes in task choice as a function of the time to prepare, i.e., RSI as well as the stimulus type.

This supports the view that p(sw) in VTS is reliable metric of endogenous control over behavior and is affected by both top-down as well as bottom-up features of the task environment (Arrington & Logan, 2004; Arrington & Logan, 2005; Arrington & Yates, 2009; Lien & Ruthruff, 2008; Mayr & Bell, 2006; Liefooghe, Demanet & Vandierendonck, 2008).

Before moving on to discuss the effects of articulatory suppression on task performance in VTS it is important to note that there were some differences in the p(sw) across these four experiments. In Experiment 1b individuals had higher levels of switching compared to the other experiments. When a subsample of high switchers was used in the p(sw) analysis for Experiment 1a (see Appendix B) the pattern of effects was identical to that seen in Experiment 1b. This suggests that individuals who switch at high rates in the VTS procedure may be adopting different strategies for guiding task choice.

According to Monsell and Mizon (2006), individuals can adopt a task-updating processing mode or a task-monitoring mode when in an EITS. Which mode of processing an individual adopts appears to be sensitive to the probability of switching in a given task-switching environment. When an individual expects to switch tasks often they adopt an inhibitory, or task updating, mode of processing. In this mode of processing the individual inhibits the just executed task set in order to prepare the new task set because it is most likely to be required on the next trial. . On the other hand, if an individual does not expect high levels of switching they may be encouraged to maintain the previous task set. This task-maintenance mode shifts the emphasis from inhibiting the previously executed task set to the maintenance of that task set because the individual has the expectation that the previous task set is likely to repeat. These different strategies are likely to emphasize different components of the multi-component working memory model and may explain the different pattern of interactions between stimulus type and concurrent load when switching levels are higher.

The idea that task choice in VTS may depend on the processing mode adopted by the participant is supported by individual differences work. Mayr and Bell (2006) reported that individuals with high switching rates demonstrated a selective slowing of repeat task reaction times. They interpreted their data as evidence that individuals who switched often adopted a *discrete-event approach,* a strategy that entails treating each trial as a singular event. In this view, individuals actively inhibit the previous task set allowing for more frequent task switching and slowing reaction times when a task is repeated. This is similar to the idea proposed by Monsell and Mizon (2006), but applied to VTS rather than EITS.

Individual differences in the strategies adopted to support task choice in VTS may also explain why Butler, Arrington and Weywadt (2010) failed to find reliable correlations between a variety of task choice metrics and working memory, but did find relationships between task performance and working memory. The authors interpreted this as evidence that individuals with higher levels of working memory may be better able to instantiate new S-R maps, but this did not translate to differences in task choice performance. Like this work, they noted that factors such as stimulus type, stimulus availability and time to prepare all affected task choice, but did so fairly independently. They proposed that task choice may depend on the relative impact of any one of these factors at the point of decision and related this to models of task-switching that allow for the influence of multiple independent parameters. The data from these experiments are compatible with this view.

6.2 Task Performance

Unlike task selection metrics, the task performance metric of reaction time was affected by the load conditions differently when the RSI was fixed (Experiments 2 and 3) compared to variable (Experiments 1a and 1b). Only when the RSI was variable did the transition type interact with load to affect reaction times. Interestingly, when the RSI was variable there was a reduction in switch costs, but the effect was driven by a speeding of switch trial reaction times under articulatory suppression compared to the no load condition.

It is possible that this is the result of a speed/accuracy trade off, but the results of Experiment 1b complicate this interpretation. Compared to Experiment 1a, in Experiment 1b individuals were 4.1% more accurate for switches under an articulatory suppression load. Thus in Experiment 1b, overall switch trial accuracy was higher than in Experiment 1a, but the speed up in reaction times was more pronounced (45 ms difference in Experiment 1a, compared to an 89 ms difference in Experiment 1b). Granted, it is tenuous to make comparisons across experiments, especially if VTS is sensitive to the strategies adopted by the participant, but the pattern suggests that a speed/accuracy trade off may not account for the faster switch trial reaction times observed under articulatory suppression in Experiments 1a and Experiment 1b.

The different effect of articulatory suppression on reaction times under variable and fixed RSIs supports the view that individuals may adopt different strategies for executing task choice in the VTS procedure. This is important, in part, because many

VTS studies often use a consistent, or predictable, RSI (e.g., Mayr & Bell, 2006; Demanet et al., 2010). Only when the RSI was fixed (Experiment 2 and Experiment 3) did the expected effect of load occur, i.e., reaction times for switch trials were slowed when individuals performed a concurrent articulatory suppression task. Although this may be the result of a speed-accuracy trade-off, it highlights that our interpretation of how switch costs are generated may need to be reviewed with more caution. This is in line with work by Liefooghe, Demanet and Vandierendonck (2008) that found reductions in switch costs at long inter-trial intervals compared to short inter-trial intervals, an effect that was the same regardless of manipulating this interval within-subjects or between-subjects.

Compared to previous work with articulatory suppression and task switching, this work similarly demonstrates that the phonological loop is important for supporting the instantiation of a new task set when the environment does not directly cue the relevant task. This is important because it supports the view that task performance in VTS relies on resources of the phonological loop to maintain S-R maps until the presentation of the new stimulus appears and final step of reconfiguration can occur much like EITS. A more interesting point, however, is that this conclusion supports the view that cued-task switching does not capture features of endogenous control when the stimulus directly identifies the relevant task set (Logan & Bundesen, 2003). This is a vital piece of evidence that VTS does measure processes that are distinct from processes involved in directly-cued EITS.

6.3 Theoretical and Practical Implications

These data support the view that both task choice parameters and task performance parameters are affected by a combination of bottom-up and top-down influences (Arrington, 2008; Mayr & Bell 2006; Meiran, 2000, Rubinstein, Meyer & Evans, 2001; Ruthruff, Remington, & Johnston 2001). One example of a model that dissociates task choice process from task performance processes is the Executive Control Theory of Visual Attention (ECTVA) model (Logan & Gordon, 2001). According to the model, working memory is involved in dual-task performance in two ways. First, working memory is involved in maintaining goal-level instructions (e.g., *perform the parity task)*. Second, working memory is involved in controlling how these goal-level instructions are translated into control at the task-parameter level. This distinction may explain why task choice and task performance metrics are differentially affected by articulatory suppression, RSI and stimulus type.

ECTVA was intended to explain EITS, but can be extended to VTS environments when one assumes that the bias parameter is not dictated by the environment in VTS. Of the four parameters of the model, the bias parameter, β, is important to VTS because this parameter is thought to control the activation of the currently relevant categorization rules (e.g., the rules for making a parity categorization). This parameter is independent of the stimulus environment and influences task outcomes by supporting either a task-maintenance mode of processing or a task updating mode. For example, an individual who adopts a task-maintenance mode of processing might set β to favor the previously performed task making it more likely that they will repeat tasks. On the other hand, an individual who sets β to update the task set trial-to-trial (e.g. a task updating mode), will be more likely to switch tasks.

Although speculative, if we consider that individuals in VTS environments use processes similar to those proposed in ECTVA we can account for differences observed across the four experiments. ECTVA can also explain differences observed within experiments for task choice and task performance metrics. For example, when individuals set the β to update tasks trial-to-trial, they may recruit additional resources of working memory to support the process of updating.

Extended to more real world decision-making and task-switching situations, these results suggest that verbal resources are useful to for voluntary control over behavior that relies on activating goal-relevant task sets. This is especially the case when factors in the task environment bias goal-incongruent tasks (e.g., stimulus repetitions). Furthermore, verbal distraction might be especially detrimental for executing goal-directed behavior because it interferes with the instantiation of new goals

Verbal distraction can come in many forms, but one form that is especially relevant for day-to-day performance is verbal distraction that originates from reflection and our inner narrative (e.g., talking to yourself or allowing your mind to wander). As one's mind wanders, this work suggests that one's behavior may be more influenced by the environment. Take, for example, the first few times one enters a new password to access email. If one is waiting for an important e-mail about a recently submitted manuscript, attention may be redirected from the task at hand to task-irrelevant thoughts about the potential correspondence. In this case, the environment may offer multiple cues that have been linked to a previous password, but not the correct one. The surprise, however, occurs when they expect to see their inbox but they get an error message instead. Granted, this work suggests that this is the effect of simply doing more than one thing at a time, but it also suggests that passive task-irrelevant thoughts can interfere with goal-directed behavior.

6.4 Limitations and Future Directions

The sensitivity of VTS to the task-environment established by the experimenter should not be understated as a factor to consider when interpreting these conclusions (Liefooghe, Demanet & Vandierendonck, 2010). The possibility that individuals use different components of working memory to support different features of task switching in a multitasking environment is supported by the ECTVA model mentioned above (Logan & Gordon, 2001), and could cause problems for replicating effects across experiments as well as labs.

Individuals may adopt different processing modes to support VTS task choice supporting the view that the cognitive processes involved in VTS likely depend on the individual's understanding of the goal level instructions. As mentioned above, some individuals may place more emphasis on maintaining the most recently performed task in an effort to guide "random" task choice and, inadvertently, present with lower levels of switching. Similarly, others might outsource this control to the environment, allowing features of the stimulus to bias task choice more so than the previously performed task.

The task environment itself is one source of information that could affect the way an individual represents the task-level instructions in VTS. For example, Demanet et al. (2010) observed switching behavior across 12 trials while the average block length in the studies reported here is 60 trials. It is possible that the probability of switching in VTS would differ with longer and shorter "runs" and may help explain why Demanet et al. (2010) observed higher rates of switching compared to the rate of switching seen in Experiment 1a, Experiment 2 and Experiment 3. If individuals have different task level representations of "random" that are based on the length of the VTS block, they may engage different strategies to achieve those levels which may translate to different parameter level settings.

Future studies should systematically investigate how task level and parameter level manipulations affect the mode of processing adopted by individuals in the VTS environment. If task choice is not assumed to occur on each trial, then it is especially important to understand the conditions that result in the different modes of processing. For example, many researchers agree that acts of self-control can impact the efficacy of future acts of self-control (Baumeister, 2002). Constantly using central executive resources might be too demanding for an extended block of VTS trials especially when there are multiple blocks (Inzlicht & Gutsell, 2007).

In conclusion, goal-directed behavior involves multiple systems of working memory. The link between language, intention and behavior has a lengthy and controversial history (Haggard, 2008; Libet, 1985), and it is unlikely that any one study will be able to resolve how individuals use language to influence complex behavior. It is quite likely that the processes involved in an inner narrative (e.g., worry or planning, are far more complex than the processes involved in simply repeating "the" aloud. Although this work cannot speak to these higher level issues, the work reflects an initial step towards understanding how a novel task switching environment, VTS, can offer insight into the verbal contributions to goal-directed behavior.

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Tables:

Table 1

Probability of Switching as a function of Load, RSI and Stimulus Type

	RSI			
	100ms *M (SE)*	500ms *M (SE)*	900ms *M (SE)*	1300ms *M (SE)*
Experiment 1a (N=75)				
No Load				
Stimulus Repeated	.232 (.032)	.234 (.026)	.286 (.024)	.298 (.022)
Stimulus Changed	.273 (.021)	.306 (.019)	.349 (.020)	.356 (.020)
Articulatory Suppression				
Stimulus Repeated	.159 (.026)	.196 (.023)	.198 (.019)	.246 (.025)
Stimulus Changed	.229 (.020)	.265 (.019)	.297 (.019)	.309 (.018)
Experiment 1b (N=32)				
No Load				
Stimulus Repeated	.419 (.045)	.422 (.041)	.383 (.037)	.438 (.038)
Stimulus Changed	.418 (.031)	.445 (.025)	.482 (.027)	.482 (.029)
Articulatory Suppression				
Stimulus Repeated	.306 (.049)	.307 (.042)	.337 (.035)	.353 (.036)
Stimulus Changed	.359 (.030)	.395 (.031)	.429 (.028)	.441 (.031)

Table 2

Reaction Time (ms) as a function of Load, RSI and Transition Type for Experiment 1a and Experiment 1b

	RSI			
	100ms *M (SE)*	500ms *M (SE)*	900ms *M (SE)*	1300ms *M (SE)*
Experiment 1a (N = 61)				
No Load				
Task Repeated	803 (25)	773 (21)	764 (20)	793 (23)
Task Switched	1076 (30)	968 (27)	928 (30)	919 (28)
Switch Costs	**273**	**195**	**164**	**126**
Articulatory Suppression				
Task Repeated	810 (22)	768 (21)	771 (19)	811 (19)
Task Switched	1021 (27)	898 (26)	881 (28)	894 (26)
Switch Costs	**211**	**130**	**110**	**83**
Experiment 1b (N = 32)				
No Load				
Task Repeated	822 (34)	781 (29)	743 (31)	770 (28)
Task Switched	1028 (44)	966 (45)	888 (45)	884 (41)
Switch Costs	**206**	**185**	**145**	**114**
Articulatory Suppression				
Task Repeated	772 (34)	756 (35)	757 (35)	764 (30)
Task Switched	939 (35)	890 (37)	859 (39)	828 (37)
Switch Costs	**167**	**134**	**102**	**64**

Table 3

Reaction Times (ms) as a function of RSI and Task Transition for Experiment 1a and Experiment 1b

	RSI			
	100ms *M (SE)*	500ms *M (SE)*	900ms *M (SE)*	1300ms *M (SE)*
Experiment 1a (N=61)				
Task Repeated	806 (22)	770 (19)	767 (17)	801 (18)
Task Switched	1048 (26)	933 (24)	904 (25)	906 (24)
Switch Costs	**242**	**163**	**137**	**105**
Experiment 1b (N=32)				
Task Repeated	797 (31)	769 (29)	750 (29)	767 (27)
Task Switched	983 (38)	928 (39)	873 (40)	856 (38)
Switch Costs	**186**	**159**	**122**	**89**

Table 4

Accuracy as a function of RSI, Load and Task Transition for Experiment 1a and Experiment 1b

	RSI			
	100ms *M (SE)*	500ms *M (SE)*	900ms *M (SE)*	1300ms *M (SE)*
Experiment 1a (N=61)				
No Load				
Task Repeat	99.7% (.001)	99.5% (.002)	99.5% (.002)	99.2% (.002)
Task Switch	87.6% (.015)	87.3% (.014)	88.9% (.014)	89.3% (.012)
Switch Cost	**12.1%**	**12.2%**	**10.6%**	**9.9%**
Articulatory Suppression				
Task Repeat	98.1% (.005)	98.0% (.006)	98.0% (.003)	97.8% (.007)
Task Switch	84.4% (.013)	78.8% (.017)	79.3% (.015)	80.4% (.016)
Switch Cost	**13.7%**	**19.2%**	**18.7%**	**17.4%**
Experiment 1b (N=32)				
No Load				
Task Repeat	98.6% (.005)	99.3% (.004)	99.3% (.003)	99.4% (.004)
Task Switch	93.7% (.012)	92.7% (.011)	93.1% (.014)	93.2% (.012)
Switch Cost	**4.9**%	**6.6**%	**6.2**%	**6.2**%
Articulatory Suppression				
Task Repeat	99.1% (.003)	99.2% (.003)	98.0% (.006)	98.3% (.005)
Task Switch	89.8% (.015)	86.7% (.018)	88.7% (.013)	86.9% (.017)
Switch Cost	**9.3**%	**12.5**%	**9.3**%	**11.4**%

Table 5

Probability of Switching as a function of Load, Stimulus Type and RSI for Experiment 2 (N = 37)

	RSI			
	100ms *M (SE)*	500ms *M (SE)*	900ms *M (SE)*	1300ms *M (SE)*
No Load				
Stimulus Repeated	.141 (.032)	.211 (.027)	.237 (.036)	.303 (.033)
Stimulus Changed	.279 (.026)	.302 (.025)	.320 (.023)	.363 (.023)
Articulatory Suppression				
Stimulus Repeated	.128 (.023)	.132 (.024)	.216 (.021)	.211 (.032)
Stimulus Changed	.243 (.025)	.233 (.022)	.297 (.025)	.329 (.025)

Table 6

Reaction Time (ms) as a function of Load, RSI and Task Transition for Experiment 2 (N = 37)

	RSI			
	100ms	500ms	900ms	1300ms
	M (SE)	*M (SE)*	*M (SE)*	*M (SE)*
No Load				
Task Repeated	729 (20)	672 (23)	653 (19)	673 (23)
Task Switched	1036 (42)	848 (37)	768 (35)	787 (35)
Switch Costs	**307**	**176**	**115**	**114**
Articulatory Suppression				
Task Repeated	732 (21)	710 (22)	749 (27)	777 (23)
Task Switched	1037 (41)	890 (38)	847 (35)	876 (35)
Switch Costs	**305**	**180**	**98**	**99**

Table 7

Accuracy as a function of Load, Task Transition and RSI for Experiment 2 (N=37)

	RSI			
	100ms *M (SE)*	500ms *M (SE)*	900ms *M (SE)*	1300ms *M (SE)*
No Load				
Task Repeated	98.9% (.003)	99.1% (.003)	99.2% (.002)	99.4% (.003)
Task Switched	86.0% (.016)	85.7% (.015)	86.3% (.013)	88.2% (.011)
Switch Costs	**12.9%**	**13.4%**	**12.9%**	**11.2%**
Articulatory Suppression				
Task Repeated	98.6% (.003)	97.5% (.005)	98.5% (.004)	98.5% (.004)
Task Switched	80.7% (.020)	76.3% (.019)	82.1% (.017)	84.5% (.018)
Switch Costs	**17.9%**	**21.2%**	**16.4%**	**14.0 %**

Table 8

Probability of Switching as a function of RSI, Stimulus Type and Load for Experiment 3 (N=49)

	RSI	
	500ms *M (SE)*	1300ms *M (SE)*
No Load		
Stimulus Repetition	.263 (.024)	.294 (.024)
Stimulus Changed	.355 (.022)	.420 (.021)
Foot-Tapping		
Stimulus Repetition	.188 (.024)	.272 (.023)
Stimulus Changed	.346 (.022)	.390 (.018)
Articulatory Suppression		
Stimulus Repetition	.181 (.023)	.246 (.023)
Stimulus Changed	.291 (.022)	.344 (.021)

Table 9

Reaction Time (ms) as a function of concurrent load and RSI for Experiment 3 (N=49)

	RSI	
	500ms *M (SE)*	1300ms *M (SE)*
No Load		
Task Repeated	698 (21)	728 (21)
Task Switched	829 (31)	801 (28)
Switch Costs	**131**	**73**
Foot-Tapping		
Task Repeated	771 (24)	838 (25)
Task Switched	900 (31)	860 (26)
Switch Costs	**129**	**22**
Articulatory Suppression		
Task Repeated	737 (23)	813 (28)
Task Switched	868 (34)	896 (32)
Switch Costs	**131**	**83**

Table 10

Accuracy as a function of concurrent load and RSI for Experiment 3 (N=49)

	RSI	
	500ms *M (SE)*	1300ms *M (SE)*
No Load		
Task Repeated	99.5 % (0.2)	99.8% (0.1)
Task Switched	89.5% (1.5)	92.2% (1.1)
Switch Costs	**10.0%**	**7.6%**
Foot-Tapping		
Task Repeated	98.7% (0.3)	99.7% (0.1)
Task Switched	86.2% (1.5)	90.2% (1.1)
Switch Costs	**12.5%**	**9.5%**
Articulatory Suppression		
Task Repeated	98.8% (0.3)	99.2% (0.2)
Task Switched	83.5% (1.7)	87.1% (1.4)
Switch Costs	**15.3%**	**12.1%**

Figures:

Figure 1. Probability of Switching as a function of Load and RSI for Experiment 1a and Experiment 1b (error bars are standard errors).

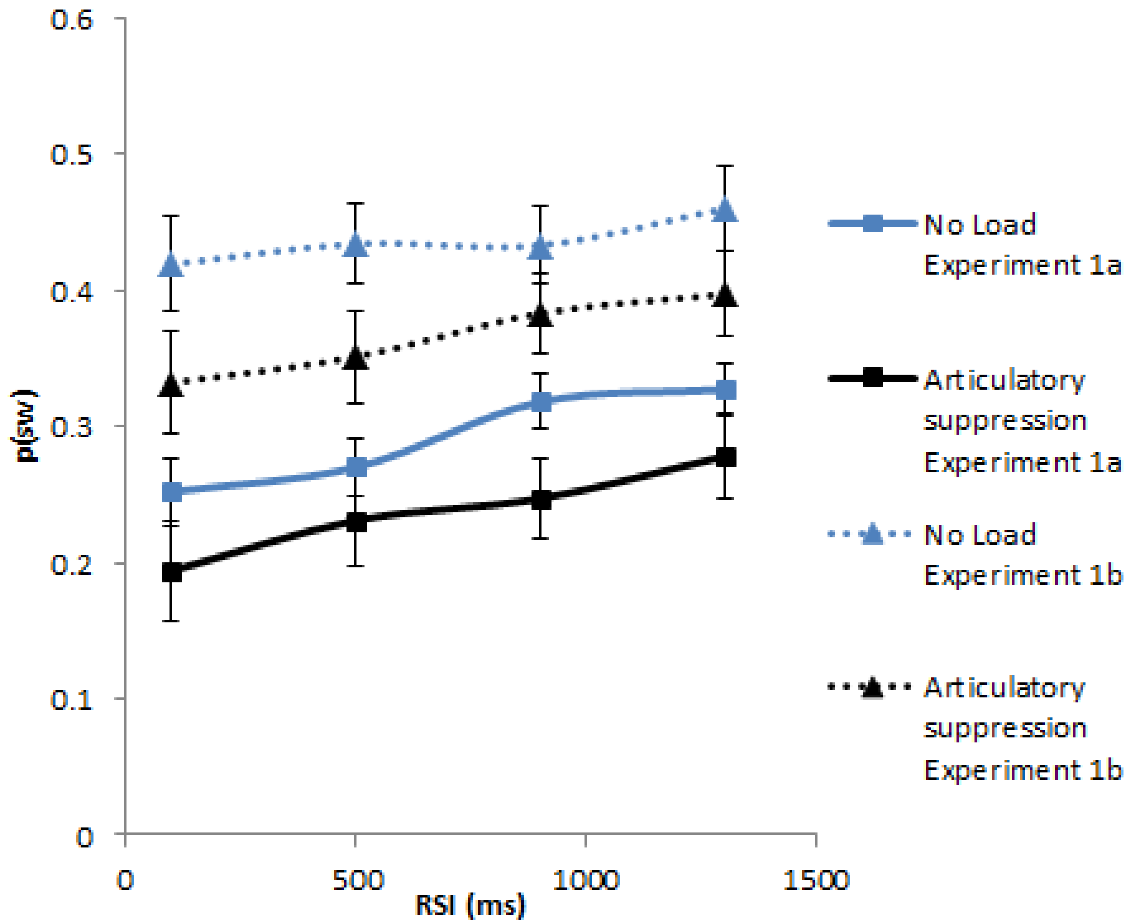


Figure 2. Reaction Time (ms) as a function of RSI and Task Transition for Experiment 1a (error bars are standard errors).

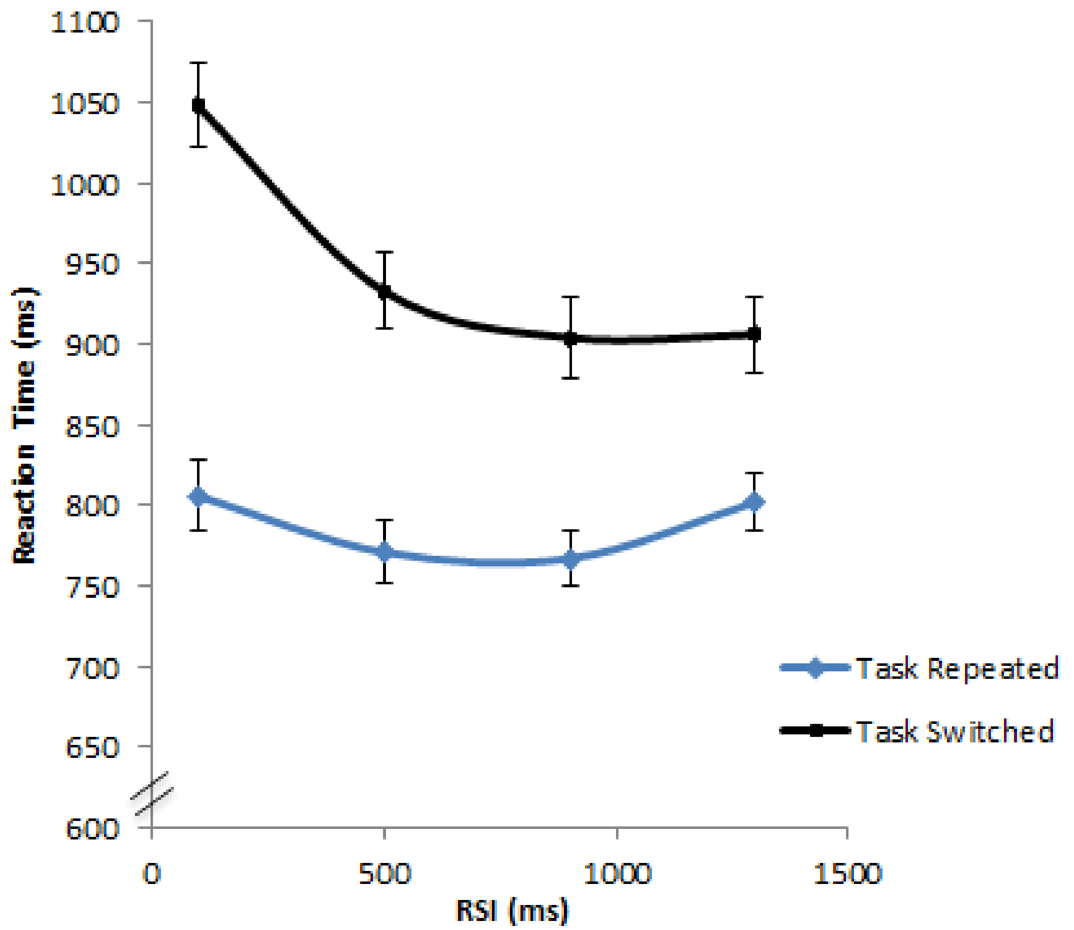


Figure 3. Reaction Time (ms) as a function of Load and Task Transition for Experiment 1a and Experiment 1b (error bars are standard errors).

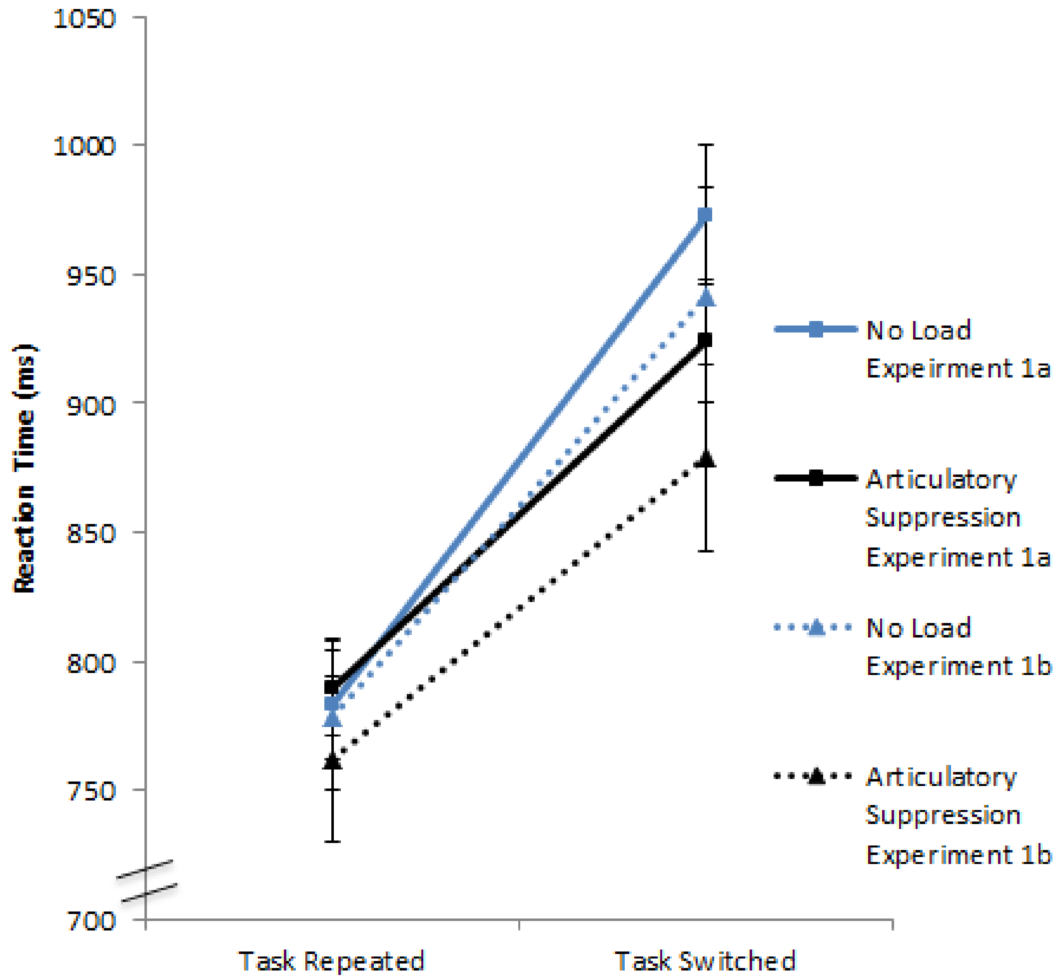


Figure 4. Probability of Switching as a function of Load and Stimulus Type for Experiment 1b (error bars are standard errors).

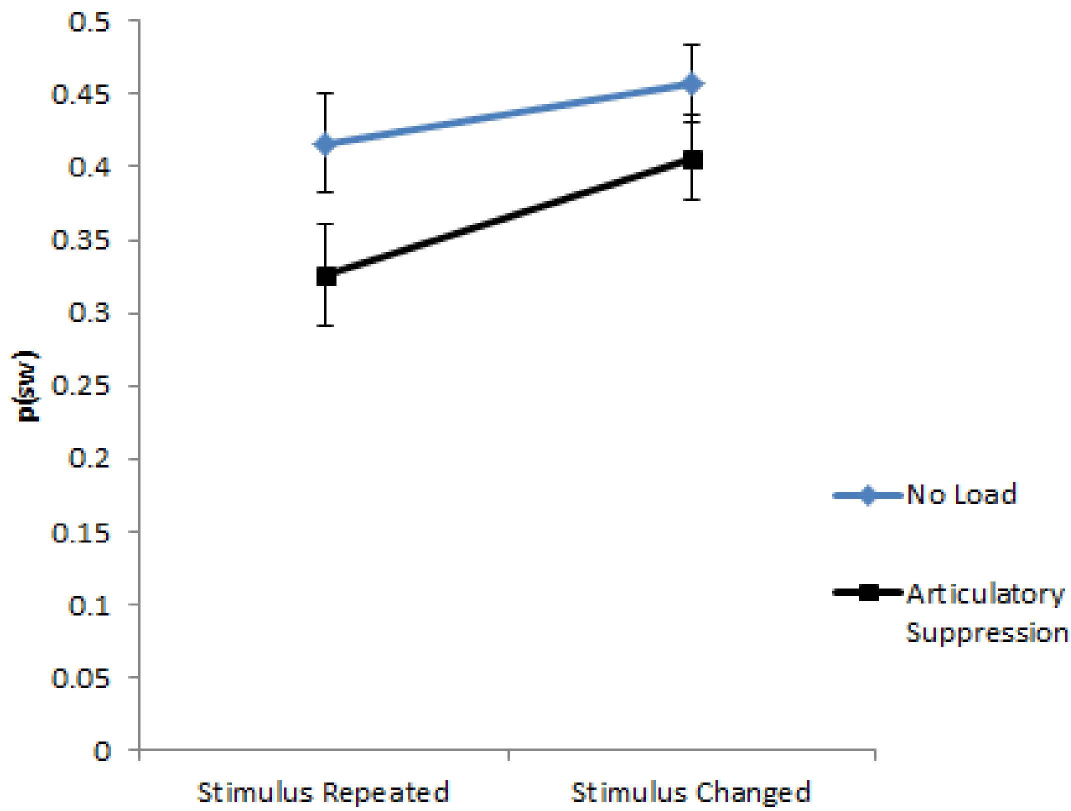


Figure 5. Accuracy as a function of Load and Task Transition for Experiment 1b (error bars are standard errors).

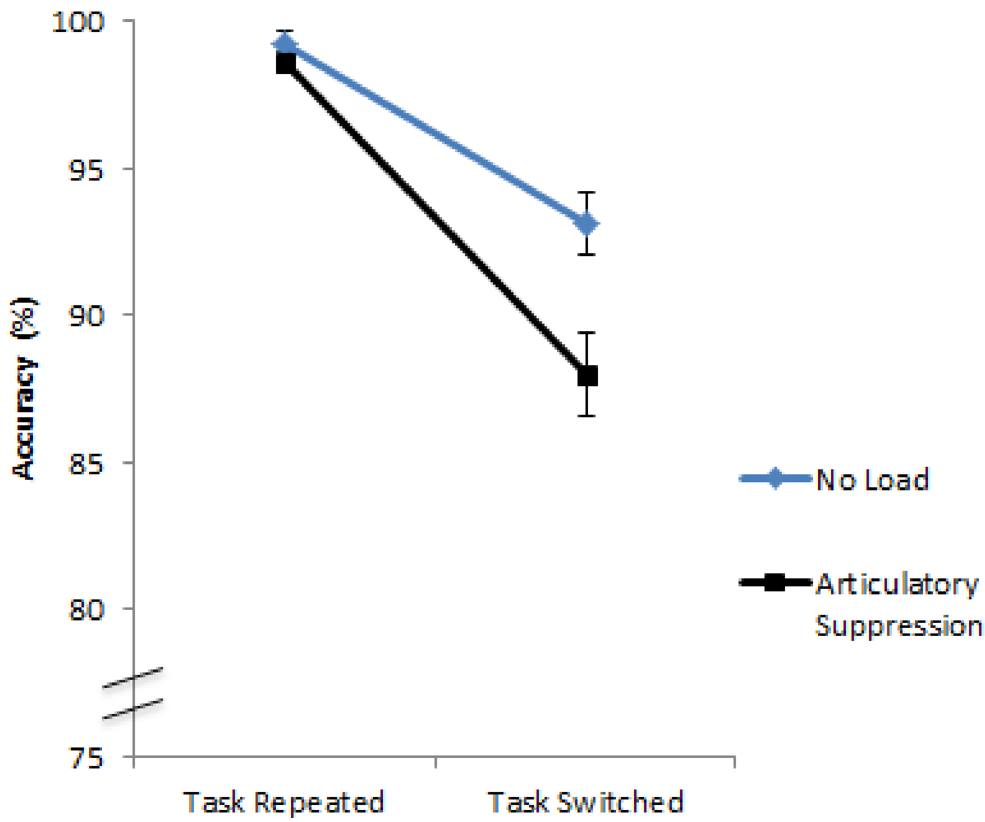


Figure 6. Probability of Switching as a function of Load and RSI for Experiment 2 (error bars are standard errors).

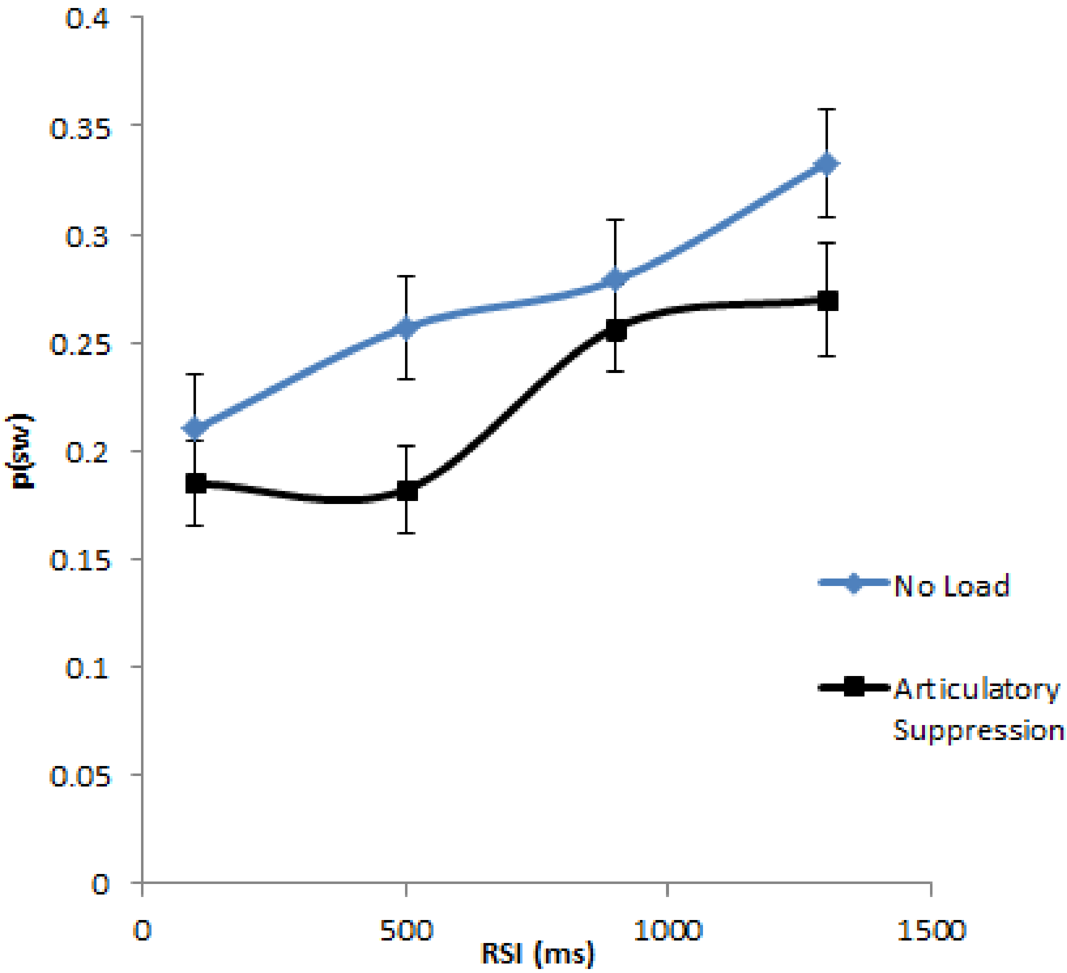


Figure 7. Reaction Time (ms) as a function of RSI and Load for Experiment 2 (error bars are standard errors).

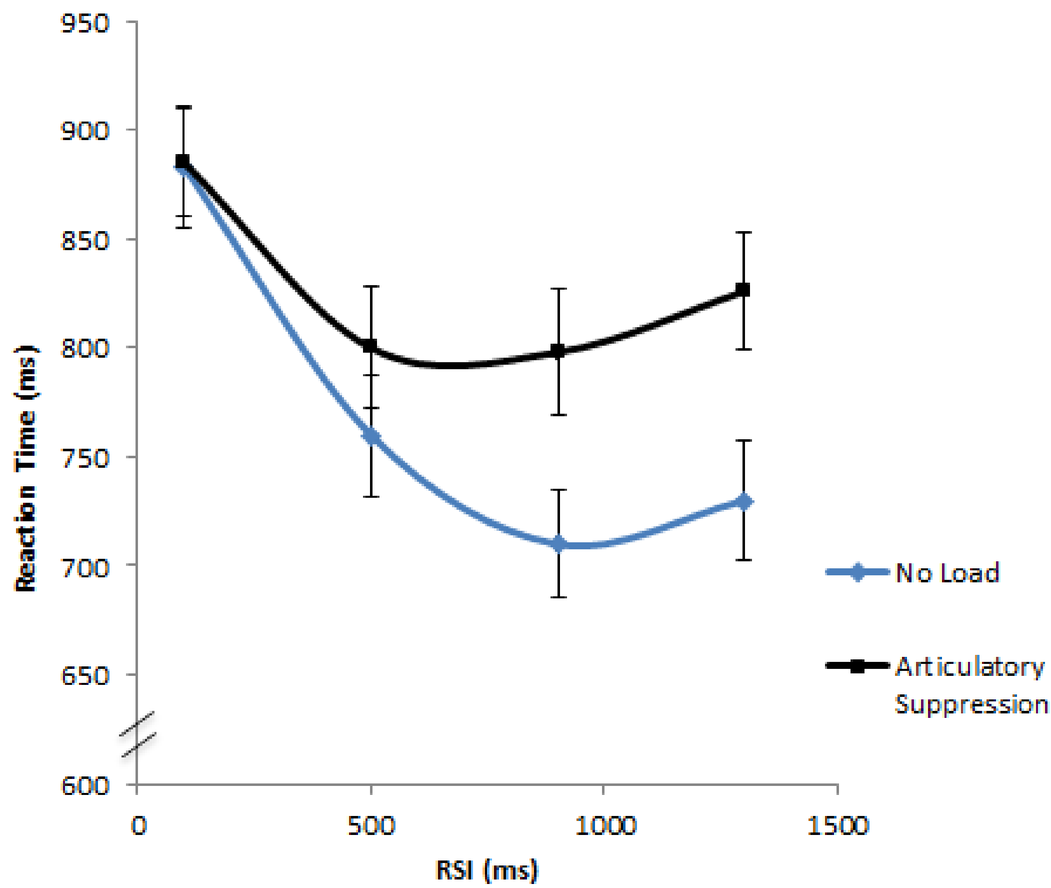


Figure 8. Reaction Time (ms) as a function of the RSI and Transition Type for Experiment 2 (error bars are standard errors).

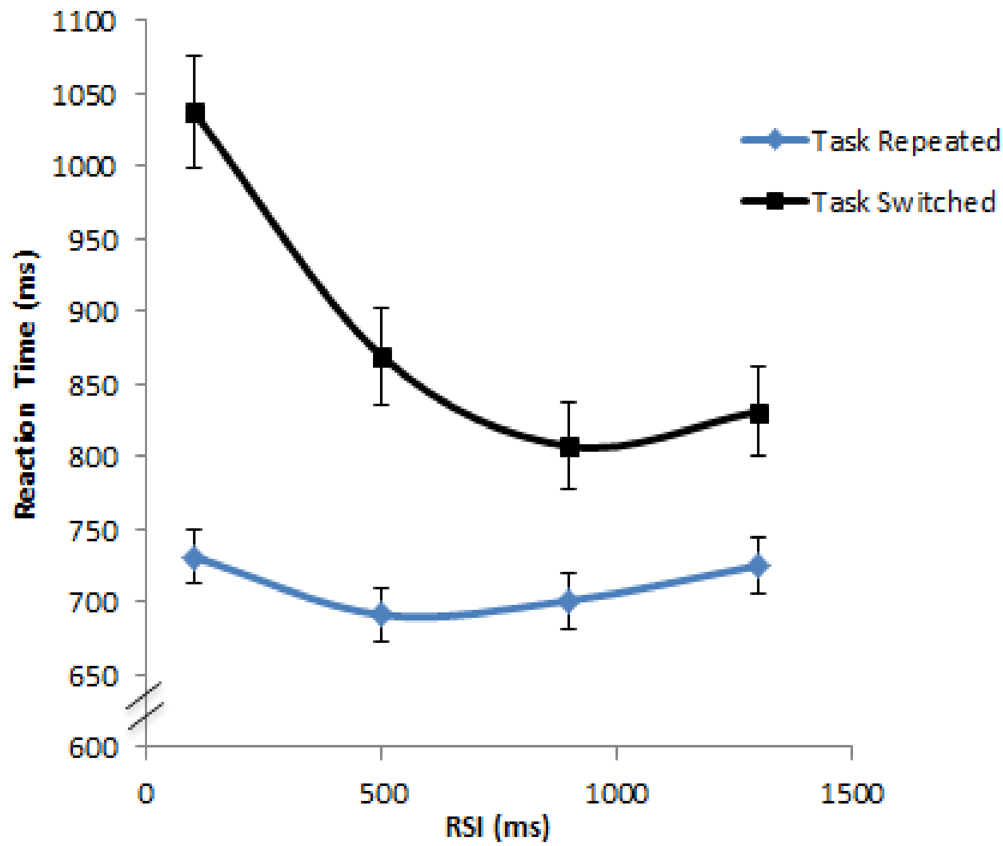


Figure 9. Probability of Switching as a function of Load and Stimulus Type for Experiment 3 (error bars are standard errors).

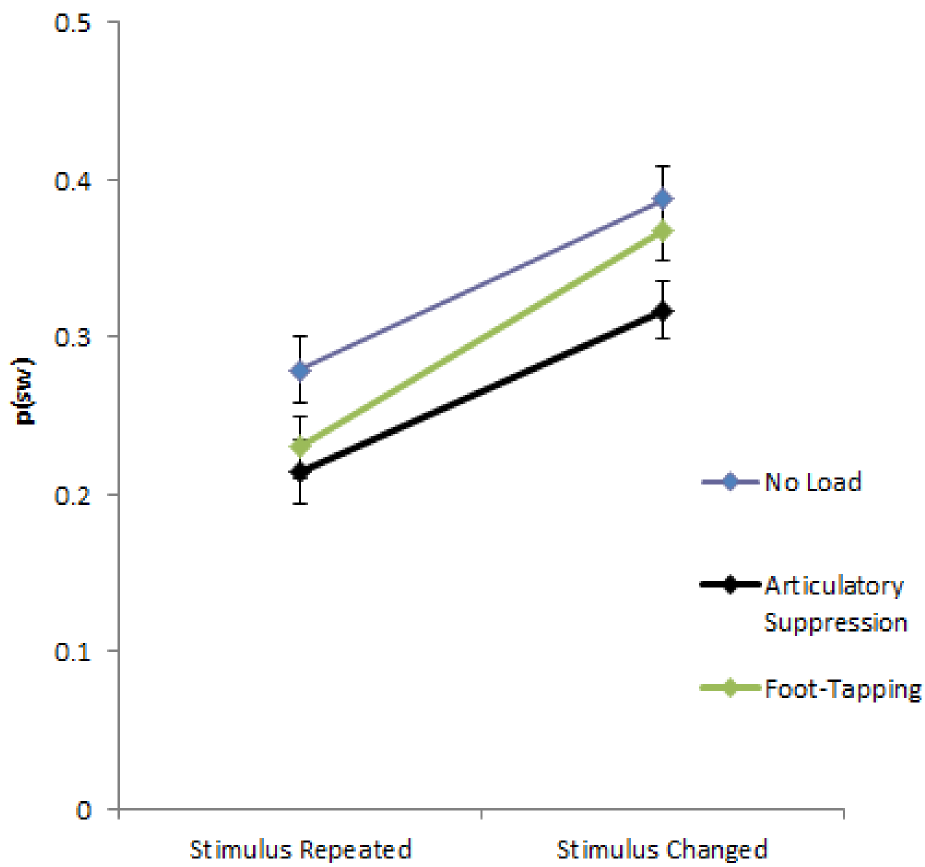
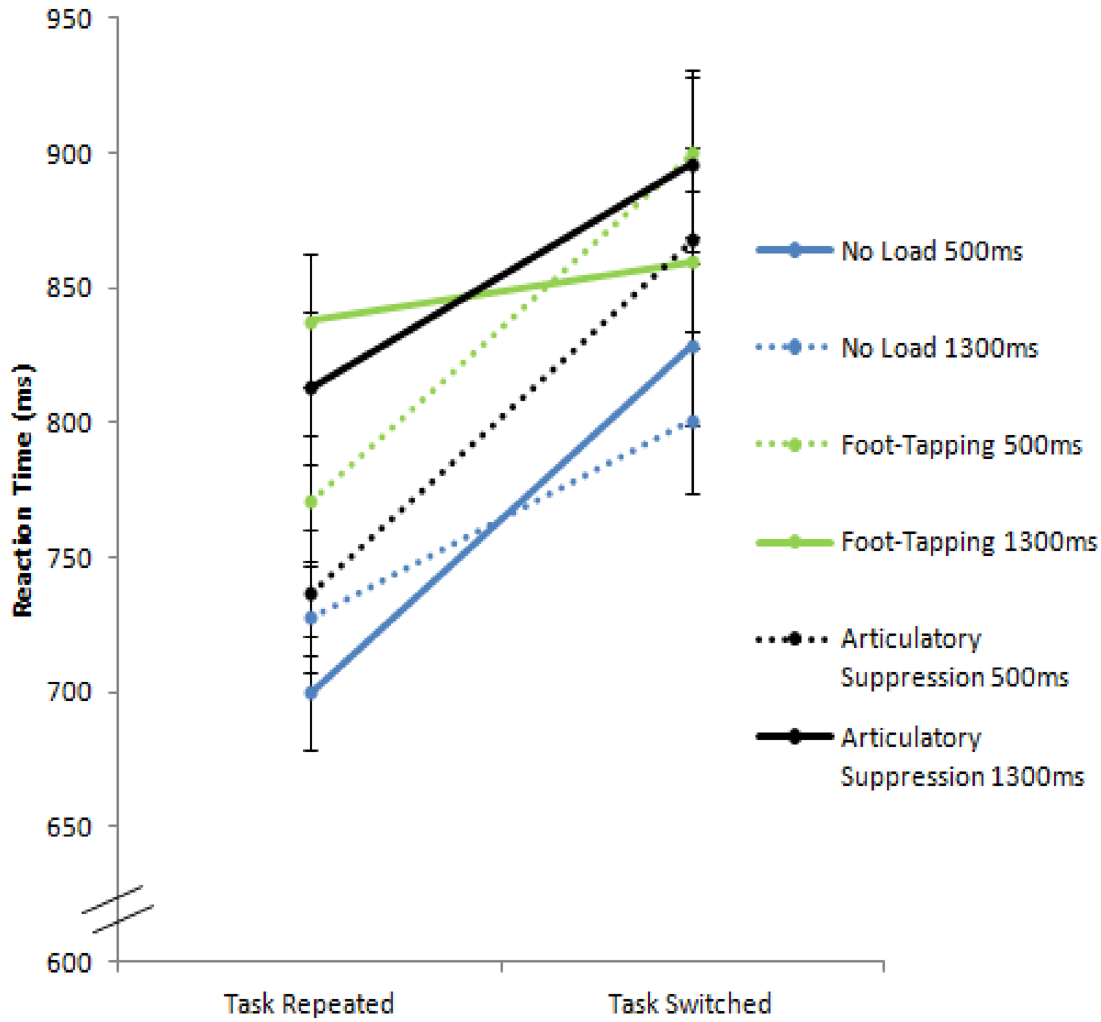


Figure 10. Reaction Time (ms) as a function of Load and Transition Type for Experiment 3 (error bars are standard errors).



Appendix A

Subject Data Form *Experiment:* _________________

Please answer the following questions to the best *Subject Number:* _____________

of your knowledge. All responses will be kept *Today's Date:* ____/____/______

strictly confidential.

Year of Birth: _________

Current Age: ________

Gender: ___ Male ___ Female

Educational History:

What is the highest grade level you achieved in formal schooling?

____

Racial/Ethnic Origin (please choose all that apply):

___ I do not choose to indicate
___ Asian or Pacific Islander
___ Hispanic
___ Other or Unknown
___ Black (not Hispanic)
___ American Indian or Alaskan Native
___ White (not Hispanic)

Health Status:

How would you rate your overall health at this time? (please check one)

___ Excellent ___ Good ___ Fair ___ Poor ___ Not Sure

Have there been any recent changes in your health status (e.g., stroke, hypertension, diabetes, etc.)?

____

What medications do you take regularly?

____

Have you ever been diagnosed with a learning disability (e.g., attention-deficit disorder)?

____

If yes, please elaborate.

____

In the last 5 years have you been treated for issues relating to mental health?

____

If yes , please elaborate.

____

Appendix B

Data analysis with the subset of high switchers for Experiment 1a:

We did not find the interaction between stimulus repetition and secondary load that Demanet et al. (2010) observed. It is possible that the VTS data analysis was complicated by a surprisingly low probability of switching. Low probability of switching reduces the number of observations per experimental condition. To understand if the pattern of results observed in the first experiment was affected by the low switching probability in Experiment 1a, the above analyses of p(sw) was re-run including only those individuals in the sample with a mean probability of switching higher than 32%. This sample (n=30) reflected just under half of the overall sample (n= 75).

Probability of Switching for High Switchers

The p(sw) data for the highest switching sub-sample was submitted to a 2 (load: concurrent articulatory suppression or no concurrent load) by 4 (variable RSI: 100ms, 500ms, 900ms, 1300ms) by 2 (stimulus type: the stimulus repeated or the stimulus changed) within subjects ANOVA.

Like in the full sample analysis, there was a main effect of load, $F(1, 29) = 12.7$, $p = .002$, $\eta_p^2 = .305$ and stimulus type, $F(1, 29) = 10.5$, $p = .004$, $\eta_p^2 = .266$. Concurrent articulatory suppression decreased the probability that an individual would switch tasks by approximately 8%. Individuals were less likely to switch tasks if the stimulus repeated (M=37.9%) compared to when the stimulus changed (M=45.7%). Also, by restricting the sample to more frequent switchers, the two-way interaction was revealed, F (1, 29) = 6.01, $p = .02$, $\eta_p^2 = .172$ When performing a concurrent articulatory suppression individuals were significantly more likely to repeat a task if the stimulus repeated.

In the restricted sample, there was no main effect of preparatory interval (F=1.7). No other interactions were significant (all Fs< 2.3).