AN INDIVIDUAL DIFFERENCES APPROACH TO INVESTIGATE TASK-SWITCHING AND ITS RELATIONSHIP TO MEDIA MULTITASKING

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ABSTRACT

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While multitasking with media has increased dramatically in recent years (Rideout, Foehr, & Roberts, 2010), the association between media multitasking and cognitive performance is poorly understood. In addition, the literature on the relationship between media multitasking and task-switching, one measure of cognitive control, has produced mixed results (Alzahabi & Becker, 2013, Minear, et al., 2013; Ophir, Nass, & Wagner, 2009). The goal of this work was to examine the relationship between media multitasking and task-switching performance. However, in order to do so, we began by first examining the structure of task-switching and identifying the factors that contribute to switch costs. We used an individual differences approach to evaluate how the different putative mechanisms (advanced preparation, passive decay, attentional filtering, and response conflict resolution) are related to task-switching performance. Participants performed a series of three different task-switching paradigms, each designed to isolate the effects of a specific putative mechanism (e.g., advanced preparation). For each paradigm, participants completed three blocks of trials, each with a different classification task and different stimuli (animal/furniture, number/letter, and plant/transportation classification tasks). The use of these three different types of classifications within the same paradigms allowed us to perform a latent variable analysis using structural equation modeling to examine the fit of a model that captures the inter-relationship between these

putative factors within an individual. Participants also completed a series of surveys to measure media multitasking and (fluid and crystallized) intelligence.

The results suggest that task-switching performance is related to two somewhat independent factors, namely an advanced preparation factor and passive decay factor. This two-factor model provided best fit for both reaction time and error data. We found no support for the putative attentional filtering and response conflict resolution factors being related to an individual's task-switching performance. In addition, multitasking with media was related to a faster ability to prepare for tasks, resulting in faster taskswitching performance without a cost to accuracy. Fluid intelligence was associated with slower task-switching ability, but higher task-switching accuracy. This indicates that fluid intelligence may allow one to recognize the need to prepare for a task-switch, causing one to slow down and effectively prepare for a task-switch, which in turn, improves accuracy. Media multitasking and intelligence were both less related to passive decay factors. These findings are consistent with a two-component model of taskswitching (Sohn & Anderson, 2001), as well as an automatic/executive framework of cognitive control (Shneider & Shiffrin, 1977).

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CHAPTER 1. INTRODUCTION

Media use has become one of the most prevalent activities of the current decade. Much of this is due to the increasing accessibility and portability of technologies. The speed and scope of the shift in media use can be appreciated when one considers that over a span of just eight years, the number of online U.S. adults who use social media has risen from 8% to 72% (Brenner & Smith 2013). The number of Facebook users, for example, rose from around 1 million users in 2004 to 1.1 billion users by the year 2013 (Olenski, 2013). Additionally, a trend that has accompanied the rise in media use is that of media multitasking, or engaging with multiple forms of media simultaneously. This sort of activity has become increasingly common, now making it rare to find instances of an individual engaging with a single form of media (Rideout, Foehr, Roberts, 2010). Despite the pervasiveness of multitasking with media, little is known about its cognitive impacts. The questions one may begin to ask regarding this topic are both numerous and important. Also, given that prolonged exposure to an environment or the learning of new skills can lead to dramatic cortical reorganization (Blakemore, et al, 1975; Draganski & May, 2008). This striking shift offers a unique and timely opportunity to investigate the impact that media multitasking has on cognition. However, establishing the causal impacts of media multitasking on cognition is difficult given that one cannot randomly assign individuals to varying levels of media multitasking. As such, a first approach to investigating these issues would be to determine if there is a relationship between ubiquitous media multitasking and cognitive performance.

While past research has begun to address issues relevant to media use, there has

been an absence of discussion regarding how the media are being used. The reality is that rather than interacting with a single form of media at one time, more and more, media are being consumed in combination with one another (Hassoun, 2012). For instance, children and young adults switch between different media forms an average of twenty-seven times per hour of television viewing (Steinberg, 2012). Also, the tendency to multitask with media involves individuals of all ages, although youth are found to multitask more than older adults (Carrier, *et al*, 2009). Other researchers have questioned why multitasking with media has become so common. Studies have found that users interleave tasks in a way that is consistent with maximizing their marginal rate of return, which allows them to produce the greatest current benefit while performing tasks (Duggan, Johnson, & Sorli, 2013). Others have suggested that people multitask so that their emotional gratifications are met, and that this is a self-perpetuating cycle in itself (Wang & Tchernev, 2012).

Some of my earlier work on this topic examined the relationship between media multitasking and cognitive control. One way to successfully multitask is by rapidly shifting back and forth between tasks, which as a ubiquitous behavior, may impact the relationship between media multitasking and task-switching. Media multitasking involves shifting from one form of media to another, or may involve shifting between different tasks within a form of media. This sort of activity provides one with multiple opportunities to practice switching between tasks, which may generalize to improved task-switching performance. For example, one study found that action video game use resulted in a better ability to rapidly task-switch (Green, *et al*, 2012).

We performed a series of experiments that compared task-switching and dual-

task performance in heavy and light media multitaskers. We found that media multitasking was associated with an enhanced ability to switch between tasks and was not related to dual-task performance (Alzahabi & Becker, 2013). The paradigm we used involved performing a number-letter task (classifying the number as odd or oven and the letter as a consonant or vowel). The stimulus contained both a number and letter, regardless of the task being performed on that specific trial. Each trial was accompanied (experiment 1) or preceded (experiment 2) by an explicit task cue and the cue was randomly selected, thus the tasks were presented in an unpredictable sequence. The relationship we found between multitasking and task-switching was present for both univalent responding, in which each response corresponded to one button press (experiment 1), and bivalent responding, in which two responses were mapped onto one button press (experiment 2). In addition, the reduced task-switching costs were driven by faster responses during task-switch trials, rather than slower responding during repeat trials. Taken together, this pattern of results suggests that media multitasking is associated with a more efficient ability to task-switch.

However, although we report a positive relationship between media multitasking and task-switching ability, other studies report different results. For instance, Minear et al. (2013) found that heavy media multitaskers perform more poorly on measures of fluid intelligence than those who multitask with media less frequently. However, they find no differences in task-switching performance between heavy and light media multitaskers. Also, Ophir, Nass, and Wagner (2009) report that heavy media multitaskers have a decreased ability to filter irrelevant information, and more specifically, are worse at taskswitching than light media multitaskers. As such, the ultimate goal of this work is to more extensively investigate the relationship between media multitasking (MMT) and task-switching. A more nuanced investigation of the task-switching literature finds that there are multiple unique cognitive processes that have been posited to be involved in task-switching. Researchers have identified a number of potential sources such as advance preparation ability and attentional filtering ability, which may contribute to task-switching costs. In addition, these researchers seem to suggest that each of these putative processes may be unique and independent contributors to switch costs. Thus, it is possible that ubiquitous multitasking with media may have different influences on each of these processes. If so, an examination of the relationship between media multitasking and task-switching may find different results depending on which aspects of task-switching are most important in a given study.

In order to further investigate the relationship, we initially sought to determine how MMT was associated with different putative mechanisms of task-switching. Upon careful review of the task-switching literature, it became apparent that it was unclear whether these putative mechanisms were truly independent sources or if they were driven by more general cognitive processes. Most of the work investigating these sources focus on a single cognitive source, and thus, are unable to determine the extent to which these different putative mechanisms are truly independent contributors or may all be interrelated, suggesting that they may be driven by a common mechanism. As such, in order to appropriately examine the relationship between media multitasking and taskswitching, it is first necessary to investigate the structure of task-switching performance to

determine the extent to which each of these processes are unique contributors to the ability to rapidly task-switch.

To do this, the approach we developed was two-fold. First, we wanted to examine the structure of task-switching performance with the goal of identifying unique factors that contribute to task-switch costs. Second, we wanted to investigate the relationship between media multitasking and the different components of task-switching that we identified in part one. An individual differences approach will be taken to achieve both these goals. It will allow us to determine how the processes of task-switching performance are structured within an individual and also to determine how individual differences in media multitasking impact each of the task-switching processes.

1.1 Putative Mechanisms Involved in Task-Switching

1.1.1 Cognitive Control and Task-Switching

Cognitive control allows for one to respond to inputs from the environment in an appropriate and timely manner. Because the environment is dynamic and ever-changing, this often requires task-switching, or shifting from performing one task to another. Task-switching is typically associated with a switch cost, or a delayed reaction time (RT) and/or increased error rate following the switch of a task. The switch cost has traditionally been thought of as an index of the control processes involved in preparing and performing the appropriate task (Rogers & Monsell, 1995). A great deal of research has been devoted to investigating switch costs and the mechanisms that are responsible for task-switching performance. Researchers have proposed and developed multiple models to explain the empirical observations in the task-switching literature. Each of these models aims to provide a framework for understanding how our cognitive systems

ensure both stability and flexibility while dynamically shifting between tasks. However, to date there remains a lack of consensus about which model and explanations of switch costs are most appropriate. Following will be a broad overview of the different mechanisms that have been proposed and the relevant empirical support for each.

1.1.2 Advance Preparation

Early evaluations of task-switching performance suggested that switch costs arise due to the fact that switching to a new task requires some sort of active preparation process (Rogers & Monsell, 1995). This involves retrieving and reinstating the relevant task-set (Monsell, Yeung, & Azuma, 2000). A task-set was specified as including a configuration of mental resources that select and link the processes necessary to accomplish a particular task (Monsell, 2003). Primarily, this includes a representation of the stimuli, the responses, and the corresponding stimulus-response (S-R) mappings. To the extent that switch costs are associated with the need to perform this reinstatement of the appropriate task-set, providing increased time for task preparation should reduce or eliminate the switch cost.

Early studies found that reaction times were reduced when a cue was presented before the performance of a task, suggesting that individuals benefit from the opportunity to reconfigure a task-set in advance. As early as 1973, Biederman showed that cueing a participant about which type of arithmetic task they would need to perform resulted in faster RTs. Later, studies manipulated the time interval prior to the onset of a stimulus to directly examine how preparation time is related to task-switching performance. Rogers and Monsell (1995) used an alternating runs paradigm in which participants switched predictably between two tasks and examined the effect of varying the response-stimulus

interval (RSI) on switch costs. Rather than cuing each trial, participants knew which task to perform based on its current position in the run as well as the spatial position of where the stimulus appeared (this assisted participants in keeping track of their current position in the run). Switch costs decreased progressively as the RSI increased from 150 to 600 ms. The authors interpreted these findings to suggest that preparation time (as indexed by the RSI) allowed participants for more time to reconfigure for the upcoming task, which resulted in decreased switch costs.

However, a limitation to this finding is that the RSI includes two components, both decay of prior task-set as well as advanced preparation for the upcoming task. Rogers and Monsell (1995) interpreted the RSI as only a measure of advanced preparation, suggesting that the "switch cost may be securely attributed to the need to reconfigure task-set", failing to account for decay processes that may also be a component of the switch cost measure.

Accounting for this limitation, Meiran (1996) used a cued choice task to index the impact of advance preparation on task-switch performance. This provided for a more pure measure of the role of advance preparation in task-switch performance. Because the task in each trial was randomly selected and cued beforehand, one can assume that reconfiguration could not take place until the cue for the task appeared. As such, Meiran accounted for a confound present in many of the previous studies examining advanced preparation by using cues to tease apart processes related to advance reconfiguration from those of decay, which may include any carryover from the previous task. Similar to Rogers and Monsell (1995), Meiran found that prolonging the cue-stimulus interval (CSI) reduced switch costs in a spatial judgment task. Relative to Roger and Monsell's method,

Meiran's cueing paradigm did provide leverage for better isolating preparation and decay processes.

Meiran and collegues (2000; 2008) have developed models to describe how cognitive control is executed during a task-switch. Under this framework, the task-set during a task-switching paradigm with two tasks is comprised of three components: a stimulus-set and two response-sets. The stimulus-set contains the cue for the current trial, one response-set contains the relevant response set from the previous trial and the other response-set contains the irrelevant response set from the previous trial. During a task-switch, a stimulus-set must be biased toward the currently relevant task, a timeconsuming process that comprises the preparation of a task. This type of preparation is not required for task-repetition trials because the stimulus-set is already biased towards the currently relevant task. As such, the execution of a switch trial takes longer than a repeat trial. Thus, Meiran et al suggest that that this preparation phase is switch-specific, and is an extra operation that must occur only on switch trials.

As such, a simple straightforward account for the switch cost is that a switch trial requires a reconfiguration of the task-set. Under this view, increasing the CSI allows time for the new task-set to be implemented and thus reduces task-switching costs. While this straightforward explanation is possible, there are other explanations for the switch cost and influence of CSI on its magnitude. For instance, some have questioned whether preparation is switch specific. Instead, they argue that preparation is the same for switch and repeat trials, but just takes longer for switch trials (Kiesel, et al., 2010). They propose that the same task updating process occurs for both switch and repeat trials, but there is more interference on switch trials because of having had performed the

irrelevant task most recently (Koch, 2003; Koch & Allport 2006).

The first line of evidence in support of preparation being non-switch specific is that increasing preparation time leads to reduced reaction times for both switch and repeat trials (Altmann, 2004). Rather than manipulating preparation time, a number of other studies manipulated the predictability of task. These types of studies found that the benefit of task predictability was not switch specific. Performance was worse for unpredictable sequences and better on predictable sequences for both switch and repeat conditions (Dreisbach et al, 2002; Koch, 2005). Together, these studies were taken to suggest more generic preparation applied for both switch and repeat trials, rather than switch specific reconfiguration.

In addition, many studies investigating the role of preparation in task-switching have varied the CSI while failing to hold the RSI constant, thus leading to potential confounds when interpreting the data (e.g., Allport et al., 1994; Rogers & Monsell, 1995). In these studies, the cue-stimulus intervals were varied while the response-cue interval was kept constant, causing preparation time to be inherently confounded with decay of the previous task. That is, as preparation time for a task increases, the time passing after completing the previous task naturally increases as well. The patterns observed in the data that have been attributed to reconfiguration processes may in fact also be due to decay processes. Indeed, Meiran's (2000) model describes the carryover of response sets from previous trials during the processing of a task, in addition to task preparation. In one study, Meiran, Chorev, & Sapir (2000) independently manipulated the response-cue interval and the cue-stimulus interval. They found that increasing either interval reduced switch costs, suggesting that they were independent components. These findings

challenged the traditional preparation account of task-switching and urged researchers to examine if other components, such as the decay of a previous tasks, impacted switch costs.

1.1.3 Passive Decay

Therefore, another proposed source of a switch cost is that the preceding task-set is still in an active state, or more biased, when one attempts to switch to another task. Under this account, switch costs are related to the level of activation of the prior task-set. If there has been little passive decay of activation of the preceding task set the previous task may interfere with performing the current task (Allport et al., 1994; Altmann, 2005). This account of switch costs fits with the general proposition, as in the case of advanced preparation, that increasing the time between trials should decrease task-switch costs, since more time is available for decay of prior task-sets. Instead of attributing reduced switch costs at long response-stimulus intervals to having increased time to prepare for the upcoming task, it attributes them to more complete decay of prior task-sets, which leads to decreased interference for the current task.

Cognitive control model (Altmann & Gray, 2008) illustrates how the level of activation of a current task, and the activation of a previous old task, determines ones performance in terms of response times and error rates. Under this model, a task-set is represented as a code in episodic memory. These codes are formed when the system is presented with a task cue and each code has a varying level of activation. The activation of a code is represented by a density function, where code activation is most likely to be at the mean level but may also be at a higher or lower level than the mean. More recently presented task codes are in a more active state than previously presented task

codes. The retrieval threshold lies at the intersection of the density functions and acts as a filter such that only codes that are above a threshold of activation are able to produce interference. To the extent that an old code has had time to decay, it will interfere less with the current code because its level of activation has decayed and does not exceed the threshold. More specifically, the separation between the two density functions is greater such that there is less proactive interference from old codes. However, with less time to decay, more of the old code activation will be above threshold, and thus, will be more likely to be the most active control code. With less decay time and more interference from old codes, performance will be slower and less accurate.

Studies investigating passive decay as a process involved in task-switching have found that increasing the response-cue interval (RCIs), while holding the cue-stimulus interval (CSI) constant, resulted in decreased switch costs (Altmann, 2005; Meiran et al., 2000). This finding provided support for the idea that switch costs are reduced when a previous task decays because there is reduced competition when a new task-set needs to be activated on a switch trial. Similarly, Allport et al. (1994; 2000) proposed the idea of task-set inertia, in which the persisting activation of previous, but currently irrelevant information interferes with performance on the current task. Taken together, when the intertrial interval is prolonged, the size of the switch cost is reduced, suggesting that preparation for the upcoming task as well as decay of the preceding task impact taskswitch performance.

Unlike other models, this explanation of task-switching does not attribute taskswitching to cognitive control processes per se. Instead, the behavioral results suggest that task-switching is implemented through a simple property of episodic memory

representations and the patterns observed in the data can be attributed to decay processes. Switch costs are explained as being products of repetition priming rather than reconfiguration-like processes. The less decay that has occurred, the more potent repetition priming is because the episodic task codes from the previous tasks are still in the focus of attention. That is, on task-repeat trials, the episodic task code is already in an active state from the previous task, thus speeding its execution for the upcoming task. On task-switch trials, on the other hand, there is no benefit because the previous task has not primed the relevant episodic task code. Instead, the now relevant task is different from the most recently completed task, causing the retrieval of the episodic task code to take longer.

Under some accounts, the reason for switch costs is due to proactive interference of tasks (Allport et al, 1994). While the distinction between proactive interference and passive decay is unclear, it is evident that there are many parallels between these two processes. In fact, they may be undistinguishable in some cases. The less time there is for a task-set to decay from a previous trial, the more it will interfere with performance of the current task. Primary support for the interference of task-sets come from studies that have observed switch cost asymmetries when participants switched between two tasks that are of unequal strength (Allport et al., 1994; Meuter & Allport, 1999). The main finding is that switch costs are higher for the easier, more dominant task. This is explained under the assumption that stronger tasks are inhibited more when they are not relevant. The inhibition persists in the form of proactive interference, such that it takes more activation to switch back to the dominant task. Weaker tasks are suppressed less, so the after effects of switching back to the weaker task are smaller.

Nevertheless, the passive decay account of switch costs has been challenged. Horoufchin et al. (2011) argue that the observed effects are due to the temporal distinctiveness of a task. In their studies, they manipulated RCI length randomly from trial to trial. They found that decreased switch costs were not due to the absolute time of the RCI, but rather, how isolated the representation of the task is in memory (termed "temporal distinctiveness"). Temporal distinctiveness was defined as the ratio between the previous and current trial RCI. Switch costs were only reduced when a long RCI trial was preceded with a short RCI trial because the temporal distinctiveness of the task increased. As such, rather than attributing the reduction in switch costs at long RCIs to decay processes, Horoufchin et al. suggest that this effect is due to the distinctiveness of the tasks' episodic retrieval.

Until now, the efficiency of task-switching has been discussed in terms of advanced preparation and passive decay of prior task-sets. However, both of these factors cannot account for the fact that many studies find a "residual" switch cost, that is, even at long response-stimulus intervals (RSIs) there remained a small but consistent switch cost (Mayr & Kliegl, 2003; Rogers & Monsell, 1995). When the RSI increases beyond ~600 ms, it was found that there was little further reduction in switch costs. This finding became subject to many investigations, prompting researchers to propose alternative hypotheses for the source of switch costs (Kiesel et al., 2010). These hypotheses focused on the processing of a task after the cue has cleared and once the task stimulus has appeared, mainly consisting of attentional filtering and response conflict resolution mechanisms.

1.1.4 Attentional Filtering

As such, another proposed source of switch costs may stem from stimulus-based interference, or the fact that the stimulus itself can contain information that is irrelevant to the task (Kiesel et al., 2010). Attentional filtering operates to filter irrelevant information so that relevant information can be processed more effectively. The ability to constrain attention to only the task-relevant stimulus may help people effectively switch between tasks, while an inability to constrain attention to relevant stimuli might exacerbate switch costs (Kiesel, et al., 2010). This is particularly true if the irrelevant stimulus is associated with the opposite response of the relevant stimulus (i.e., an incongruent trial). However, the speed on an incongruent trial is likely a function of both the participant's ability to constrain attention to the task relevant stimuli and the ability to resolve response conflict, two processes that might interact with one another.

Thus, the processes of attentional filtering and response conflict resolution may be related. In fact, response conflict resolution is contingent on whether attentional filtering is complete or not. When there is a lack of proper attentional filtering, the irrelevant stimulus is processed and response conflict resolution will be needed to inhibit making a response to the irrelevant stimulus. More specifically, on an incongruent trial, two different responses may be activated and it is the goal of an individual to respond to only one of the stimuli. If the competing response becomes activated, then it becomes necessary to resolve this response conflict. Alternatively, on this type of trial, it can be that the competing response is never activated, that is, it is filtered out completely. These processes may operate independently such that an individual can have good or poor attentional filtering as well as good or poor response conflict resolution. While the necessity of response conflict resolution is contingent on the effectiveness of attentional

filtering, in the case when attentional filtering is complete, response conflict resolution may no longer be necessary.

A number of studies have examined the impact of attentional filtering on taskswitching performance. Rogers & Monsell (1995) conducted a study that required participants to switch between classifying digits and letters. Participants responded with a left button press for an even digit or consonant letter and a right button press for an odd digit or vowel letter. They found that RTs were fastest for univalent stimuli (afford only one task, e.g., G#) in a digit-letter classification task, and slowest for incongruent bivalent simuli (e.g., G3) compared to congruent bivalent stimuli (e.g., G2) (afford both tasks). Interestingly, congruent stimuli were still slower than univalent trials, even though it may be assumed that congruent trials should be fastest because both stimulus components activate the same response. This finding provides support for the completeness of the attentional filtering process because the irrelevant task is not being activated, and as such, the irrelevant congruent stimulus does not speed up reaction times. Importantly, the differences in RTs between the congruent and univalent trials were more marked on switch trials compared to repeat trials, which is why we see a relationship between attentional filtering and switch costs. This particular study highlights two processes that might be at play during task-switching: attentional filtering operates to allow one to constrain attention to task relevant information while response conflict resolution allows one to produce accurate responses in the case when attentional filtering is not complete and the irrelevant stimulus is associated with a different response.

Some studies suggest that attentional filtering is implemented through in inhibition process. This account suggests that when a stimulus affords multiple tasks,

inhibition is applied to the irrelevant dimension of the stimulus-response mapping (Goschke, 2000). This inhibition carries over to the next trial. On switch trials, the formerly irrelevant and inhibited task set becomes relevant, so activation of this task set takes longer than repeat trials, in which the inhibited task-set remains inhibited. This logic is in line with asymmetrical switch costs, in which the more difficult task is more inhibited. The idea of attentional filtering being implemented through inhibition is supported by both behavioral and neural studies (Houghton & Tipper, 1996). It is argued that the process of attentional selection occurs through the inhibition of irrelevant information. The negative priming paradigm has been used extensively to demonstrate that inhibitory processes result in longer RTs when a previous distractor becomes a relevant target (Tipper, 1985). This translates to task-switching as the negative priming on the level of task-sets, which causes increased RTs for switch trials compared to repeat trials.

1.1.5 Response Conflict Resolution

As discussed, another proposed source of switch costs is when there is a need to resolve response conflict, due to the stimulus affording multiple tasks and mapping on to multiple responses. As such, an irrelevant task can interfere with performance of the relevant task when attentional filtering is incomplete and the irrelevant stimulus becomes processed to the point of response execution. More specifically, when two stimuli map onto different responses, it becomes necessary to resolve conflict at the response selection stage. A way to index this competition is by examining the congruency of a stimulus. Responses are typically faster for stimuli that afford the same responses for both stimuli (i.e, congruent) compared to when the stimuli afford different responses (i.e.,

incongruent). For instance, consider the digit-letter classification task described above (responding with a left button press for an even digit or consonant letter and a right button press for an odd digit or vowel letter). Faster responses would be observed for a "G2" stimulus because it is congruent, compared to a "G3" stimulus because it is incongruent.

Furthermore, this congruency effect is typically unimpacted by manipulations of preparation time (Allport et al., 1994; Fagot, 1994), suggesting that stimulus itself may be a unique source of interference in task-switching. However, not all studies have reached this conclusion. Meiran et al. (2000) found that the congruency effect is reduced when there is increased time for preparation, particularly on switch trials. More recent data suggests that preparation time does impact the congruency effect, but only when there is a low probability of a task-switch (Monsell & Mizon, 2006). In sum, the data is inconclusive regarding how preparation time impacts the congruency effect and how it is related to response conflict resolution. More studies are needed to examine if the advanced preparation and response conflict resolution mechanisms interact with one another or if they are unrelated.

Passive decay (previously discussed) is similar to a response conflict resolution process in that both refer to the level of interference that the irrelevant task has on the processing of the relevant task. However, passive decay refers to the level of interference at the task level, as one progresses from one trial to the next, while response conflict resolution occurs at the response production level. Passive decay corresponds to the decay of an entire task-set, while response conflict resolution corresponds to a component of the task-set (only the response production processes). When there is more time for the

passive decay of a previous task to occur, there becomes reduced competition when a new task is to be activated because activation of the old task has subsided. Of course, it is possible that these two processes interact with one another. Studies have found that switch costs are higher after a trial with an incongruent stimulus (Goschke, 2000). This is because the response conflict elicited by the incongruent stimulus causes additional strengthening of the relevant task-set and/or inhibition of the competing task-set. Depending on the time of decay from the previous trial, this relative strengthening and inhibition carries over to the next trial and impacts the magnitude of the switch cost.

As such, the mechanisms responsible for response conflict resolution seem to be an "online" strengthening of the current task-set in addition to the inhibition of an irrelevant task-set. One component of the task-switching model proposed by Brown et al. (2007) is an incongruency detector that reacts to response conflicts. This detector is activated when incongruent stimuli create coactivation of conflicting stimulus-response mappings. Task-relevant pathways are then amplified so that inappropriate responses are overridden and the conflict is resolved. Under this model, the incongruency detector is involved in the strengthening of task-sets. This falls in line with a decay account of switch costs, rather than a reconfiguration account.

While focusing on response conflict resolution a factor involved in taskswitching, it is worth noting that conflict may arise not only at the response level, but also at the task level. This interference at the task-level is what was discussed as the passive decay account of switch costs, the type of interference that would occur if a task has not had enough time to decay after the previous trial. Whether response-based and taskbased interference are two separate mechanisms was examined by Steinhauser and

Hubner (2009) by having participants do a stroop switching task. Their modeling results showed that task-based and response-based interference produced differential effects on the RT distributions, as each type of interference had a better fit by different components of the model. This study demonstrated that these different types of interference are indeed dissociable, but still not negating the fact that they can interact with one another. If less passive decay has occurred, response conflict resolution can be exacerbated because of the additional interference there is from the old task-set.

1.1.6 Integrative Summary

In sum, researchers have identified a number of potential sources (e.g. advanced preparation ability, attentional filtering ability, etc.) that may contribute to task-switching costs. Some models rely more heavily on cognitive control processes, such as the reconfiguration account of task-switching (Rogers & Monsell, 1995), while others rely more on automatic processes such as decay (Altmann & Gray, 2008). The literature thus far seems to suggest that each of these putative processes may be unique and independent contributors to switch costs. But this tendency to view these sources as independent may be a by-product of the fact that most of the work investigating task-switching has, until recently, focused on a single cognitive source. Such designs are unable to determine the extent to which different putative mechanisms are truly independent contributors or may all be interrelated or interact. In order to reach a more parsimonious understanding of the research on task-switching, it is imperative to think about how these processes interact with one another. Research now suggests that these processes can work mutually to produce flexible and controlled task-switching performance, and many researchers acknowledge the need for a plurality of mechanisms to explain switch costs (Monsell &

Driver, 2000; Monsell, 2003). Thus, the first goal of this work is to investigate which of these mechanisms are involved in task-switching performance and how they may or may not be related to one another.

1.2 Media Multitasking and Task-Switching Performance

In addition to investigating the structure of task-switching performance, the second goal of this work is to investigate the relationship between media multitasking and task-switching. An individual differences approach will be used to assess how one's media multitasking proclivity is related to each of the different task-switching factors. In the end, we will have a more complete model that provides a nuanced understanding of how multitasking is associated with task-switching performance. This in turn may provide insight into the discrepancies found in the literature on the relationship between task-switching and media multitasking.

The grounds for pursuing such work stems from research in the cognitive domain that suggests that extensive exposure to media and technology use are influencing basic cognitive processes (Cardoso-Leite, Green, & Bavelier, 2014). For instance, some argue that technologies such as mobile devices and vehicle navigation systems are lowering the need for human memory and spatial skills, thus reducing the cognitive effort required to complete daily tasks (Rogers, 2009). Others have suggested that the internet is becoming a primary form of external memory, thereby changing the way our brains remember information (Sparrow, Liu, & Wegner, 2011). Lui & Wong (2012) find that media multitasking is correlated with better multisensory integration. In addition, several reports have provided evidence that the habitual use of video games can influence performance on a range of cognitive tasks and alter visual attention processes

(Green & Bavelier, 2003).

While there is a wide range of cognitive processes that may potentially be impacted by ubiquitous media multitasking, a first step to addressing this issue is by examining how media multitasking might be related to task-switching performance, a hallmark of cognitive control processes in operation. Moreso, multitasking involves shifting between tasks frequently (Brasel & Gips, 2011), which is why media multitasking may impact task-switching performance. One study that examined taskswitching between media content on a computer found that switches occurred every 19 seconds (Yeykelis, Cummings, & Reeves, 2014). Interestingly, 20% of content was viewed for less than 5 seconds, and 75% was viewed for less than one minute. In addition, this study reported an anticipatory arousal spike 12 seconds before switching to other content, and this arousal was moderated by the type of content one was switching between.

More specifically, multitasking with media may uniquely impact each of the taskswitching mechanisms aforementioned. Consider, for instance, the case of an individual multitasking with multiple forms of media. In switching from one media form to another, one must reconfigure such that a task-set is reinstated for the new media to be used. Also, in order to perform a task, the stimuli in one's environment should be properly filtered so that only relevant information is processed. In the case where irrelevant information is processed, one may be required to resolve response conflict so that they are responding appropriately to the relevant task. Lastly, in switching between media forms, the task one is engaging in must decay before a new task can be performed. The current work will provide insight into the relationship between media multitasking

and each of these task-switching processes.

1.3 Overview of the Current Study

First, we will apply an individual differences approach to identify the number of unique factors influencing task-switching performance. Specifically, we will be testing the extent to which the putative mechanisms outlined above (advanced preparation, passive decay, attentional filtering, and response conflict resolution) are unique contributors to task-switching performance. To do so, we will use a latent factor approach and apply confirmatory factor analysis (see figure 1). To date, no work has investigated the inter-relationship between these putative factors within an individual. Thus, this approach should provide a unique research opportunity to determine how performance on these different tasks may correlate to determine the number of factors needed to account for the pattern of correlations among the measured variables. Furthermore, investigating individual differences is particularly useful when one's goal is to examine the associations and dissociations between constructs (Vogel & Awh, 2008).



Figure 1. *Latent factor analysis model to explore the structure of task-switching.* Key: AP = advanced preparation; PD = passive decay; AF = attentional filtering; RC = response conflict resolution. Number-letter pairs denote manipulation and task combination (described in methods section).

To do this, each participant will complete three different task-switching paradigms, which are adopted from prior methods designed to isolate the effects of a specific putative mechanism (e.g., advanced preparation). For each paradigm, participants will perform three blocks of trials, each with a different classification task and different stimuli (see appendix A). The use of these three different types of classifications within the same paradigms will allow us to perform a latent variable analysis and this approach is bolstered based on research that suggests that factor analyses provide more accurate results when factors are each represented by multiple measured variables (Fabrigar, et al., 1999). Structural equation modeling will allow us to examine the fit of various models in order to identify the key task-switching factors. Once we have identified the key factors impacting switch costs we will then add a media multitasking measure to the model to examine how media multitasking may be related to each of the factors (see figure 2). At this stage, we will also include measures of fluid intelligence (Raven's Progressive Matrixes) and crystallized intelligence (indexed by ACT scores), with the goal of identifying a more complete model given that IQ correlates with many cognitive



Figure 2. Latent factor analysis model with the addition of the media multitasking and IQ

Figure 2 (cont'd) *measures.* Key: AP = advanced preparation; PD = passive decay; MMT = media multitasking. Number-letter pairs denote manipulation and task combination (described in methods section). For illustrative purposes, model depicted reflects the reduced model based on the findings.

Each experimental manipulation was designed to allow us to isolate the different proposed sources of switch costs. Manipulation 1 varied the cue-stimulus interval (CSI) to allow us to assess the impact of advanced preparation on task-switching performance. With longer times to prepare for a task, reaction times are typically reduced compared to when there is little preparation time (Meiran, 1996). By comparing response times for the long CSI condition to the short CSI condition, we can obtain an index of how sensitive task-switching performance is to preparation time. To the extent that advanced preparation is an important factor in task-switching, we would expect response times for short CSI switch trials to be substantially longer than response times for long CSI switch trials.

Manipulation 2 varied the response-cue interval to allow us to examine the impact of passive decay on task-switching performance. To the extent that passive decay plays an important role in task-switching performance, we would expect relatively fast responses for long response-cue interval (RCI) switch trials and relatively slow responses for short RCI switch trials. With longer times for decay, response times for switch trials are typically reduced because there is less competition during the activation of a task-set on the upcoming trial. Depending on how sensitive task-switching performance is to the decay of prior task-sets, we should see larger differences in performance between the long and short RCIs.

Manipulation 3 held the RCI and CSI constant but varied whether the to-be-

classified stimulus appeared alone, with an irrelevant distractor that was not part of the classification set of stimuli, or appeared with a stimulus from the other classification task. These manipulations of the types of stimuli presented, allow us to assess the impact of attentional filtering and response conflict resolution on task-switching performance. To the extent that attentional filtering is an important contributor to switch costs we would expect response times to be substantially longer on switch trials that had an irrelevant distractor than switches that had only the to-be-classified stimulus.

The condition with two stimuli, one from each classification task allows us to evaluate the extent to which response conflict resolution is an important contributor to task-switching costs. If it is, we would expect long response times when the to-beclassified stimulus was associated with the opposite button press as the to-be-ignored stimulus. In addition, we would expect relatively short response times when the two stimuli mapped onto the same button press. By comparing response times from the conditions that include an irrelevant distractor to the single condition (in which no irrelevant information is presented), and the incongruent condition to the congruent conditions, we can get a measure of the impact of attentional filtering and response conflict resolution on task-switching performance.

Together, these manipulations will allow us to isolate the different proposed sources responsible for switch costs and in combination with the different tasks, we can explore the structure of task-switching performance with the goal of identifying the unique factors involved in task-switching.

CHAPTER 2. METHODS

2.1 Participants

One-hundred eighty-seven university undergraduates (117 females; mean age = 19.60 years) successfully completed both parts of the experiment. They participated for course credit and had normal or corrected-to-normal vision. Approval was obtained from the Michigan State University Institutional Review Board, and all participants provided informed consent.

2.2 Task-Switching Paradigm

Each participant completed nine blocks of trials, with 192 trials per block, resulting in a total of 1,728 task-switching trials per participant. The trials were comprised of a factorial combination of three task manipulations by three classification tasks. One classification task was an Animal/Furniture task that involved classifying either an animal as a fish/bird or classifying a furniture item as chair/table. The second task was a Number/Letter classification task that involved classifying either a letter as consonant/vowel or a number as odd/even. The final task was a Plant/Transportation task that involved classifying either a plant as a tree/flower or a transportation vehicle as a car/plane (see Appendix A for stimuli). Each of the classification tasks appeared three times, once for each of the experimental manipulations (see below).

Participants responded by pressing one of two possible response buttons on an Eprime serial response (SR) box. The left/right button response mappings were as follows: fish/bird for the Animal task, chair/table for the Furniture task; even/odd for the Number task, consonant/vowel for the Letter task; tree/flower for the Plant task and car/plane for

the Transportation task. Participants sat with their index finger from each hand over a button. Button labels were provided on the bottom of the monitor screen on every trial.

On each trial, a cue appeared at the center of the screen indicating the task to be performed, followed by the stimulus display that remained on screen until the participant responded. The cue was randomly selected on each trial, yielding approximately 50% switch trials, in which the type of stimulus to be classified changed from one trial to the next, and 50% repeat trials, in which the type of stimulus to be classified remained the same from one trial to the next.

2.2.1 Advanced Preparation Manipulation

Three blocks of trials were designed to investigate the impact of advanced preparation on task-switching. In these blocks there were two cue-stimulus interval (CSI) conditions. In the short CSI condition, the cue appeared for 216 ms while in the long CSI condition, it appeared for 1,716 ms. The to-be-classified stimuli onset immediately after the offset of the cue. For both CSI conditions, the response-stimulus interval (RSI) was held constant at 1,848 ms by varying the time between the previous response and the onset of the cue (see figure 3) (adapted from Meiran, 1996). Holding the RSI constant meant that CSI was not confounded with remoteness from the previous trial, and thus difference between CSI conditions cannot be attributed to explanations based on carryover from the previous task (Allport, et al., 1994).

The long CSI condition was long enough that we anticipated most people could complete the preparation process for the upcoming task. In fact, increasing the RSI (which includes both the CSI and the RCI) beyond ~600 ms, will have little impact on
switch costs (Rogers & Monsell, 1995). However, the short CSI condition did not allow enough time to completely prepare for the upcoming task before the stimulus display appeared. Thus, to the extent that advance reconfiguration has an important impact on switch costs, the time required to perform a switch trial with a short CSI should be elevated relative to the time required to perform a switch trial with a long CSI or a repeat trial. The difference between the long and short CSI conditions will allow us to index the efficiency of the preparation process by examining how delayed an individual is by having less time to prepare for an upcoming task-switch. To the extent that advanced preparation plays a large role in task-switching, we should see a greater difference in performance between the long and short CSI conditions. The stimulus display comprised of a pair of stimuli, one stimulus from each of the possible classifications within a task. There were 96 trials for each CSI condition and CSI condition was blocked, resulting in a total of 576 trials for the advanced preparation manipulation.



Figure 3. *Timings for advanced preparation manipulation*. CSI = cue-stimulus interval.

2.2.2 Passive Decay Manipulation

Three blocks of trials were designed to investigate the impact of passive decay on task-switching. In these blocks there were two response-cue interval (RCI) conditions. The duration of the RCI at the short RCI condition was 232 ms and the duration of the RCI at the long RCI condition was 1,632 ms. The duration of the CSI was held constant at 216 ms (see figure 4) (adapted from Meiran, Chorev, & Sapir, 2000). The to-beclassified stimuli onset immediately after the offset of the cue. In the long RCI condition, the previous task should have ample time to decay before the new task is to be performed (Meiran, Chorev, & Sapir, 2000). However, in the short RCI condition, the previous task may not have time to decay before the participant is presented with the next task, and as such, will interfere in processing of the current task. To the extent that passive decay plays a large role in task-switching, we should see greater difference in performance between the short and long RCIs. That is their response time for short RCI trials should be elevated relative to the long RCI trials and repeat trials. There were 96 trials for each RCI condition that were blocked and this was repeated across all three tasks, resulting in 576 trials for the passive decay manipulation.

Long RCI: Response From prey Trial		Cue	Stimulus until response	
1,63	2 ms		216 ms	_
Short RCI:				
Response From <u>prev</u> Trial	Cue Stir	nulus until response		
232 ms	216 ms			

Figure 4. *Timings for passive decay manipulation*. RCI = response-cue interval.

2.2.3 Filtering/Response Resolution Manipulation

Another three blocks of trials were designed to investigate the impact of both attentional filtering and response conflict resolution on task-switching. In these blocks, the stimulus display was varied while the CSI and RCI was held constant across trials. The duration of the RCI was 1,632 ms and the duration of the CSI was 216 ms (see figure 5). There were 192 randomly interleaved trials for each of the three task blocks, resulting in 576 trials for the filtering/response resolution manipulation.

To assess the impact of attentional filtering, we included trials that presented only one stimulus, which we refer to as single trials, and trials that included two stimuli, referred to as paired-with-neutral trials. Single trials presented only one stimulus in the stimulus display that corresponded to one of the described tasks. Paired-with-neutral trials presented two stimuli, one stimulus corresponded to a task, and another stimulus was neutral, in that it did not afford one of the relevant tasks described. For example, a neutral stimulus for the Animal/Furniture task was a shoe, as this stimulus type did not fall under the animal or furniture category. By comparing response times from the single and paired-with-neutral trials, we can examine the effects of attentional filtering. The additional time it takes to process the irrelevant information reflects the amount of information that has leaked through the attentional filter. To the extent that filtering processes operate, response times from paired-with-neutral trials should be more similar to single trials. The difference in response times between the single and paired-with-neutral trials reflects the additional time it takes to filter irrelevant information that is present in the paired-with-neutral trials. To the extent that attentional filtering plays a role in task-switching, we should see a greater difference in performance between the single and paired-with-neutral trials.

To assess the impact of response conflict resolution, we included typical trials that consisted of stimulus displays comprising a pair of stimuli. This will allow us to compare response times on congruent and incongruent trials, while the CSI and RCI durations were held constant. Congruent trials were when correct responses for each stimulus corresponded to the same response button while incongruent trials were when correct responses to each stimulus corresponded to different button responses. To the extent that the irrelevant task interferes with performance on the relevant task, we should see prolonged response times on the incongruent trials and shorter response times on the congruent trials. The difference between incongruent and congruent trials is an index of the efficiency of response conflict resolution. It will allow us to examine how delayed an individual is by having to overcome conflict at the response selection stage. To the

extent that response conflict resolution plays a large role in task-switching, we should see a greater difference in performance between the incongruent and congruent trials.



Figure 5. Timings for filtering/response resolution manipulation.

2.3 Surveys

A revised Media Multitasking Index Questionnaire¹ was used to assess participants' level of media multitasking. The original Media Multitasking Index (MMI) was developed by Ophir, Nass, & Wagner (2009) and indexes how often a person uses each of 12 forms of media and how often each form of media is used with different forms of media simultaneously. The MMI requires participants to indicate how many hours per week they use each of 12 forms of media (television, computer-based video, music, nonmusical audio, video or computer games, telephone and mobile phone, instant messaging, SMS (text messaging), email, web surfing, and other computer based applications (such as word processing). Then for each media form, they indicate how often they use this

¹For the purposes of this work, the analyses included the original MMI measure to allow for more direct comparisons with our previous work as well as others work on the relationship between media multitasking and cognition.

primary media form concurrently with the each of the other 11 media forms. This is done by making 11 ratings of "Most of the time (=1)," "Some of the time (=0.67)," "A little of the time (=0.33)," or "Never (=0)". These responses are summed to provide a measure of the average amount of media used while using each primary medium (this corresponds to

m_i in the formula below). The formula for the index is
$$MMI = \sum_{i=1}^{11} \frac{m_i x h_i}{h_{total}}$$

where, h_i is the number of hours per week spent using primary medium i, and h_{total} is the total number of hours per week spent with all primary media. The MMI indicates the average amount to media multitasking that is occurring during a typical hour of media usage.

The revised Media Multitasking Index is based on the original MMI but incorporates some additional components. First, it classifies medias as primary and secondary, with "Primary" media referring to the main media one is engaging with and "Secondary" media referring to the media that is less prominent, or one that is in less focus than the primary media. It also incorporates non-media activities, such as studying or exercising, in order to include the times people engage in media while doing other types of activities. Additionally, it asks people to report their total time spent using media, divorced from the time they are media multitasking, in order to get a measure of the absolute time spent using media. Lastly, it incorporates some exploratory questions in order to address other issues relevant to people's media use, such as the number of tasks typically being combined on a single device or the number devices people access at a given moment in time. While these additional items in the MMI allow for a more nuanced understanding of media multitasking practices, it is still possible to derive the original MMI measure from the revised version so that we can make comparisons with previous work that have used this measure.

The beginning of the MMI questionnaire included demographic questions and asked participants to report their ACT or SAT college admissions exam scores as a measure of crystallized intelligence (Koenig, Frey, & Detterman, 2008). Participants also completed the 18 odd-numbered items of Raven's Progressive Matrices as a measure of fluid intelligence and reasoning ability (Raven, Raven, & Court, 1998). Each item consisted of a series of patterns, arranged in three rows and three columns. The pattern in the lower right was always missing. The participant's task was to choose the pattern that logically completed the series (see Appendix B for all surveys).

2.4 Procedure

Task-switching data were collected individually in sound-attenuated booths. After completing the behavioral portion of the experiment, participants were provided with a link to access a series of online surveys. Surveys were administered through Survey Monkey and participants were encouraged to complete the surveys as soon as they were able. The behavioral task was programmed in E-prime and presented on a 19-inch CRT monitor with a 100-Hz refresh rate. All participants completed the advanced preparation trials first, followed by the filtering/response resolution trials, and the passive decay trials last. For the advanced preparation manipulation, short CSI trials were completed first, followed by long CSI trials. For the passive decay manipulation, short RCI trials were completed first, followed by long RCI trials. Within each experimental manipulation, the Animal/Furniture task was completed first, followed by the Number/Letter task, and the Plant/Transportation task last. Maintaining a fixed task order is common based on standard methods in individual differences research (e.g., Foster et al, 2014), as this helps one avoid confounding individuals with a task order that would complicate the interpretation of individual differences analyses (Salthouse & Babcock, 1991). After completing all the trials within each experimental manipulation, there was a participant-terminated rest break.

2.5 Data Preparation

Trials with RTs greater than 4000 ms and less than 250 ms were eliminated from further analysis. SAT scores were converted to ACT scores.

CHAPTER 3. RESULTS

The results will be divided into four sections. The first will report mean effects of the experimental manipulations collapsed across classification tasks. The second will discuss the reliability estimates of the RT measures and will describe the z-scoring method that will be used in the individual differences analyses. The third section will be an application of structural equation modeling to identify the different components of task-switching. The fourth section will examine how media multitasking and intelligence are related to the factors involved in task-switching performance.

Eighteen participants whose overall accuracy was less than 60% were removed from further analyses. Mean accuracy of the remaining subjects was 90.00% (SE = .6%). Responses to the MMI Questionnaire produced a relatively normal distribution (M = 5.90, SD = 3.33, skewness = .54, kurtosis = -.03). The average self-reported ACT score for the sample was 25.6 (SD = 3.82), with a range from 17 to 36. Mean accuracy on Raven's Progressive Matrices was 52.2% (SD = 24%), with a range from 0% to 94.4%. Thus, although it may be assumed that there was restriction of range in cognitive ability given that the participants were undergraduate students at a moderately selective university, there was still a relatively wide range of ability in the sample.

3.1 Effects of Experimental Manipulations

First, a set of analyses were performed to examine the effects of the experimental manipulations on RT measures. Because this was a check to examine the impact of the experimental manipulations, we collapsed across classification task type. Two-by-two repeated measures analyses of variance (ANOVAs) with two levels of trial type (switch,

repeat) and two levels of condition (e.g., short CSI, long CSI) were first conducted to compare switch and repeat trial RTs for each of the experimental manipulations (see Table 1). For the advanced preparation manipulation, the ANOVA confirmed that there was a main effect of both trial type, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, and condition, F(1, 168) = 193.46, p < .001, P = 1000, P = 10000, P = 10000, P = 10000, P =168) = 494.26, p < .001, and the two factors interacted, F(1, 168) = 11.44, p = .001. RTs were faster in the long CSI condition compared to the short CSI condition. For the passive decay manipulation, there was a main effect of both trial type, F(1, 168) = 71.73, p < .001, and condition, F(1, 168) = 52.09, p < .001, and again, the two factors interacted, F(1, 168) = 20.16, p < .001. RTs were faster in the short RCI condition compared to the long RCI condition. For both of these manipulations, RTs were faster on repeat trials compared to switch trials. In addition, the interaction resulted from a larger difference in RTs between switch and repeat trials for the short CSI and short RCI conditions, compared to the long CSI and long RCI conditions respectively. In addition, switch trial RTs for the advanced preparation manipulation and repeat trial RTs for the passive decay manipulation differed more across conditions compared to repeat and switch trial RTs respectively. This lends support for preparation processes playing a large role when executing a task-switch (Rogers & Monsell, 1995), as well as repetition priming playing a role in the decay of prior task-sets (Altmann & Gray, 2008). In addition, advanced preparation and passive decay are particularly involved in task-switching performance, as performance varied across conditions for both manipulations. For the attentional filtering manipulation, there was a main effect of both trial type, F(1, 168) = 140.70, p < .001, and condition, F(1, 168) = 355.98, p < .001, but the two factors did not interact, F(1, 168) =2.47, p = .118. RTs were faster in the single condition compared to the paired-withneutral condition. For the response resolution manipulation, there was a main effect of trial type, F(1, 168) = 17.57, p < .001, but no effect of condition, F(1, 168) = 0.72, p = .399, and the two factors did not interact, F(1, 168) = 1.32, p = .252. RTs were not statistically different for the incongruent and congruent conditions. For both these manipulations, RTs were faster on the repeat trials compared to switch trials. However, the difference in RTs between the switch and repeat trials was similar in magnitude across conditions. Together, these effects suggest that attentional filtering and response resolution are not major factors in task-switching because the magnitude of differences between the switch and repeat trial RTs did not vary across condition.

Second, an average switch cost within each experimental manipulation (e.g., short CSI, long CSI) was calculated for each participant across tasks (see figure 6). Paired samples t-tests were conducted to compare switch costs within each of the experimental manipulations (e.g., short CSI vs long CSI). For the advanced preparation manipulation, the paired samples t-test revealed that switch costs were larger in the short CSI condition compared to the long CSI condition, t(168) = -3.38, p < .001. This is in line with previous work that finds that reducing the time one is allowed to prepare for a task increases switch costs (Meiran, 1996). For the passive decay manipulation, switch costs were larger in the short RCI condition compared to the long RCI condition, t(168) = -4.56, p < .001. This finding is also consistent with previous work that finds that switch costs are larger when there is less time for a prior task-set to decay, as a less decayed task-set interferes with performance of the current task (Altmann, 2005; Koch, 2001). For the attentional filtering manipulation, switch costs were not statistically different across the paired-with-neutral and single conditions, t(168) = -1.57, p = .118. Paired

samples t-tests comparing RTs from paired-with-neutral trials to single trials within each task (i.e, not collapsing across tasks) showed that the presence of a neutral distractor slowed performance relative to single trials in all tasks, ts > 7.37, ps < .001, but the magnitude of slowing was similar for switch and repeat trials. These effects are inconsistent with attentional filtering being a major factor involved in switch costs, as additional irrelevant information produced a general slowing in RTs rather than a more pronounced slowing for switch trials compared to repeat trials. Finally, for the response resolution manipulation, switch costs were larger in the incongruent condition compared to the congruent condition across all tasks, but this difference was not statistically significant t(168) = 1.06, p = .290. While we expected that switch costs would be significantly larger in the incongruent condition based on previous work (Rogers & Monsell, 1995; Rubin & Koch, 2006), the fact that this experiment included a much larger set of category classifications than is typically included in task-switching studies added to the number of stimulus-response mappings and for this reason, specific stimulus-response associations may have been weakened such that they did not produce the typical interference observed in the congruency effect.

In addition, the lack of significant effects we observed for the filtering/response resolution manipulation may have been an artifact of the fact that the different trial types were not blocked as was the case in the advanced preparation and passive decay manipulations. Strayer & Kramer (1994) find that people adopt different strategies depending on whether experimental conditions are blocked. When different conditions are interleaved within a block, people generally adopt one strategy, regardless if the strategy is optimal for all conditions. In contrast, when there is one condition per block, people adopt one strategy that happens to be optimal for that particular condition.

Furthermore, Los (1996) suggests that mixed blocks introduce greater intertrial

variability than pure blocks, causing people to implement different strategies.

Switch RT (ms)	Repeat RT (ms)	Switch Cost (ms)
1284.14	1191.18	92.96
1042.34	977.64	64.70
886.05	819.81	66.24
939.90	914.64	25.26
989.51	936.98	52.54
898.08	830.17	67.90
1062.59	1020.30	42.29
1048.17	1022.42	25.75
	Switch RT (ms) 1284.14 1042.34 886.05 939.90 989.51 898.08 1062.59 1048.17	Switch RT (ms) Repeat RT (ms) 1284.14 1191.18 1042.34 977.64 886.05 819.81 939.90 914.64 989.51 936.98 898.08 830.17 1062.59 1020.30 1048.17 1022.42

Table 1. Average switch and repeat trial RTs for each experimental manipulationcondition.



Figure 6. Average RT switch costs for each experimental manipulation condition. Error bars indicate standard error of the mean. p < .001.

Second, a set of analyses were performed to examine the effects of the experimental manipulations on error rates. Accuracy costs were determined by subtracting the proportion of correct responses on switch trials from the proportion of correct responses on repeat trials. For the advanced preparation manipulation, accuracy costs were no different in the short CSI and long CSI conditions, t(168) = -1.23, p = .220. This suggests that the RT switch cost effects cannot be explained by a speed-accuracy tradeoff, as error rates were no different across conditions. For the passive decay manipulation, there was a significant difference in accuracy costs between the short and

long RCI conditions, t(168) = 3.69, p < .001,with greater accuracy costs in the short RCI condition. In Altmann & Gray's (2008) model, our short RCI condition is akin to the shorter run lengths (compared to longer run lengths) because shorter run lengths have a higher rate of new task cues being presented and a shorter time between the task cues, resulting in more interference from old task codes. Our findings are in line with the predictions of their model, as they find higher overall error rates and steeper slopes of within-run error increases for the short run lengths compared to the long run lengths. For the attentional filtering manipulation, accuracy costs were statistically no different from one another in the paired-with-neutral and single conditions, t(168) = 1.18, p = .238. This again suggests that attentional filtering may not be a major factor involved in task-switching, as error rates were no different for switch trials compared to repeat trials. Lastly, for the response resolution manipulation, as expected, accuracy costs differed in the incongruent condition compared to the congruent condition, t(168) = 3.58, p < .001, with larger accuracy costs for the incongruent condition.

Overall, these mean analyses lend support for the involvement of advanced preparation and passive decay in task-switching performance. For the advanced preparation manipulation, RT switch costs differed in the short CSI condition compared to the long CSI condition, and both RT and accuracy costs were larger in the short RCI condition compared to the long RCI condition for the passive decay manipulation. In contrast, the attentional filtering and response conflict resolution manipulations do not provide support for these two factors being specific to task-switching performance. Switch costs were statistically no different across conditions for both experimental manipulations.

3.2 Reliabilities and Z-Scores

Switch costs have long been used to investigate task-switching and are the most frequently used measure of task-switching performance. However, when investigating individual differences in task-switching performance, the use of switch cost measures has been criticized on the grounds that the derived switch measures have low reliability (Hughes, et al., 2013). The reliability of a difference score reflects the reliability of the components, and the correlation between the components, where the higher the correlation, the lower the reliability (Chiou & Spreng, 1996). In task-switching paradigms, correlations between the components (i.e., repeat and switch) tend to be quite high, and thus, switch costs tend to have low reliability. Moreover, difference score reliability has been found to vary significantly across task types (e.g., Miyake, et al., 2000). In short, before investigating individual differences, one needs to ensure that the measures being used are reliable.

To examine reliabilities we used the following formula for difference score reliability (Lord, 1963):

$$\rho_{DD'} = \frac{\rho_{XX'}\sigma_X^2 + \rho_{YY'}\sigma_Y^2 - 2\rho_{XY}\sigma_X\sigma_Y}{\sigma_X^2 + \sigma_Y^2 - 2\rho_{XY}\sigma_X\sigma_Y}$$

where $\rho DD'$ is the reliability of the difference score (X-Y), $\rho XX'$ and $\rho YY'$ are the reliabilities of the components X and Y, σX and σY are their standard deviations, and ρXY is their correlation. To calculate $\rho XX'$ and $\rho YY'$ (reliabilities of RT means for each condition), odd-even split-half estimates of internal consistency were used.

Consistent with the concerns outlined above, reliabilities for the derived switch cost measures were low (see Table 2). As some researchers have done in the past

(Cronbach & Furby, 1970; Faust et al., 1999, Edwards, 2001) we therefore employed an alternative approach to estimating switch cost that makes use of a z-score transformation technique (Bush, Hess, & Wolford, 1993). For this approach, we calculated the mean and standard deviation of RTs for each individual for each block of trials. Then we converted the raw RTs for each condition within the block to a z-score based on that participant's mean and standard deviation for the block. This approach allowed us to derive measures reflecting effects of the experimental manipulation effects without performing any subtractions; thereby, we avoided problems of low reliability inherent in difference scores. This approach also allowed us to control for individual differences in overall response latency, as z-scores are calculated within an individual and are within-subjects measures that are not confounded by overall difference in mean response time (i.e., that fast people are fast at all tasks).

Factor and Measures	Reliability	
Advanced Preparation		
Short CSI Switch Cost	0.50	
Long CSI Switch Cost	0.48	
Passive Decay		
Short RCI Switch Cost	0.53	
Long RCI Switch Cost	0.47	
Attentional Filtering		
Single Switch Cost	0.50	
Paired-with-neutral Switch Cost	0.48	
Response Resolution		
Congruent Switch Cost	0.49	
Incongruent Switch Cost	0.47	

 Table 2. Switch cost reliability (averaged across tasks).

To clarify how the use of this z-score method avoids the need for subtraction of one distribution from the other, consider the case where we want to evaluate whether advanced reconfiguration plays an important role in task-switching. The z-score method allows us to simply examine participant's z-scores for the short CSI condition. If advance reconfiguration has a large impact on task-switching, then RTs for short CSI trials should be substantially larger than RTs for the long CSI switch trials, and the repeat trials. In short, the short CSI switch trials should make up the right tail of the distribution of RTs in the block of trials. In addition, if an individual was particularly slow at performing this advanced preparation stage, his/her RTs for the short CSI switch condition should be particularly large, relative to their other responses, resulting in large positive z-scored RTs for that condition. By contrast, an individual who was fairly fast at performing advanced reconfiguration would have RTs for the short CSI switch condition that were not that discrepant from their RTs for other conditions, and thus their z-scores for that condition would be closer to 0. Thus, one can directly investigate the magnitude of the z-scored RTs for the short CSI switch trials to investigate the extent to which an individual's switch costs are influenced by the need to perform advanced preparation. In short, we can directly compare individual subjects' z-scores for the short CSI trials without having to perform a subtraction between conditions. In addition, the method computes performance within an individual so any shift in overall speed of responding will be eliminated from the analyses.

In line with this logic, the z-scored short RCI RTs will be used to assess whether passive decay play a large role in task-switching. Z-scored short RCI switch trials should increase in magnitude (be slower relative to other conditions) in direct relationship to the influence that passive decay has on task-switching. If passive decay has a large impact on task-switching, then RTs for short RCI trials, in which passive decay has not had time

to occur, should be substantially larger than RTs for the long RCI and repeat trials, and thus should be large positive z-score values. To assess the role of attentional filtering in task-switching, we will use the z-scored paired-with-neutral switch RTs, as these trials will reflect the additional time it takes to filter information that is irrelevant to the current task. These RTs should be substantially larger than the single trials, which only contain information that is relevant to the current task. Lastly, the z-scored incongruent switch RTs will be used to evaluate whether response conflict resolution plays a large role in task-switching. If response resolution has a large impact on task-switching, then RTs for the incongruent trials should be larger than the congruent trials because the incongruent trial RTs include the additional time it takes for one to resolve the conflict at the response selection stage. In all of these cases, the relatively larger RTs will comprise the right tail of the RT distribution, and as such, will have higher mean z-scores.

In sum, the main z-scored dependent variables to be used as indicators in the individual difference models will be the participants' mean z-scored reaction times for the short CSI switch trials, short RCI switch trials, paired-with-neutral switch trials, and incongruent switch trials. The reliabilities for these z-scored measures are presented in Table 3. Note that the reliabilities are fairly high for the advance preparation and passive decay factors, but are fairly low for the attentional filtering and response conflict resolution factors. These low reliabilities for the latter two factors is not terribly surprising given that those factors were not shown to be particularly influential to task-switching performance at the level of the means.

Factor and Measures	Reliability
A draw and Dependention	
Advanced Preparation	
Z-Scored Short CSI Switch Trials	0.67
Passive Decay	
Z-Scored Short RCI Switch Trials	0.78
Attentional Filtering	
Z-Scored Paired-with-neutral Switch Trials	0.37
Response Resolution	
Z-Scored Incongruent Switch Trials	0.35

Table 3. Reliability of indicators for each putative factor (averaged across tasks).

3.3 Identifying the Task-Switching Factors

One of the primary purposes of the present study was to investigate the structure of task-switching performance by examining the relationships among measures of four putative task-switching processes. We performed structural equation modeling (SEM) to investigate the existence of these four task-switching factors (advanced preparation, passive decay, attentional filtering, and response conflict resolution) at the level of latent variables. The indicators for each factor were the z-scored RTs for all three tasks: short CSI switch RTs for the advanced preparation factor, short RCI switch RTs for passive decay, paired-with-neutral switch RTs for attentional filtering, and incongruent switch RTs for response conflict resolution.

We tested four models via confirmatory factor analyses. Model 1 included a single factor, with the 12 task-switching measures as the indicators. The fit of this model was poor, $\chi^2(54) = 93.21$, p < .01, CFI = 0.59, NFI = 0.42, RMSEA = 0.07. Model 2 included the four hypothesized task-switching factors (i.e., advanced preparation, passive decay, attentional filtering, and response conflict resolution), with three indicators per

construct. This model would not converge (i.e., inadmissible solution), indicating a poor fit to the data.

Through the next two post-hoc models, we sought to identify the source of the misfit in Model 2. Reliability was low for the attentional filtering switch-cost measures; also, as already noted, the difference in RTs across experimental conditions was nonsignificant for this factor. Thus, we dropped the attentional filtering factor in Model 3, leaving the advanced preparation, passive decay, and response conflict resolution factors. This model would not converge (i.e., inadmissible solution) and fit remained poor. The response conflict resolution factor had weak factor loadings (all ps > 0.21). Furthermore, as shown in Table 2, reliability was low for the indicators, and the differences in RTs across experimental conditions were non-significant. Thus, in Model 4, we further reduced the number of factors to two, leaving advanced preparation and passive decay. Model fit was excellent, $\chi^2(8) = 5.40$, p = 0.71, CFI = 1.00, NFI = 0.93, RMSEA = 0.00 (see figure 7). The fit of Model 3 was also excellent when error rates were used as indicators for the two factors, $\chi^2(8) = 43.87$, p < 0.01, CFI = 0.92, NFI = 0.90, RMSEA = 0.16 (see figure 8). Table 4 displays the model fits for Models 1-4 and Table 5 displays the factor loadings from Model 4.

Model	$\chi^2 df$	CFI	NFI	RMSEA
Model 1: Single Factor	93.21 54	.591	.424	.066
Model 2: Four-Factors	No minimum	.949	.673	.025
Model 3: Three-Factors	No minimum	.983	.797	.019
Model 4: Two-Factors (RT)	5.40 8	1.00	.933	.000
Model 4: Two-Factors (errors)	43.87 8	.915	.900	.163

Table 4. Models examining best fit for task-switching factors.

Factor and Measures	RT Model	Error Model	
Advanced Preparation			
Short CSI_Switch (AF)	.274	.241	
Short CSI_Switch (NL)	.506	.709	
Short CSI_Switch (PT)	.486	.646	
Passive Decay			
Short RCI_Switch (AF)	.396	.825	
Short RCI_Switch (NL)	.531	.883	
Short RCI_Switch (PT)	.815	.839	

Table 5. Factor loadings for advanced preparation and passive decay factors fromModel 4 (RT and Error).



Figure 7. *Model 4- RT Factor analysis examining the fit of a model including two task-switching factors, advanced preparation and passive decay.* ShCSI = Short cue-stimulus interval; ShRCI = Short response-cue interval; AF = animal/furniture task; NL = number/letter task; PT = plant/transportation task. *Significant at p < .05.



Figure 8. Model 4- Error rate factor analysis examining the fit of a model including two task-switching factors, advanced preparation and passive decay. ShCSI = Short cuestimulus interval; ShRCI = Short response-cue interval; AF = animal/furniture task; NL = number/letter task; PT = plant/transportation task. *Significant at p < .05.

Thus, we find support for two factors involved in task-switching performance. These factors are moderately correlated, r = .31 (p = .026) based on RT measures, and highly correlated based on error rates, r = .76 (p < .001), suggesting that they may be related in their contribution to task-switching performance. This raised the possibility that a single factor might be able to account for performance on the six indicators that remained in the reduced two-factor model. To evaluate this possibility, we reduced the model further to have only a single latent variable using RT data from the same six indicators (short CSI switch RTs for the advanced preparation factor and short RCI switch RTs for passive decay for all three tasks). This single factor model provided a less adequate fit, $\chi^2(9) = 18.19$, p = .03, CFI = 0.86, NFI = 0.77, RMSEA = 0.08, than the two-factor model. A chi-squared test comparing the model fits showed that the two factor model produced a significantly better fit than the single factor model, $\chi^2(1) =$ 12.79, p < .001. Thus, even though advanced preparation and passive decay are related at the latent level, they nonetheless represent separate aspects of task-switching as they each provide independent contributions. We also evaluated the possibility that the factors we found support for reflect an overall speed factor. We ran a model that factored out participants' overall RT from each of the six indicators, and found that the two-factor model fit remained unchanged, $\chi^2(23) = 13.88$, p = .93, CFI = 1.00, NFI = 0.91, RMSEA = 0.00, suggesting that any relationships we find between these two factors and other measures are not due to overall speed.

In sum, of the four hypothesized independent task-switching factors, an individual differences approach using latent variables provides evidence for the existence of two unique factors, an advanced preparation process and a passive decay process. However, the data do not provide support for independent factors of attentional filtering and response conflict resolution. Given that we did not observe effects of attentional filtering that we do not observe individual differences effects. The two factors we do find evidence for provide support for the involvement of both active (advance preparation) and passive (passive decay) cognitive processes in task-switching.

3.4 The Relationship of Media Multitasking & General Intelligence to the Task-Switching Factors

We next examined how media multitasking (MMT) and intelligence (G) are related to the two factors involved in task-switching, advanced preparation and passive decay. The media multitasking measure was the media multitasking index questionnaire, and the measures of general intelligence were ACT scores as an index of crystallized intelligence and Raven's Matrices as an index of fluid intelligence. This model had good fit based on both RT data, $\chi^2(20) = 12.95$, p = .88, CFI = 1.00, NFI = 0.89, RMSEA = 0.00 (see figure 9), and error data, $\chi^2(20) = 51.83$, p < 0.01, CFI = 0.93, NFI = 0.89, RMSEA = 0.10 (see figure 10).

Based on the RT model, MMT (r = -.07, p = .50), ACT (r = -.02, p = .87), and Ravens (r = .07, p = .45) were all unrelated to the passive decay factor. In addition, ACT was unrelated to advanced preparation (r = .12, p = .38). By contrast, MMT (r = -.26, p = .04) and Ravens (r = .31, p = .01) were both significantly correlated with the advanced preparation factor, but in opposite directions.

Based on the error model, MMT was unrelated to the advanced preparation (r = -.03, p = .75) and passive decay (r = -.10, p = .25) error rates. ACT was also unrelated to advanced preparation (r = -.08, p = .49) and passive decay (r = .04, p = .66). However, Ravens was significantly correlated with advanced preparation (r = .22, p = .03) and passive decay (r = .21, p = .02) error rates.

These data suggest that crystallized intelligence, as indexed by ACT scores, is not associated with one's ability to effectively perform a task-switch. However, one's fluid intelligence is associated with advanced preparation ability. Interestingly, the nature of this relationship suggests that as Ravens increases, so does the time to do a short CSI switch. At first blush, this seems unexpected; as fluid intelligence increases an individual's ability to rapidly reconfigure to a new task decreases. However, the error data might clarify this relationship. Performance on the Ravens measure was positively associated with accuracy; as fluid intelligence increased, one's performance in switching tasks also increased. Taken together, the RT and error data suggest that those with high fluid intelligence may be more likely to realize that one needs to perform a task reconfiguration prior to responding in the short CSI switch trials. As a result, they may delay their responses to allow the reconfiguration process to complete, leading to higher accuracy. By contrast, those with low fluid intelligence may not take the time required for reconfiguration resulting in fast but often inaccurate responses.

Also, one's level of media multitasking is related to their ability to implement advanced preparation during task-switching such that a higher MMT score is associated with a shorter time to implement a switch during a short CSI switch trial. However, MMT was not associated with higher errors in the short CSI switch trial. This reduction in switch costs without an increase in errors, suggest that increased media multitasking is related to faster ability to reconfigure tasks rather than a simple speed-accuracy trade off. The finding that MMT is associated with faster reconfiguration, is consistent with other work that showed reduced switch costs among people who frequently multitask with media (Alzahabi & Becker, 2013). Finally, media multitasking and Ravens are negatively correlated, r = -.19 (p = .02), suggesting ubiquitous media multitasking may be associated with lower fluid intelligence.

Together, these data suggest that one's level of media multitasking is associated with a faster ability to task-switch, but is not associated with better task-switching accuracy. In addition, one's fluid intelligence is associated with slower task-switching ability, but higher task-switching accuracy. This indicates that fluid intelligence may

allow one to recognize the need to prepare for a task-switch, causing one to slow down and effectively prepare for a task-switch, which in turn, improves accuracy. Fluid intelligence is also associated with more accurate performance during a task-switch when a prior task has had little time to decay.



Figure 9. *RT 2-factor (advanced preparation and passive decay) task-switching model, with the addition of intelligence (Ravens, ACT) and media multitasking (MMT) measures.* ShCSI = Short cue-stimulus interval; ShRCI = Short response-cue interval; AF = animal/furniture task; NL = number/letter task; PT = plant/transportation task. *Significant at p < .05.



Figure 10. Error data 2-factor (advanced preparation and passive decay) task-switching model, with the addition of intelligence (Ravens, ACT) and media multitasking (MMT) measures. ShCSI = Short cue-stimulus interval; ShRCI = Short response-cue interval; AF = animal/furniture task; NL = number/letter task; PT = plant/transportation task. *Significant at p < .05.

CHAPTER 4. DISCUSSION

The ultimate goal of this work was to examine the relationship between media multitasking and task-switching performance. However, in order to do so, we began by first examining the structure of task-switching and identifying the factors that contribute to switch costs. We used an individual differences approach to evaluate how different putative mechanisms (advanced preparation, passive decay, attentional filtering, and response conflict resolution) were related to task-switching performance.

Our application of an individual differences approach to examine the structure of task-switching performance is a unique contribution to the task-switching literature. Investigating individual differences in performance can be a powerful addition to standard cognitive science studies as they can help constrain existing theories by allowing one to examine the covariation in performance on different tasks (Vogel & Awh, 2008). Many areas in psychology, including working memory for example, are now more informed and better understood because of the successful application of individual differences research (e.g., Cowan et al., 2005, Daneman & Carpenter, 1980: Kane & Engle, 2003). As such, by extending the methodologies used to investigate task-switching we are able to provide a better understanding of the existing literature on this topic as well as determine how task-switching fits into the larger framework of cognitive function.

Our individual difference approach suggests that task-switching performance is related to two somewhat independent factors, namely an advanced preparation factor and passive decay factor. We found no support for the putative attentional filtering and

response conflict resolution factors being related to an individual's task-switching performance.

Our demonstration that advanced preparation is a primary mechanism involved in task-switching is consistent with several accounts. Studies that find a reduction in switch costs at longer CSIs take this finding as evidence that the time interval prior to the onset of the stimulus is used to facilitate preparation that is differentially necessary for switch trials compared to repeat trials (Kiesel et al, 2010), either by implementing a reconfiguration process (Meiran, 1996), or by activating relevant processing pathways and deactivating irrelevant ones (Rogers & Monsell, 1995). In addition, studies suggest that preparation time does not alter the nature of the shifting processes that occur when a task-switch is required, it simply allows for the necessary processing to occur before the onset of the stimulus instead of after (Karayanidis & Jamadar, 2014). While our study finds evidence that advanced preparation is a key component of switch costs, it is still unclear whether this represents the need for an extra operation that occurs only in switch trials (i.e., reconfiguration), or if the same processes occur for switch and repeat trials, but take longer for switch trials (Kiesel, et al., 2010). Event-related potential (ERP) studies find some preparation processes common to both switch and repeat trials, but some more specific to switch trials (Jamadar, Michie, & Karayanidis, 2010). fRMI studies examining the neural correlates of switch costs find that activity is generally increased on switch trials compared to repeat trials, but there are no activation patterns selective to switch trials only (Richter & Yeung, 2014).

Our finding that passive decay is another primary factor involved in taskswitching is also supported by a substantial body of work. Allport et al. (1994) suggest

that switch costs reflect carryover from prior task-sets. Additional time is needed when switching to another task because there is a task-set inertia that interferes with performance of the current task. Similarly, the amount of decay of activation of prior task-sets impacts performance on the current trial (Koch et al, 2010). Altmann & Gray (2008) suggest that the impact of prior task-activation is determined by the activation level of task codes with the most highly active task code driving performance at a given moment. These decay processes have parallels with proactive interference processes (Allport et al., 1994), such that when there is less time for a task-set to decay, the more it will interfere with performance on the current task. Imaging studies find neural evidence for inhibition being one of the mechanisms that regulate interference of irrelevant tasksets during task-switching (Dreher & Berman, 2002).

Thus, in our study, an individual differences approach revealed two primary components involved in task-switching performance, advanced preparation and passive decay. First, these findings converge with a dual control system, which suggests that flexible and goal-directed cognitive behavior is driven by both executive and automatic mechanisms (Schneider & Shiffrin, 1977). Second, they provide converging evidence for Sohn & Anderson's (2001) two-component model of switch costs, which suggests that advanced preparation and activation of prior task-set are the primary contributors to switch costs.

As such, a two-factor model of task-switching performance fits with the classical view of the control mechanisms involved in human cognition. This view states that an executive control mechanism and an automatic control mechanism operate together in order to allow one to achieve goals that are relevant at a particular moment (Baddeley,

1986; Norman & Shallice, 1986, Schneider & Shiffrin, 1977). While the executive mechanism is an intentional and goal-directed application of cognitive control, automatic mechanisms operate based on the external stimulus, not necessarily consistent with one's current goals. Applying this logic to our results, it seems that the advance configuration factor is likely to reflect the executive control mechanism that actively prepares for the upcoming task. It is dependent on one's knowledge of the task because this affords them the ability to effectively prepare for the upcoming task. By contrast, the passive decay factor may reflect the more automatic or passive control mechanisms. The persisting activation of prior task-sets impact performance of one's current task and this occurs regardless of one's current goals.

Furthermore, Sohn & Anderson (2001) proposed a two-component model of taskswitching, which is consistent with the two-factor model we find support for in our study. Their model suggests that preparation, as well as prior task activation, are both contributors to one's task-switching performance. In addition, the two components are somewhat related, as repetition effects (which indicate prior task activation) occur even while an upcoming task is being prepared for. Their model is derived from a pattern of results that occurred when foreknowledge of task transition (switch vs repeat) was manipulated across different RSIs. With foreknowledge, the reduction of switch costs was due to faster switch trial RTs and without foreknowledge, reduced switch costs were due to slower repeat trial RTs. Importantly, their pattern of results could not be predicted by assuming a single source of switch costs and lends support for a dual component model of switch costs.

Consistent with the view that advanced preparation is associated with an active cognitive control process, our individual differences approach suggests that the magnitude of switch costs for an individual is related to their fluid intelligence. This is in line with the descriptions laid out by Schneider and Shiffrin (1977), in that the executive component is modified relatively easily and can be adopted without extensive training. In contrast, passive decay is a type of automatic process, and we find no relationship between passive decay and intelligence. The description of automatic processes is that they are difficult to modify and require considerable training to develop. Thus, this lends support to a two-factor model with an active and passive component, such that the active component is associated with fluid intelligence ability and the passive component is less related to reasoning ability. In addition, we found associations between fluid intelligence and task-switching performance, but no relationships between crystallized intelligence and the task-switching factors. This is consistent with what we know about fluid intelligence, in that it refers to the ability to reason, independent of previous knowledge, and is known to be particularly important for performance on a wide variety of tasks (Carpenter, Just, & Shell, 1990; Gray & Thompson, 2004). Having established a twofactor model, we were also able to evaluate the relationship between media multitasking and the two task-switching components. Again we found that the executive advanced preparation component is related to one's level of media multitasking, while media multitasking was unrelated to the automatic component of the model.

Although our work does not provide causality, our data suggest an increased ability to task-switch when provided with shorter preparation time among those who media multitask more frequently. In regards to the disparate findings concerning task-

switching and media multitasking, the data also suggest that a task-switching paradigm that emphasizes advanced preparation is likely to find a relationship between media multitasking and task-switching performance (e.g., Alzahabi & Becker, 2013). In contrast, a paradigm that is more sensitive to passive decay factors might fail to find such a relationship. At a more general level, research on practice and training suggests that task-switching performance can be improved, but the switch cost is rarely eliminated entirely (e.g., Kray & Lindenberger, 2000). Our data speak to the multiple processes involved in task-switching performance and suggest that the switch cost is composed of several processes differentially impacted by practice, which is why other studies may find residual costs after extensive training. More specifically, our findings suggest that a training study that uses a task-switching paradigm more sensitive to passive decay may find switch costs even after training, while one that is more sensitive to advanced preparation processes may find more pronounced reductions in switch costs because automatic processes (i.e. passive decay) are less susceptible to practice effects than executive (i.e, advanced preparation) processes. In addition, the extent to which training improves general task-switching ability is still debated. While some researchers find substantial transfer effects (e.g., Karbach & Kray, 2009), others argue that training is limited to the tasks that are trained for (Enriquez-Geppert, Huster, & Herrmann, 2013).

More importantly it seems that different types of media can have dramatically different effects on task-switching performance. Thus far, lab-based studies show weak transfer across different multitasking paradigms. Real-world situations, such as video game playing, appear to be more associated with improved task-switching performance (Cardoso-Leite, Green, & Bavelier, 2014). Thus, accurately capturing media

multitasking practices in lab-based media multitasking measures is essential examining how media multitasking impacts cognition. Studying the effects of media use on cognition is still in its infancy, but the rapid rise in the number of people and amount of time people are spending using media makes this issue more relevant and pressing.

Thus, understanding the real-world applications of media multitasking and taskswitching ability is important. This is especially critical because some studies find that people who perceive themselves as expert multitaskers actually performed poorly on labbased multitasking paradigms (Sanbonmatsu, et al., 2013). In addition, our study highlights the multiple mechanisms involved in task-switching performance, and how training can differentially impact them. Thus, studies examining real-world taskswitching performance would benefit from identifying the processes in a task-switching paradigm that are more likely to be related to practice effects. Our data suggests a taskswitching paradigm that relies heavily on advanced preparation processes may be related to better task-switching performance with practice.

Furthermore, in evaluating the relationship between task-switching performance and media multitasking, two particular areas of research would provide beneficial realworld applications. First, research in the education domain can provide useful information regarding cognitive implications of media multitasking during academic learning. For instance, one study that investigated media-induced task-switching practices while studying found that participants worked on a task for an average of six minutes before they switched to another task, often because of a technological distraction (Rosen, Carrier, & Cheever, 2012). In addition, participants who accessed social media had lower grade point averages than those who avoided social media use. Another study

found that non-academic internet use is related to lower academic performance, regardless of intellectual ability (Ravizza, Hambrick, & Fenn, 2014). Second, an application of these types of research question to the developmental domain would provide interesting implications. First, children are constantly immersed in a mediaengaged world and are now "growing up digital" (Pea, et al., 2012), providing for a unique, yet important, opportunity to investigate the impact of media use on cognition. Second, using a longitudinal methodology in the developmental domain can provide insight into the trajectory of cognitive performance beginning at a young age, particularly because research shows that plasticity of task-switching may vary along the developmental time course (Karbach & Kray, 2009). In addition, it can allow us to begin to assess the directionality of the association between task-switching performance and media multitasking levels.

In sum, this work provides results regarding the processes involved in taskswitching performance and how they are related to media multitasking and intelligence. Nevertheless, there are some limitations. First, the nature of our design does not allow for any causal inferences. While determining if there are associations between media multitasking and various cognitive functions is a first step to evaluating the impact of media multitasking on cognition, it will be necessary for future work to employ alternative methodologies, such as extensive training methods or longitudinal designs, to begin to assess the degree of causality.

In addition, the low reliability of switch cost measures caused us to rely on somewhat unorthodox z-score methods. This alternative scoring technique would have ideally been used to augment traditional RT data, but this was not possible due to the
issues with low reliabilities. Furthermore, the failure to find evidence for the involvement of attentional filtering and response conflict resolution processes in taskswitching may reflect the complexity of our design. As discussed, interleaving different stimulus manipulations within a block may have caused participants to employ strategies of responding that may not have been optimal for that particular trial (Los, 1996; Strayer & Kramer, 1994). While we decided to combine different manipulations within a block in attempt to minimize participant fatigue due to a lengthy experiment, this may have impacted responding strategies. Given that we did not find effects that we would expect at the mean level, it is perhaps not surprising that the individual differences analyses did not support the inclusion of these factors to accurately model task-switching. However, it is possible that these factors might be important in studies that use different designs. In addition, the two-factor model we found support for was a post-hoc model. Future work investigating the structure of task-switching performance should verify the structure of this model as an a priori model.

Lastly, we were unable to capture the nuances of media multitasking activities using a single measure. For instance, studies that have investigated media multitasking behavior find that there is structure to media consumption patterns that are not reflected in the total amount of media multitasking (Cardoso-Leite, Green, & Bavelier, 2014). The use of certain forms of media tend to co-occur more frequently with other forms, and the range of media multitasking differs qualitatively, rather than on a continuum of low to high media multitasking levels. In addition to measuring the amount of media multitasking people engage in, future work in this area would benefit from decomposing the media multitasking measure to assess the types of media forms that people are

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engaging in simultaneously and evaluating the degree to which people are combining different goals (i.e., tasks) and sub-goals together. A more granular understanding of media multitasking behavior will afford future work in this area a more powerful tool to examine the impact of media multitasking on cognition.

In conclusion, we applied an individual differences approach to examine the underlying structure of task-switching. Our analyses of four putative task-switching factors (advanced preparation, passive decay, attentional filtering, response conflict resolution) found evidence for only two (advanced preparation and passive decay). In addition, we found support for the active advanced preparation component being related to both media multitasking and intelligence, while the passive decay component was unrelated to either of these measures. This pattern of findings provides support for existing two-factor models of task-switching which posit an active preparation process and a passive decay process (Sohn & Anderson, 2001), and suggest that the active factors may be related to cognitive factors like fluid intelligence and practice effects (MMT) while the passive factor seems unrelated to these factors.

APPENDICES





Animal/Furniture Task: Classify animal as *fish/bird* and furniture as *chair/table*.

Number/Letter Task: Classify letter as *consonant/vowel* and number as *even/odd*. Consonants: G, K, M, R Vowels: A, E, I, U Even: 2, 4, 6, 8 Odd: 3, 5, 7, 9 Neutral: &, ?, *, %

Plant/Transportation Task: Classify plant as *tree/flower* and transportation as *car/plane*.



Figure 11. Stimuli for tasks.

Appendix B. Surveys

Media Multitasking Index Questionnaire (Revised)

- 1. Personal Information:
 - Please enter your HPR ID number:
 - Sex: M or F
 - Age:
 - Are you a native English speaker: Yes or No
 - ACT/SAT score:
- 2. Instructions: Thank you for taking the time to fill out this questionnaire about your media usage. The questions focus on media usage and combining media use with other activities.

The questionnaire will refer to "Primary" and "Secondary" media. A "Primary" media refers to the main media that you are engaging with, the one that is more prominent when you are using more than one media at a time. A "Secondary" media refers to the media that is less prominent, or one that is in less focus than the primary media, when you are using more than one media at a time. For instance, if you are involved in mostly watching television while occasionally text messaging a friend, television would be considered the "Primary" media and text messaging would be considered the "Secondary" media.

If you feel that while using multiple media at the same time, both are equally "Primary" media, choose one of the media that is closest to being primary, while the other is considered secondary.

When entering number of hours, please use standard numerical format (e.g., "12", "56") and use decimals to denote portions of an hour (e.g., "14.5", "31.25"). Avoid using ranges (e.g., 12-14 hours); just enter the average of the range you have in mind (e.g., 13). Also, avoid using labels such as "hours" or "hours per week."

Call the experimenter if you have any questions at this time. If not, continue to the next page.

3. Reading

- Do you read print media (for either work or pleasure)? This would include books, newspapers, magazines, traditional mail, etc. (If no, go on to the next page): Yes OR No
- Approximately how many hours a week do you spend doing this activity?
 As a "Primary" media:

- As a "Secondary" media:
- When reading print media is PRIMARY, how often are you also doing the following at the same time: Never, A little of the time, Some of the time, OR Most of the time
 - -Watching television, video, and/or DVDs (on a TV)
 - -Watching video content on a computer
 - -Listening to music
 - -Listening to non-musical audio (news radio, podcasts, etc...)
 - -Playing video or computer games
 - -Talking on the phone
 - -Instant messaging (chat)
 - -Mobile phone text-messaging
 - -Reading/writing e-mails
 - \circ -Reading web pages, pdfs, and/or other electronic documents
 - -Using other computer applications (word processing, spreadsheets, programming, etc...)
 - -Reading other print media simultaneously
 - -Commuting (walking, driving, etc...)
 - –Performing daily routine activities (eating, cooking, getting dressed, etc...)
 - o -Studying, sitting in class, sitting in office, etc...
 - -Spending time in social contexts (while with friends, family, etc...)
 - −Relaxing
 - −Exercising
 - -Other (please specify- must be a non-passive activity that requires some thought)
- When reading print media is SECONDARY, how often are you also doing the following at the same time: Never, A little of the time, Some of the time, OR Most of the time
 - -Watching television, video, and/or DVDs (on a TV)
 - o -Watching video content on a computer
 - -Listening to music
 - -Listening to non-musical audio (news radio, podcasts, etc...)
 - -Playing video or computer games
 - \circ -Talking on the phone
 - -Instant messaging (chat)
 - -Mobile phone text-messaging
 - -Reading/writing e-mails
 - -Reading web pages, pdfs, and/or other electronic documents
 - -Using other computer applications (word processing, spreadsheets, programming, etc...)
 - -Reading other print media simultaneously
 - -Commuting (walking, driving, etc...)
 - -Performing daily routine activities (eating, cooking, getting dressed, etc...)
 - o -Studying, sitting in class, sitting in office, etc...

- -Spending time in social contexts (while with friends, family, etc...)
- −Relaxing
- −Exercising
- -Other (please specify- must be a non-passive activity that requires some thought)
- 4. Television and Video: same format as question 3
- 5. Computer video: same format as question 3
- 6. Music: same format as question 3
- 7. Non-musical Audio: same format as question 3
- 8. Video Games: same format as question 3
- 9. Phone: same format as question 3
- 10. Instant Messaging: same format as question 3
- 11. Mobile Text Messaging: same format as question 3
- 12. E-mail: same format as question 3
- 13. The Web: same format as question 3

14. Other Computer Applications: same format as question 3

(see figures 12 and 13 for illustrations of formatting of questions 3-14)

15. Non-media activities

- When combining media usage with non-media activities, typically, what types of activities are you doing? Select one or all that apply:
 - Commuting (walking, driving...)
 - Performing daily routine activities (eating, cooking, getting dressed...)
 - Studying, sitting in class, sitting in office...
 - Spending time in social contexts (while with friends, family...)
 - Relaxing
 - Exercising
 - Other, please explain:

16. Summary

- When using multiple forms of media, how many forms of media are you typically accessing simultaneously:
 - 1 (e.g., only watching television)
 - 2 (e.g., watching television and sending emails)

- 3 (e.g., watching television, sending emails, and listening to music)
- 4 (e.g, watching television, sending emails, listening to music, and text messaging)
- 5 (e.g, watching television, sending emails, listening to music, text messaging, and reading a magazine)
- o 6 or more
- Typically, how many media tasks are you doing on a single device (e.g., instant messaging and word processing on laptop = 2 tasks per device; instant messaging on phone while word processing on laptop = 1 task per device):
 - o 1
 - o 2
 - o 3
 - \circ 4 or more
- For each of the following devices, indicate if you own one or not. If you do, indicate the number of hours a week you spend using that device: (No or Yes)
 - Smartphone:
 - Laptop:
 - Portable media player (e.g., iPod, etc.):
 - Tablet computer (e.g., iPad, Kindle Fire, etc.):
 - E-book reader (e.g., Kindle, Nook, etc.):
- If you do own one of the above devices, indicate the number of hours a week you spend it: (hours/week)
 - Smartphone:
 - Laptop:
 - Portable media player (e.g., iPod, etc.):
 - Tablet computer (e.g., iPad, Kindle Fire, etc.):
 - E-book reader (e.g., Kindle, Nook, etc.):
- During an average week, how many hours do you spend using one or more forms of media? It may be easiest to think of media usage in a typical day and multiply this by 7:
- When you are engaging with media while doing a secondary task, why are you doing multiple tasks at once? Indicate how much you agree with the following statements: (scale: 5-1 with 5 being strongly agree)
 - Because it makes me feel efficient.
 - o I'd rather be doing one task but feel I have to do multiple tasks.
 - I like to do more than one task at a time.
 - I can focus better when I'm engaging in multiple tasks.
 - I get bored with the primary task and so engage in multiple tasks.
 - I like to keep updated and connected with the world around me.
 - Other, please explain:
- 17. Thank You: Thank you for participating in the questionnaire.

	Never	A little of the time	Some of the time	Most of the time		
Watching television, video, and/or DVDs (on a TV)	\bigcirc	0	\bigcirc	0		
Watching video content on a computer	\bigcirc	0	\bigcirc	\bigcirc		
Listening to music	\bigcirc	0	\bigcirc	0		
Listening to non-musical audio (news radio, podcasts, etc)	\bigcirc	0	\bigcirc	0		
Playing video or computer games	\bigcirc	0	\bigcirc	0		
Talking on the phone	\odot	0	\bigcirc	0		
Instant messaging (chat)	\bigcirc	0	\bigcirc	0		
Mobile phone text-messaging	\bigcirc	0	\bigcirc	0		
Reading/writing e-mails	\bigcirc	0	\bigcirc	0		
Reading web pages, pdfs, and/or other electronic documents	\bigcirc	0	\bigcirc	0		
Using other computer applications (word processing, spreadsheets, programming, etc)	0	0	0	0		
Reading other print media simultaneously	\bigcirc	\odot	\bigcirc	\bigcirc		
Commuting (walking, driving, etc)	\bigcirc	0	\bigcirc	0		
Performing daily routine activities (eating, cooking, getting dressed, etc)	\bigcirc	0	\bigcirc	\bigcirc		
Studying, sitting in class, sitting in office, etc	\bigcirc	0	\bigcirc	0		
Spending time in social contexts (while with friends, family, etc)	\bigcirc	0	\bigcirc	\bigcirc		
Relaxing	\bigcirc	0	\bigcirc	0		
Exercising	\bigcirc	0	\bigcirc	\bigcirc		
Other	\bigcirc	0	\bigcirc	0		
Other (please specify- must be a non-passive activity that requires some thought)						

10. When reading print media is PRIMARY, how often are you also doing the following at the same time:

Figure 12. Part 1 illustration of formatting for Media Multitasking Index (Revised) questions 3-14.

	Never	A little of the time	Some of the time	Most of the time		
Watching television, video, and/or DVDs (on a TV)	\bigcirc	\bigcirc	0	0		
Watching video content on a computer	\bigcirc	\odot	\bigcirc	\bigcirc		
Listening to music	\bigcirc	0	\bigcirc	0		
Listening to non-musical audio (news radio, podcasts, etc)	\bigcirc	0	\bigcirc	0		
Playing video or computer games	\bigcirc	0	\bigcirc	0		
Talking on the phone	\bigcirc	0	0	0		
Instant messaging (chat)	\bigcirc	0	0	0		
Mobile phone text-messaging	\bigcirc	0	0	0		
Reading/writing e-mails	\bigcirc	0	\bigcirc	0		
Reading web pages, pdfs, and/or other electronic documents	\bigcirc	0	\bigcirc	\bigcirc		
Using other computer applications (word processing, spreadsheets, programming, etc)	0	0	0	0		
Reading other print media simultaneously	\bigcirc	\odot	\bigcirc	\bigcirc		
Commuting (walking, driving, etc)	\bigcirc	0	\bigcirc	0		
Performing daily routine activities (eating, cooking, getting dressed, etc)	\bigcirc	0	0	\bigcirc		
Studying, sitting in class, sitting in office, etc	\bigcirc	0	\bigcirc	0		
Spending time in social contexts (while with friends, family, etc)	\bigcirc	\odot	\bigcirc	\bigcirc		
Relaxing	\bigcirc	0	0	0		
Exercising	\bigcirc	\odot	0	\bigcirc		
Other	\bigcirc	0	\bigcirc	0		
Other (please specify- must be a non-passive activity that requires some thought)						

11. When reading print media is SECONDARY, how often are you also doing the following at the same time:

Figure 13. Part 2 illustration of formatting for Media Multitasking Index (Revised) questions 3-14.

Raven's Progressive Matrices (odd items)

For each item in this test, you will see a box with 3 rows and 3 columns. The box should consist of 9 objects, but only 8 are provided. The object in the lower-right corner is always missing. Your job is to determine which of the 8 possible solutions logically fits in the missing box.

You can do this by looking for patterns. These patterns may occur across the rows, down the columns, both across the rows and down the columns, or throughout all of the spaces. Each of the possible solutions is numbered (1 to 8). When you have determined the correct answer, please select it from the options. There is one, and only one, correct answer for each item.

You will now see some practice problems to get an idea of what the problems will be like.

This is an example of the kind of problem you will solve during this test.

The top part of this problem is a pattern with a bit cut out of it. Look at the pattern, think what the piece needed to complete the pattern correctly both along and down must be like. Then find the right bit out of the eight bits shown below.

Only one of these pieces is perfectly correct. Number 1 completes the pattern correctly going downwards but is wrong going the other way. Number 4 is correct going along, but is wrong going downward.

Which piece is correct going both ways?

Number eight is the right bit.

Please press enter to continue.





Figure 14. Raven's Progressive Matrices practice problem.



Figure 16. Raven's Progressive Matrices items 4-6.





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Figure 17. Raven's Progressive Matrices items 7-9.















Figure 18. Raven's Progressive Matrices items 10-12.















Figure 19. Raven's Progressive Matrices items 13-15.













Figure 20. Raven's Progressive Matrices items 16-18.

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