TOWARDS THE DEVELOPMENT OF AN ECOLOGICALLY VALID ASSESSMENT OF MULTITASKING: A SERIES OF EXPERIMENTS

A Dissertation

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ABSTRACT

The literature investigating the effects of media multitasking on executive function has found mixed results, with both negative and null effects being reported. However, the majority of these findings have been derived from paradigms originally used to investigate other, more specific cognitive processes not necessarily analogous to multitasking, such as working memory. As such, the literature is sorely in need of a paradigm devised solely to emulate a real-world multitasking environment. In chapter 1 of this dissertation, the current state of the media multitasking literature is discussed, with attention being brought to the current lack of an ecologically valid paradigm to assess real-world multitasking. In chapter 2, we detail the first iteration of this paradigm. It consists of a primary and secondary task, with prompts to switch to the secondary task displayed on random trials, similar to a modern-day computer environment. We used this paradigm in. conjunction with the Media Use Questionnaire, Multitasking Preference Inventory, and Barratt's Impulsiveness Scale to examine for an effect of media use frequency, multitasking preference, and impulsivity, respectively, on task performance within the paradigm. We found several weak relationships between media use frequency and task performance, with inconsequential findings regarding the latter two measures. We also identified several areas for improvement in our paradigm, such as an improvement to performance incentivization to encourage more task switches. This, in chapter 3, we addressed these issues and added two further components to the experimental procedure, including transcranial direct current stimulation (tDCS) and electroencephalography (EEG). We expected to replicate the negative effect of media use frequency on task performance seen in chapter 2, but we instead found a mix of anecdotal and moderate evidence for a null effect, suggesting that media multitasking incidence does not affect cognitive function. We also expected to see differences in ERP (event related potential) elicitation during EEG recording in primary task popup representation, but we found very little evidence supporting this prediction. Finally, we also found no evidence of an effect of tDCS stimulation on task performance. In chapter 4, we added a "distractor" popup that would occasionally take the place of a switch popup to test for differences in distractor filtering. We again examined for a relationship between media use frequency and task performance, including distractor filtering, as well as differences in primary task and popup representation using EEG. Replicating our findings in chapter 3, we found no effect of media multitasking on task performance, and no differences in ERP amplitude with media use frequency as a covariate. Taken together, these results inform the current prevailing literature stating that media use incidence is not related to executive function as indexed by task performance. Despite this, there are many future directions the literature may take, and these are detailed in chapter 5.

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NOMENCLATURE

BIS-11	Barratt's impulsiveness Scale-11
EEG	Electroencephalography
ERP	Event Related Potential
MMI	Media Multitasking Index
MPI	Multitasking Preference Inventory
MUQ	Media Use Questionnaire
MVPA	Multivariate Pattern Analysis
PRP	Psychological Refractory Period
RT	Reaction Time
tDCS	Transcranial Direct Current Stimulation
VTS	Voluntary Task Switching

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CHAPTER 1

GENERAL INTRODUCTION

Introduction to Multitasking

Multitasking is broadly defined as performing more than one task concurrently (Kim, Cilles, Johnson, & Gold, 2012). Given the prevalence of technology in today's society, media multitasking, or the act of attending to more than one source or stream of content at a time, (Ophir, Nass, & Wagner, 2009) is increasingly relevant. Indeed, the proportion of time an individual spends using more than one type of media as compared to total media use has increased from 16% to 29% between 1999 and 2009 (Rideout, 2010). However, the question of media multitasking's effect on cognitive and executive function still remains largely unanswered.

To that end, research on media multitasking has aimed to establish differences in cognitive processes between individuals who spend differing amounts of time engaging in the behavior, with a typical focus on extreme groups comparisons. These differences have largely been established using methodologies that do not represent or emulate the conditions or environments that media multitasking occurs in during day-to-day life. This presents the issue of whether what each paradigm used to evaluate multitasking performance is accurately assessing an individual's propensity and aptitude to media multitask. This review aims to summarize the major findings in the field thus far, as well as provide potential future considerations for task paradigms that may more aptly mirror how individuals media multitask in daily life.

Media Multitasking, Dual Task Paradigms, and the Psychological Refractory Period (PRP)

Madore and Wagner (2019) categorize the act of multitasking as the attempt to perform more than one task concurrently. Similarly, a dual-task paradigm involves the performance of two concurrent tasks, usually with a delay in the onset of each task (Fagot and Pashler, 1992). Because media multitasking involves completing several tasks with different media types, the bodies of literature have some overlap.

According to Koch, Poljac, Mueller, and Kiesel (2020), two versions of dual task paradigms exist. The first examines dual-task performance compared to performance in a single-task environment to then index dual-task interference, or the difference in performance between a single-task and dual-task environment. Here, the paradigm may consist of single or dual-task blocks, or even a mix of the two. Typically, performance is highest in single-task only blocks.

The second version of the paradigm examines the degree of dual-task interference as a function of the temporal overlap of the two tasks, known as the Psychological Refractory Period (PRP) (Pashler, 1994). More specifically, the PRP paradigm introduces the aspect of a variable stimulus onset asynchrony (SOA) between Task 1 and Task 2 such that both tasks are temporally separate to different extents throughout the experiment. The typical effect seen here is that as the SOA decreases, the reaction time to Task 2 increases (Pashler, 1994). This is thought to be due to a “processing bottleneck” that occurs when several stimuli are presented to an individual, leading to a decrease in task performance.

Real world media multitasking will often involve a form of dual tasking similar to what is seen in a PRP paradigm, with concurrent tasks being managed at different intervals. Shin and colleagues (2019) used a multisensory version of a PRP dual-task paradigm and found a positive effect of media multitasking in task performance at longer (1000 and -1000ms) SOAs, but no effect on the psychological refractory period. Similarly, Alzahabi and Becker (2013) also found no difference in dual tasking performance between heavy and light media multitaskers. As such, the effects of media multitasking during dual tasking and the psychological refractory period are limited, but results seem to point towards a lack of an interaction.

Initial Studies of Media Multitasking

Ophir, Nass, and Wagner (2009) developed the Media Use Questionnaire (MUQ) in an attempt to quantify the amount of time an individual media multitasks during a typical media-consumption hour. Participants were asked how many hours a week they use different media sources, followed by how often they concurrently use each other media type. From this information it was possible to quantify an individual's Media Multitasking Index (MMI). Across a variety of executive function tasks, Ophir and colleagues found that heavy media multitaskers performed worse compared to those who multitask less. These tasks included an AX-CPT task, N-Back task, and a task switching paradigm. During the AX-CPT, participants were shown a series of single letters on a computer screen, forming a cue-probe pair. If they saw the cue, in this case, the letter "A", followed by the probe, the letter "X", they were to respond via key press to indicate "YES." For all other cue-probe pairs, they responded via an alternate key press indicating "NO." While there were no performance differences between media multitasking groups (heavy vs. light) in this version of the task, Ophir and colleagues tested participants using a version of this task with distractor stimuli (Braver et al., 2001). In this version, letters are depicted in a different color from the target letters. Here, heavy media multitaskers were slower to respond, suggesting that these individuals are less able to filter out distractions and are thus more affected by extraneous stimuli.

Ophir and colleagues (2009) also found that heavy media multitaskers showed worse performance on the N-back task. In this paradigm, participants are shown a series of stimuli, usually single letters. They are instructed to indicate if the current stimulus is the same as the stimulus presented *N* trials before (Owen, McMillan, Laird, & Bullmore, 2005). In Ophir and colleagues (2009), a two- and three-back version of the N-back was used. They found that heavy media multitaskers responded to false alarms more often and earlier in the task, suggesting that these individuals are less able to filter out irrelevant distractors (in this task, the non-target letters) to a greater degree than lower media multitaskers.

Finally, Ophir and colleagues also found that heavy media multitaskers showed a greater switch cost, resulting in longer reaction times on trials preceded by a switch trial than on trials preceded by a repeat trial. Switch costs are often thought to result from competition from a previously activated but currently irrelevant task set (Wylie & Allport, 2000; Yeung, Nystrom, Aronson, & Cohen, 2006). Therefore, Ophir and colleagues suggested once again that heavy media multitaskers are unable to filter out irrelevant information (in this case, information related to the previous task) as well as their lower media multitasking counterparts.

In summary, Ophir et al's. initial experiment examining the effects of media multitasking on cognitive control resulted in the development of the first measures of an individual's frequency to media multitask, as well as a pattern of results indicating differences in distractor effects between heavy and light media multitaskers. Later studies would aim to replicate these findings, as well as examine for effects of media multitasking in other cognitive processes, described below.

Media Multitasking and Distractor Filtering

Ophir et al.’s (2009) finding that heavy media multitaskers are less able to filter out distractors is not unique (Cain et al., 2016; Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Heathcote et al., 2014.; Lottridge et al., 2015; Moisala et al., 2016; Wiradhany & Nieuwenstein, 2017). Specifically, Cain and Mitroff (2011) used the additional singleton paradigm (Costello, Madden, Shepler, Mitroff, & Leber, 2010) to test for differences in distractor filtering. In this task, participants are instructed to search for a shape singleton in the presence of an irrelevant color singleton. In one of the two conditions, participants were told that the color singleton would never be the target, while in the sometimes condition, they were told that it would sometimes be the target. Performance is evaluated by reaction time and accuracy. Heavy media multitaskers were slowest on trials following trials in which the target was also a color singleton. Cain and Mitroff suggest that this shows that heavy media multitaskers’ attention is captured by the color singleton the same way it is captured by any other stimulus. Thus, these individuals are less able to ignore these distractors and as such are slower on subsequent trials due to processing all present stimuli (Pinto, Olivers, & Theeuwes, 2005). This effect has been shown to hold in subsequent studies (Cain et al., 2016; Cardoso-Leite et al., 2016; Lottridge et al., 2015; Moisala et al., 2016; Wiradhany & Nieuwenstein, 2017).

Media Multitasking and Sustained Attention

Building on Ophir and colleagues (2009) original study, further research has been conducted into examining the link between media multitasking and attention. In particular, those who engage in media multitasking to a greater degree have been found to show deficits in sustained attention (Ralph, Thomson, Cheyne, & Smilek, 2014). Ralph and colleages (2014) used the Metronome Response Task (MRT), which tasks participants with responding in synchrony with a metronome, and the Media Use Questionnaire to test for differences in sustained attention between heavy and light media multitaskers. Performance is evaluated in terms of rhythmic response times (RRT), or the time before or after onset of the tone that participants take to respond (Seli, Cheyne, & Smilek, 2013; Seli, Jonker, Cheyne, & Smilek, 2013; Smilek, Carriere, & Cheyne, 2010). Ralph and colleagues (2014) found that MMI was negatively correlated with performance on the MRT, suggesting that those who media multitask to a greater degree have difficulty maintaining sustained attention.

In an additional experiment by Ralph et al. (2014), MMI was again negatively correlated with another paradigm designed to measure sustained attention, the Sustained Attention to Response Task (SART). In the SART, participants are asked to respond to a non-target and to withhold a response to a target. Performance is evaluated in terms of correct responses and response times. Finally, Ralph and Smilek (2017) found that heavy media multitaskers were more likely to disengage during an N-back task, as evidenced by a higher proportion of false alarms, but not hits, during the task. Heavy media multitaskers also admitted responding randomly during the task more often than light media multitaskers, as well as media multitasking during the experiment itself. Taken together, Ralph and colleagues (2014) findings suggest that the more an individual engages in media multitasking, the poorer their ability to sustain attention is.

Media Multitasking and Inhibitory Control/Impulsivity

Greater impulsivity and worse inhibitory control have been linked to MMI scores (Gorman & Green, 2016; Sanbonmatsu et al., 2013; Murphy & Creux, 2021; Rogobete et al., 2021; Shin et al., 2019). Previous work indicates that sensation-seeking and impulsivity might influence the frequency of media multitasking as well. For example, Jeong and Fishbein (2007) a weak positive association between total multitasking use and sensation seeking ratings on the Brief Sensation Seeking Scale. Similarly, Kononova (2013) found that sensation seeking predicted media multitasking frequency. Baumgartner and colleagues (2014) also found that adolescents who engaged in media multitasking more often were better able to ignore irrelevant distractors during the Eriksen Flankers task, suggesting a positive relationship between media multitasking and inhibition.

Researchers have also looked into delay discounting differences between high and low media multitaskers (Schutten, Stokes, & Arnell, 2017). Delay discounting refers to the ability for an individual to compare between the value of an immediate or delayed reward or payoff. More specifically, it refers to the depreciation of the perceived value of a reward in comparison to the amount of time, or delay, in actually receiving the reward (Matta, Gonçalves, & Bizarro, 2012). Because impulsivity is related to delay discounting (Frederick, 2005) and media multitasking (Sanbonmatsu et al., 2013), Schutten et al. (2017) compared participants who completed the MUQ and a delay discounting task. During this task, participants are given hypothetical scenarios in which they can elect to receive an immediate or a delayed reward, with the immediate reward never being greater than the delayed reward. Schutten and colleagues found that those with a higher MMI (as determined by the MUQ) were more willing to take the smaller, immediate reward rather than the delayed reward. Relatedly, media multitasking has also been found to be associated with attentional impulsivity, as measured by both performance on a Go/No-Go task and a subscale of the Barratt Impulsiveness Scale (BIS), as well as lower self-reported initiatory self-control (Shin, Webb, & Kemps, 2019). Taken together, these findings suggest that those who engage in media multitasking to a greater degree are more impulsive and prone to seeking immediate gratification, pointing towards decreased inhibitory control.

A similar result was found using the Test of Variables of Attention (TOVA) (Gorman & Green, 2016). On each trial of the TOVA, participants are instructed to respond to a square that appeared on the top half of the screen. If the square appeared on the bottom half of the screen, however, they were to give no response at all. Performance on this task is evaluated in terms of reaction time and number of incorrect responses. Incorrect responses were responses given on trials in which the square appeared on the bottom half of the screen. Gorman and Green found that those who media multitask more often (as determined by the MUQ) showed poorer overall performance on the task. These results again suggest that individuals who engage in media multitasking more often are unable to inhibit incorrect responses, thus showing impaired inhibitory control.

Contradictory Findings

Though the majority of findings regarding the effect of media multitasking point towards media multitasking having a negative effect on several cognitive processes, there have been a number of experiments that found no difference between heavy and light media multitaskers, or even findings in the opposite direction of the majority of the literature. In fact, a meta-analysis by Wiradhany and Nieuwenstein (2017) found only a weak association between media multitasking and distractibility, and a different meta-analysis by Parry and le Roux (2021) found a weak association between media multitasking and cognitive function in general. These contradictory findings exist in the task switching (Alzahabi & Becker, 2013; Alzahabi, Becker, & Hambrick, 2017, Schneider & Chun, 2021) dual tasking literature (Ie, Haller, Langer, & Courvoisier, 2012), and inhibition literature (Rogobete, Ionescu, & Miclea, 2021) as well. Alzahabi and Becker (2013) used a task switching paradigm, as well as a dual tasking paradigm to examine for performance differences between heavy and light media multitaskers. In their task switching paradigm, participants were to switch between classifying either a number as odd or even, or a letter as a consonant or a vowel. They were instructed when to switch and repeat tasks (Rogers & Monsell, 1995). In the dual task paradigm, participants were to respond to both the number and letter stimuli on each trial. Surprisingly, results from this study found that heavy media multitaskers had a similar switch cost than light media multitaskers during the task switching paradigm, contradicting Ophir et al's. (2009) findings. However, there was no relationship found between media multitasking and performance on the dual tasking paradigm.

Findings such as these show that the literature is far from reaching a conclusion on the effects of media multitasking on executive function and its many domains. Complicating things further, evidence also points towards specific individuals, dubbed "Supertaskers" that are extremely effective at attending to multiple tasks at the same time (Strayer & Watson, 2012; Watson & Strayer, 2010). Further still, there is evidence that intermediate levels of media multitasking may actually show greater performance on task switching and filtering tasks than both heavy and light media multitaskers (Cardoso-Leite et al., 2016, Shin, Linke, and Kemps, 2019). However, this pattern of results has been challenged by other studies (Edwards & Shin, 2017).

There are several factors that may be contributing to these contradictory findings. Namely, there is a lack of uniformity in regard to screen time and media use measures in the overall literature, a point brought up specifically by Kaye and colleagues (2020). They suggest that the conceptualization of media use is too broad in its current state, undermining the generalizability of any findings that may result. Indeed, the literature discussed thus far has failed to establish a uniform media use questionnaire. Another possible contributing factor to the contradictory findings reported thus far is the tendency for the current literature to focus on extreme groups differences between heavy and light media multitaskers, instead of an individual differences approach. While this may be due in part to Ophir and colleagues' initial design, this may ignore effects of "moderate" media multitasking, as well as differential individual effects. Finally, the purely artificial nature of the tasks used to operationalize multitasking may also be contributing to the pattern of findings in the current body of literature. This topic will be further discussed below.

Cognitive Tasks Analogous to Multitasking

Thus far, most, if not all of the tasks discussed are cognitive behavioral tasks that have been re-purposed to examine media multitasking, and as such are not always reminiscent of the act of multitasking. In daily life, multitasking is usually carried out at the leisure of the individual, with switches occurring randomly, which runs completely counter to the majority of the paradigms used in the literature.

There are few experiments that seek to emulate the conditions in which individuals multitask, and to an even lesser degree, media multitask, in their day-to-day lives. In a series of studies, multitasking while driving was examined while completing different tasks, including listening to a radio broadcast, answering questions from a radio quiz, or using a tablet (Ni Nijboer, Borst, van Rijn, & Taatgen, 2016). In almost all conditions, the addition of a new task alongside the primary driving task resulted in overall performance deficits in both tasks. Numerous other studies studying multitasking while driving have been conducted, with mixed results (Strayer, Watson, 2011; Sanbonmatsu, Strayer, Biondi, Behrends, & Moore, 2016; Strayer & Johnston, 2001; Strayer & Ward, 2010.).

Meanwhile, Bowman et al. (2010) investigated the effects of media multitasking by examining performance on a reading comprehension task while answering instant messages

(Bowman, Levine, Waite, & Gendron, 2010). In this task, participants were placed into one of three conditions: instant message (IM) before reading, IM during reading, and a control group. The task was completed via an online interface, such that both the passage was on the screen, and the IMs would appear in the corner of the screen. There was no effect of condition on performance on the reading comprehension task, however, participants in the IM during reading condition averaged a significantly longer time to finish reading the given passage.

The tasks described above bear a much closer resemblance to the conditions and environment that individuals multitask with and without media. This is especially true for the paradigm used by Bowman and colleagues, as the IM notifications were modeled to be similar to the notifications individuals see on their computers in day-to-day life. However, it is crucial to note that the performance metrics used in the Bowman task are very broad, and as such are not as easily applied or interpreted in terms of cognitive processing or executive functioning. Similarly, the driving tasks only examine multitasking in a singular environment (while driving), which severely limits the number of secondary tasks that can be attended to and thus does not give an environment completely analogous to multitasking in daily life.

Another attempt at designing a paradigm specifically dedicated to multitasking is the Multi-Attribute Task Battery (MATB) (Morgan et al., 2013). The MATB requires participants to attend to four different tasks at the same time. Their performance is shown on the screen at all times. While this task is a good example of a paradigm evaluating multitasking, it is far from a natural representation of multitasking. It is more reminiscent of a flight simulator, with multiple panels to attend to with varying levels of difficulty for each separate task that must be attended to.

Future Directions for the Literature

If research into media multitasking is to continue, it is necessary for the tasks that are used to evaluate it to be as reminiscent as possible of the environment in which individuals media multitask in daily life. Most, if not all of the task switching paradigms discussed explicitly instruct individuals when to switch. Individuals switch to different tasks of their own accord for many different reasons, including for relaxation or entertainment (Wang & Tchernev, 2012), or due to other visual cues (Brasel & Gips, 2017), thus, paradigms that do not include a volitional aspect of multitasking fail to properly simulate a situation in which an individual would engage in multitasking. Further, tasks such as the OSPAN or N-Back are designed to evaluate working memory and as such do not capture the cognitive processes at play while multitasking (Owen et al., 2005; Turner & Engle, 1989).

Further, Lui and colleagues (2022) point to the lack of an association between the multitasking costs found using more familiar, laboratory-based paradigms and the multitasking costs found using a more realistic multitasking paradigm, featuring driving based-tasks (Lui & Wong, 2019) as evidence for the need for a more ecologically valid real-world multitasking paradigm. They argue that real-world multitasking involves the monitoring of concurrent tasks which consist of both simple and more complex tasks and allow the participant to switch tasks at their leisure, enabling them to prioritize tasks as they see fit. This is in contrast to the aforementioned laboratory-based paradigms used to study multitasking which usually only include two simple tasks that also restrict the element of choice that is otherwise seen in real-world multitasking (Lui et al., 2022).

An Ecologically Valid Multitasking Paradigm

As such, a paradigm that more closely resembles a multitasking environment should include a primary and a secondary task. If one wishes to capture the frequency of pop-ups as seen on computer screens and on modern day smartphones, on each trial of the primary task, a “popup” should appear that asks the participant if they would like to switch to the secondary task. The prompts to switch should be modeled after those very same notifications and should appear randomly so that there is only a chance of the popup appearing on each trial of the primary task. This would simulate the rate at which individuals receive email and text notifications daily. A further manipulation may include “distractor pop-ups”, or notifications that appear to be prompts to switch tasks at first glance, but in reality, are nothing more than a simple message. This would more closely mirror the various spam messages and notifications that individuals ignore while surfing the internet in their phone or laptop.

Conclusion

As has been discussed, the media multitasking literature lacks an ecologically valid paradigm with which to evaluate multitasking performance. It also lacks a consensus as to the direction and extent to which frequent media use has on task performance while multitasking. To remedy these issues, the current work will focus on designing and validating a paradigm that more closely resembles a multitasking environment. Chapter 2 of this dissertation involved the initial design of one such paradigm that we then used to evaluate several factors that comprise task performance and how it is affected by media use frequency, attentional impulsivity, and preference for multitasking.

Chapter 3 then included the second iteration of the novel paradigm proposed in the previous section and combined that with transcranial direct current stimulation (tDCS) as well as electroencephalography (EEG). The addition of tDCS was to examine for an effect of noninvasive brain stimulation on task performance, and the addition of EEG was to further validate the paradigm we developed by looking for brain activation in areas typically implicated during common cognitive tasks that have used to study media multitasking performance. Finally, Chapter 4 of the current work then introduced a new element to the experimental paradigm, a distractor component, and examined for an effect of media use frequency (again measured in the same manner as the previous experiments) on task performance. EEG data was again collected here for the same reasons as in the previous chapter.

CHAPTER II

EFFECTS OF MEDIA MULTITASKING FREQUENCY ON A NOVEL VOLITIONAL MULTITASKING PARADIGM

Introduction

The preponderance of information available at our fingertips makes multitasking seem like the norm. Unsurprisingly, the proportion of time an individual multitasks with multiple information sources increased 10% from 6 hours and 20 minutes a day, to 7 hours and 38 minutes a day between 1999 and 2009 (Rideout, Ulla, Foehr, & Roberts, 2010). Furthermore, research suggests some negative impacts of screen time (i.e., time spent viewing television, phone/tablet, or laptop), on cognitive abilities and other psychosocial factors, and particularly on the development of these functions (Domingues-Montanari, 2017; Hooghe & Oser, 2015; Sigman, 2012). As such, it is critical to understand the costs and potential benefits of frequent media multitasking, often defined as the simultaneous use of two or more media types or the act of quickly switching between different media types (Minear, Brasher, McCurdy, Lewis, & Younggren, 2013).

Previously found Effects of Media Multitasking

To that end, research has aimed to establish differences in information processing as a function of time spent media multitasking, with a typical focus on extreme groups comparisons. A number of studies have now identified a negative association between media multitasking frequency and performance on cognitive tasks that require focus and cognitive stability such as distractor filtering (Lottridge et al., 2015; Moisala et al., 2016; Murphy & Creux, 2021; Wiradhany & Nieuwenstein, 2017), inhibitory control (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014; Schutten, Stokes, & Arnell, 2017), and sustained attention (Ralph & Smilek, 2017; Ralph, Thomson, Cheyne, & Smilek, 2014). Thus far, frequent or heavy media multitasking exposure has been linked to deficits in single task settings, but research into domains where one might expect multitaskers to excel, such as task switching, has produced more mixed results. For example, Ophir and colleagues (2009) found a negative association between heavy media multitaskers and task switching, while Alzahabi and Becker (2013) found the opposite relationship. Indeed, a growing body of work suggests no relationship between media multitasking and task switching performance (Baumgartner et al., 2014; Minear, Brasher, McCurdy, Lewis, & Younggren, 2013). More recently, Rogobete, Ionescu, and Miclea (2020) found that no linear relationship of media multitasking on task switching, but, when comparing extreme groups, the heavier media multitaskers counterintuitively performed better than low media multitaskers. Given these mixed results, more insight is necessary to describe the effect media multitasking has on this aspect of executive function.

The Media Use Questionnaire (MUQ) was developed by Ophir and colleagues (2009) to quantify the amount of time an individual media multitasks during a typical media-consumption hour. Participants are first asked how many hours a week they use different media sources, followed by how often they concurrently use each other media type. From this information it is possible to quantify an individual's Media Multitasking Index (MMI). Across a variety of executive function tasks, Ophir and colleagues found that heavy media multitaskers performed worse compared to those who multitask less. With this in mind, Ophir and colleagues suggested that heavy media multitaskers are less able to filter out irrelevant information when compared to their lighter media multitasking counterparts. In line with Ophir and colleagues, a number of studies have now shown a similar pattern of results (Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Heathcote et al., 2014.; Lottridge et al., 2015; Wiradhany & Nieuwenstein, 2017).

Can propensity for media multitasking be predicted by individual emotional or attitudinal differences? Previous work indicates that sensation-seeking and impulsivity might influence the frequency of media multitasking. For example, research suggests that a weak positive association between total multitasking use and sensation seeking ratings on the Brief Sensation Seeking Scale exists (Jeong & Fishbein, 2007). Similarly, sensation seeking has also been found to predict media multitasking frequency as measured by the MMI (Kononova, 2013). Sanbonmatsu and colleagues (2013) found that individuals with higher MMI scores tended to also score high on impulsivity, and moreover, performed worse on the Operation Span Task, a complex span task that involves rapid task switching, or multitasking, as defined by Madore and Wagner (2019). Furthermore, media multitasking has been found to be associated with attentional impulsivity, as measured by both performance on a Go/No-Go task and a subscale of the Barratt Impulsiveness Scale (BIS), as well as lower self-reported initiatory self-control (Shin, Webb, & Kemps, 2019). Finally, Minear and colleagues (2013) found that heavy media multitaskers reported being more impulsive while also showing worse performance on measures of fluid intelligence. Taken together, these findings point towards the possibility of an emotional and cognitive basis behind this phenomenon. However, some research does suggest that the effects of screen time, at least in regard to adolescent well-being, have thus far been overstated and are in fact, much smaller than has been purported (Orben & Przybylski, 2019).

Although most studies suggest a negative relationship between media multitasking and cognitive performance, a number have found no difference associated with media multitasking use, or even findings in the opposite direction. Indeed, a meta-analysis by Wiradhany and Nieuwenstein (2017) found a weak association between media multitasking and distractibility and a more recent meta-analysis by Parry and le Roux (2021) found a weak association between media multitasking and general cognitive function. These weak patterns of effects are prevalent in the task switching (Alzahabi & Becker, 2013; Alzahabi, Becker, & Hambrick, 2017; Schneider & Chun, 2021), dual tasking, (Ie, Haller, Langer, & Courvoisier, 2012), and inhibition literature (Rogobete et al., 2020). Interestingly, two studies have found that intermediate or moderate multitaskers show better N-back performance compared to heavy and light media multitaskers (Cardoso-Leite et al., 2016; Shin, Linke, & Kemps, 2020). Nevertheless, research examining intermediate or average media multitaskers is much less common than the extreme groups comparisons that the literature has to date focused on.

Purpose

In summary, there are still many outstanding questions regarding media multitasking's effect on task performance. Though the literature has found some effects, these have been derived from already established paradigms that have been historically used to study other cognitive processes that are not always immediately reminiscent of multitasking. In day-to-day life, multitasking is usually done at the leisure of the individual, with task switches occurring randomly and sporadically; this is counter to most lab-based studies of multitasking, in which the experimenter dictates when and how an individual multitasks. By giving participants the choice of when to switch to a secondary task, as well as modeling the task to be more similar to a multitasking environment, we can examine whether media multitasking frequency relates to one's tendency to switch tasks often as well as overall task performance. Thus, in the current study, we developed a novel experimental framework more analogous to multitasking in day-to-day life by having participants complete a primary, monotonous task with sporadic "interruptions" presented in the form of an opportunity to switch to a different, secondary task. We hope to use this paradigm to dispel the ambiguity in the current literature in the field by allowing us to examine the differences more closely between individuals' task performance and the effect extensive daily media multitasking may have on it by using a task specifically designed to emulate real-world multitasking. The ability to replicate previously established effects with this more ecologically valid paradigm would provide further support for those effects as well. Further, a majority of the literature has focused on an extreme groups approach. While this is obviously very valuable information to have, the question still remains as to whether any degree of media multitasking can affect task performance and not only in extreme "high" or "low" cases. The current work seeks to reconcile the limitations of the extreme groups approach, as well as establish a more ecologically valid task paradigm that can then be used to further examine cognitive differences and how they are affected by media multitasking.

In the current study, we operationalized the act of multitasking as the attempt to perform more than one task concurrently which then leads to the act of switching back and forth between tasks (Madore & Wagner, 2019). To that end, we designed the framework of our novel paradigm around the Operation Span Task (OSPAN) devised by Turner and Engle (1989) as it requires participants to complete two tasks concurrently. In fact, Sanbonmatsu and colleagues (2013) previously used the OSPAN to examine multitasking ability. In our paradigm, a participants' primary task was a math problem verification task, similar to the OSPAN. However, in some trials, a pop-up message occasionally appeared which asked if the participant wanted to switch to a secondary task. The pop-up prompts were implemented to be reminiscent of the notifications that appear on our phones and computers and appeared randomly throughout a block of trials. If the participant indicated that they wanted to switch, they were then given a word stem completion to solve, after which they returned to the primary task. This is another differentiation from the OSPAN, as the secondary task in that paradigm is not optional and indexes an individual’s working memory by asking participants to recall a series of letters that are presented after each primary task trial at the end of a block. In our current task, the participant does not have to hold any objects in their working memory as they work through the task, instead indexing their ability to task-switch.

Our paradigm also draws from the voluntary task switching (VTS) literature (Arrington & Logan, 2015). We chose to model our paradigm from this literature because of the similar scenarios that are presented to participants in those paradigms. Here, the volitional aspect that is common in VTS tasks paradigms is present, albeit with some fundamental changes. The participant is only prompted to respond on a random subset of trials as opposed to having the option during each trial, a deviation from most VTS paradigms (Arrington & Logan, 2004; Mayr & Bell, 2006; Orr & Weissman, 2011). For every trial in which the option to switch tasks is not presented, the participant is only able to complete the primary task. Again, this was done in an attempt to further emulate a scenario in which real-world multitasking might occur. For example, an individual may be focused on a task on their computer, when a random popup in the corner of the screen may catch their eye. The individual then has the option to switch tasks away from their main focus to attend to this popup, a crucial element that is not present in VTS paradigms.

Hypotheses

We predicted a positive relationship between MMI score and the rate at which participants would elect to switch to the secondary task (*Switch Rate*). We also expected that participants would show a “*Return Cost*”, i.e., respond slower to return to the primary task following a switch to the secondary task that would be positively predicted by media multitasking in line with the suggestion that media multitasking frequency is associated with decreased executive function (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014; Cain et al., 2016). Additionally, we predicted that individuals who media multitask more often would choose to switch to the secondary task more quickly (in the form of a faster time to elect to switch tasks on relevant trials, which we refer to as *Popup*$_{select}$), In line with the suggestion that frequent multitaskers show increased difficulties with distractor filtering, we predicted that MMI score would also show a positive relationship with the amount of interference exhibited on trials where a pop-up was presented, but the secondary task wasn't chosen (*Interference Cost)*.

Methods

Participants

A total of 90 participants (62 female, 28 male) with ages ranging from 18-23 years (M = 19.15, SD = 0.9) fully completed the procedure. Two participants were dropped due to non-completion of the study. Participants were recruited from the Texas A&M Psychology Subject Pool and received course credit for participating. No target sample size was determined, with the intent to collect as much data as possible through the course of a full semester. A post-hoc power analysis was performed, described below. Demographic information is reported in *Table 1*. Participants were not prescreened for media multitasking frequency and only had to be English-speakers who were right-handed, neurotypical, had full color vision, and were between the ages of 18-30 years old; in addition, participants were not told this was a study on multitasking until they were consented to participate in the study. Study procedures were deemed exempt from the requirements of the Common Rule (45 CFR 46.101[b]) by the Texas A&M Institutional Review Board, approval reference number IRB2018-1456M. The authors confirm that we have reported all measures, conditions, data exclusions, and the method of sample size determination.

Media Multitasking Index

A Media Multitasking Index (MMI) was calculated in order to assess the degree to which participants multitask with different forms of media (Ophir, Nass, & Wagner, 2009). Participants first completed the Media Use Questionnaire, which asked participants to estimate how many hours per week they use each individual form of media (using a sliding scale ranging from 0-80 (in hours). They were then given a matrix asking, for each media type they use, how often they concurrently used each of the other mediums using a 5-point Likert scale ("Always," "Most of the time," "Some of the time," "A little of the time," or "Never"). Although these values are not disclosed to the participants, numeric values were assigned to each of the matrix answers, such that "1.0" represented "Always", "0.75" corresponded to "Most of the time," "0.5" to "About half the time", "0.25" to "Sometimes," and "0" to "Never." The sum of these values across primary medium use weighted by the percentage of time spent with the corresponding primary medium was then computed to yield a participant's Media Multitasking Index (MMI) score. This final MMI score can be interpreted as the level of media multitasking the participant is engaged in during a typical media-consumption hour so that the higher the MMI, the greater the amount of time that participant spends media multitasking in an hour. Figure 2.1 shows the equation Ophir and colleagues (2009) used for calculating MMI scores, again used in the current study. Briefly, the index is calculated by assigning numeric values to each of the matrix answers and weighing the sum of these values across each primary medium by the percentage of time spent with the corresponding primary medium.

$$\mathrm{MMI} = \sum_{i=1}^{11} \frac{m_{i}\ \mathrm{X}\ h_{i}}{h_{\mathrm{total}}}$$

Figure 2.1—Equation used to Calculate Media Multitasking Index

The original version of the Media Use Questionnaire (Ophir et al., 2009) was modified for the current study to reflect current trends in media usage. This modified version assessed 12 media types; computer-based applications (e.g., word processing, excel), web surfing (not including social media sites), text-based media such as print books, eBooks, magazines, newspapers (for school/work/pleasure), television programs (TV based or online streaming), streaming videos (e.g., YouTube, BuzzFeed, other short clips), listening to music, listening to nonmusic audio (e.g., audio books, podcasts,, talk radio, etc.), video based games (console, computer, phone/tablet based), voice calls (landline, cellphone, skype), reading/writing emails, viewing social media (Facebook, Instagram, Snapchat, Twitter, etc.), and "other" media types. The original version of the questionnaire's "instant messaging" media type was replaced with "social media" to reflect the rise of social media and the decline of instant messaging since the creation of the questionnaire. We also changed the wording for several media types. "Print media" was changed to "text media" to reflect the popularity of e-readers, "telephone and mobile phone voice calls" was changed to "voice calls," "computer-based video" was renamed to "streaming video" (to reflect current trends towards services such as YouTube, Netflix, and Hulu), and "video or computer games" was renamed to "video games." Ophir et al.'s version of the index used only a 4-point Likert scale ranging from “Most of the time” to ‘‘Never’’. We added the additional answer choice of “Always” in an attempt to get a more precise measure of media multitasking occurrence. The addition of the extra choice of “Always” was done to counterbalance the already existing “Never” answer choice.

Multitasking Preference Inventory (MPI)

Participants also completed the Multitasking Preference Inventory, a 14-item questionnaire devised by Poposki and Oswald (2010) to index an individual’s general “preference towards multitasking.” It consists of fourteen statements relating to their opinions on performing tasks (ex: “I prefer to work on several projects in a day, rather than completing one project and then switching to another.”) that they then indicate on a 1 (*Strongly Disagree*) to 5 (*Strongly Agree)* Likert scale as to how well each describes them. Scoring was done in accordance with Poposki and Oswald (2010) and includes the summation of all items once the appropriate questions have been reverse scored. Higher scores on this measure suggest a higher inclination to want to multitask.

Barratt Impulsiveness Scale-11 (BIS-11)

To assess impulsivity, the BIS-11 was administered and scored according to previous works, consisting of the sum of all items following the reverse scoring of the appropriate questions. (Patton, Stanford, & Barratt, 1995). The questionnaire consists of 30 items on a 1 (*Rarely/Never*) to 4 (*Almost Always/Always*) Likert scale related to impulsive behaviors and attitudes. The scale can be further broken down into 6 first order factors (Attention, Cognitive Instability, Motor, Perseverance, Self-Control, and Cognitive Complexity) and 3 second order factors (Attentional, Motor, and Nonplanning). Following Sanbonmatsu et al. (2013), all 30 questions of the BIS-11 were used, with the Attentional impulsivity sub-scale being especially of interest for the current study

Multitasking Paradigm

Figure 2.2 is a representation of the multitasking paradigm. Participants completed a computerized multitasking paradigm, created using PsychoPy version 3.0.6 (Peirce et al., 2019), on a 21-inch iMac (Apple, Inc.). All monitor settings were determined by the default test monitor settings within PsychoPy. For the primary task, participants checked the validity of math operations (e.g., ‘(3–2) × 1 = 4’) via key press, with “C” indicating the math problem was correct, and “I” to indicate an incorrect problem. The math operations were on the screen for 5 seconds. Participants were informed that a correct response to the primary task was worth 3 points. Incorrect or responses not made in time would deduct this same amount from the total. Participants were shown their running total after every trial. The points did not have a monetary value, but to incentivize participants to achieve as high a score as possible, they were shown a “high score” at the end of each block. This high score was the same for each participant.

On one out of every six primary task trials, a text “popup” would appear on the screen 500 ms after the primary task appeared, reading “A New Task is Available! Press ‘Y’ to switch tasks”. This popup would appear on the top right corner of the screen. The position of the popups was chosen so that they would be reminiscent of the notifications seen on computers and cell phones. The popup would appear on screen for 2 seconds, after which the text would disappear. Participants could choose to continue attending to the primary task instead of the popup. If participants chose to switch tasks, they would then be shown a word fragment with two letters missing (e.g., “HI_TO_Y”). Participants would then indicate which letters were missing via key press. A correct response to the secondary task was worth 10 points, with an incorrect or response not made in time would deduct this same amount from the total. The discrepancy of possible points between the primary and secondary tasks was implemented to make the secondary task more enticing and encourage multitasking, due to the greater number of points possible for successfully completing it. Participants again were shown their running total at the end of each trial.

The task consisted of 8 blocks of 20 trials each for a total of 160 trials. The number of blocks was chosen so that the task would be broken up into intervals allowing the participant to take breaks regularly while still being able to complete the experiment in under an hour. The number of pop-ups was not consistent across participants due to the randomization procedure, with an average of 27.8 (*SD* = 4.4) pop-ups per participant.

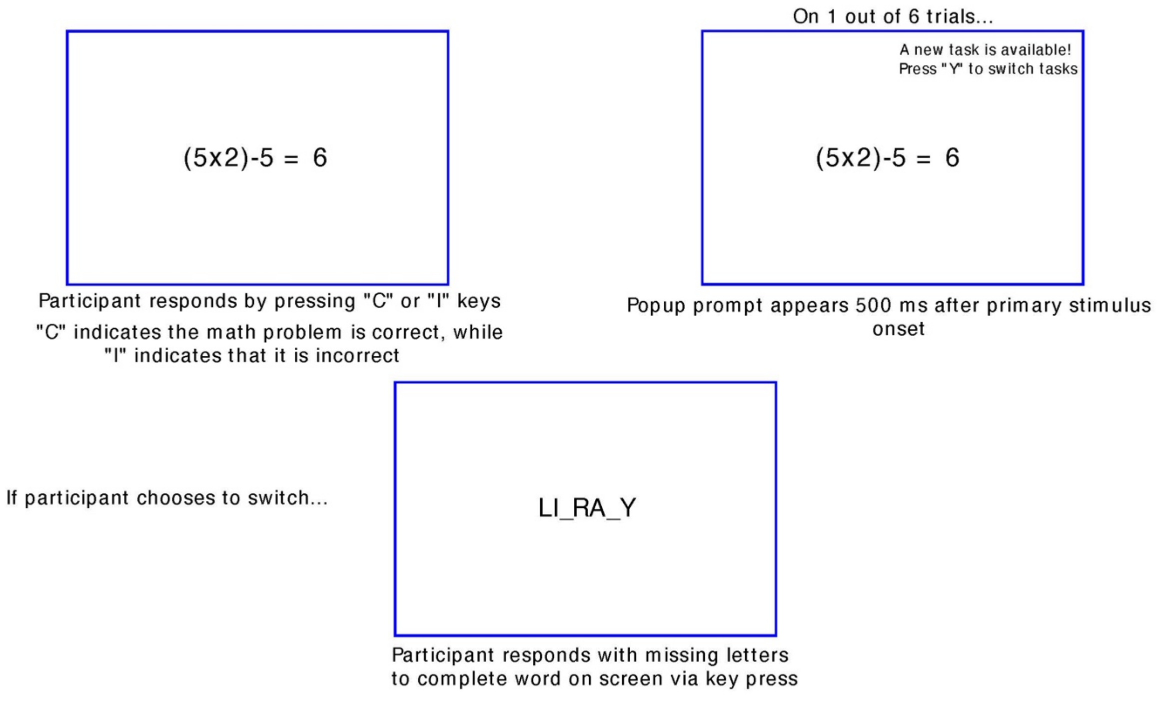


Figure 2.2—Overview of Multitasking Paradigm

Procedure

After providing consent via a written consent form, participants completed an online version of the Media Use Questionnaire, the MPI, the BIS-11, and a demographics questionnaire. After completion of the surveys, participants then completed a short practice version of the novel multitasking paradigm, followed by the full version of the task. The practice version of the task consisted of three distinct blocks. In the first block, participants completed 5 trials of only the primary task. Similarly, they completed 5 trials of only the secondary task in the second block. In the final practice block, participants completed 6 trials of the full task. Point values were identical to the full task. The total experiment duration was about 1 hour.

Data Analysis

Analyses and plots were created using RStudio Version 1.2.5033 (R Core Team, 2019). Post hoc power analysis was conducted using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009). Survey scores were compared using Pearson's 2-tailed correlations. The main dependent measures for task performance were switch rate (the percentage of trials in which a participant switched tasks across all trials in which switches were possible), $\text{Popup}_{\text{select}}$, or the reaction time for individuals to elect to switch tasks on relevant trials, i.e., the difference in average reaction time for primary tasks following a switch to the secondary task minus the average reaction time for all other primary task trials without a popup, and *Interference Cost*, i.e., the difference in reaction time for primary task trials with a non-selected pop-up and primary task trials without a pop-up.

Because some participants did not switch at all throughout the task (*n* = 23), it was not possible to calculate some measures for the entire sample. The effects of media multitasking on task performance were analyzed using a hierarchical regression model consisting of the three main surveys (Attentional BIS, MMI, and MPI) to predict each measure of task performance. In the first step of the regression, we included only MMI Score, as that was the main construct of interest. In step 2, we then included the attentional sub-scale of the BIS score, with MPI score being added in step 3.

To maximize the amount of useable data, all trials in which a participant responded to either task were included in our analyses, unless otherwise noted. The data and materials for this experiment are available at (https://osf.io/nju8a/?view_only=27e3adfafbba48488a1bf0f7c20e1f4a). This experiment was not preregistered.

Results

Survey Results

Table 2.1 (Tables 2.1-2.14 can be found in Appendix A) shows a breakdown of survey scores. Mean MMI was 2.95 (SD = 1.3), with significant deviation from normality ($W = 0.96$, $p = .01$). There was no difference in MMI between males and females, $F(1,88) = 1.77$, $p = .19$, $\eta_p^2 = 0.02$. Our mean MMI is relatively in line with that of other studies using the original MUQ questionnaire and its method of calculation devised by Ophir and colleagues (2009) (Moisala et al., 2016; Ralph et al., 2014; Schneider & Chun, 2021).

The mean MPI score was 38.5 (*SD* = 10.9), indicating an overall neutral preference for multitasking. This is slightly higher and less variable than previous studies that have also used this measure, suggesting that our sample had a slightly greater preference for multitasking. For example, a random sample of experienced Amazon MTurk workers resulted in an average of 38.01 (*SD* = 12.54) (Lascau, Gould, Cox, Karmannaya, & Brumby, 2019). Relatedly, an inperson sample of university students found an average MPI score of 29.95 (*SD* = 8.72) (Magen, 2017).

Median Total BIS was 61.0 (*SD* = 9.7), with a median Attentional score of 17.0 (*SD* = 3.9), a median Motor score of 20.0 (*SD* = 4.3), and a median Nonplanning score of 23.5 (*SD* = 4.2). MMI was significantly correlated with BIS-Motor (r = 0.27), and MPI scores were correlated with Total BIS (r = 0.26) as well as BIS-Attentional (r = 0.29), BIS-Cognitive Instability (r = .23), BIS-Self Control (r = .23) and BIS-Motor (r = 0.22) sub-scale scores. However, MMI was not correlated with MPI (r = -0.1). Expectedly, all of the BIS sub-scales were correlated with Total BIS (all $r > 0.74$). Table 2.2 (in appendix A) shows a correlation matrix of all surveys and behavioral measures.

Multitasking Performance

Participants performed the primary task (math problem verification) with high accuracy (*M* = 94.3%, *CI* = 91.8-97.1%) and the secondary task (word stem completion) with moderate accuracy (*M* = 69.7%, *CI* = 59.1-89.2%). Popups appeared on a median of 28 trials (*CI* = 24.25-30.75), and participants chose to switch to the secondary task on an average of 30.8% of pop-up trials (*CI* = 22.6-54.7%). Twenty-three participants did not respond to any of the popups, with an additional 8 only responding to 1. Primary task reaction time was then analyzed in a repeated measures ANOVA with one factor with the following levels: Ignore (i.e., popup was present but not responded to), Return (i.e., previous trial on which the secondary task was performed), and No Popup (i.e., no popup on current or previous trial). Only correct trials were included in this analysis and participants with less than 3 values in any cell were excluded, resulting in a final sample of 50 participants. There was a main effect of condition ($F(1.32, 64.7) = 24.9$, $p < 0.01$, $\eta_g^2 = 0.08$), and pairwise tests showed significant differences between No Popup and Return (i.e., Return Cost), Return and Ignore, but not No Popup and Ignore (i.e., Interference Cost), as shown in Figure 2.3. A similar analysis was run for accuracy data (as in transformed), and no effect of condition was observed ($F(1.71, 85.72) = 1.4$, $p = 0.25$, $\eta_g^2 = 0.017$).

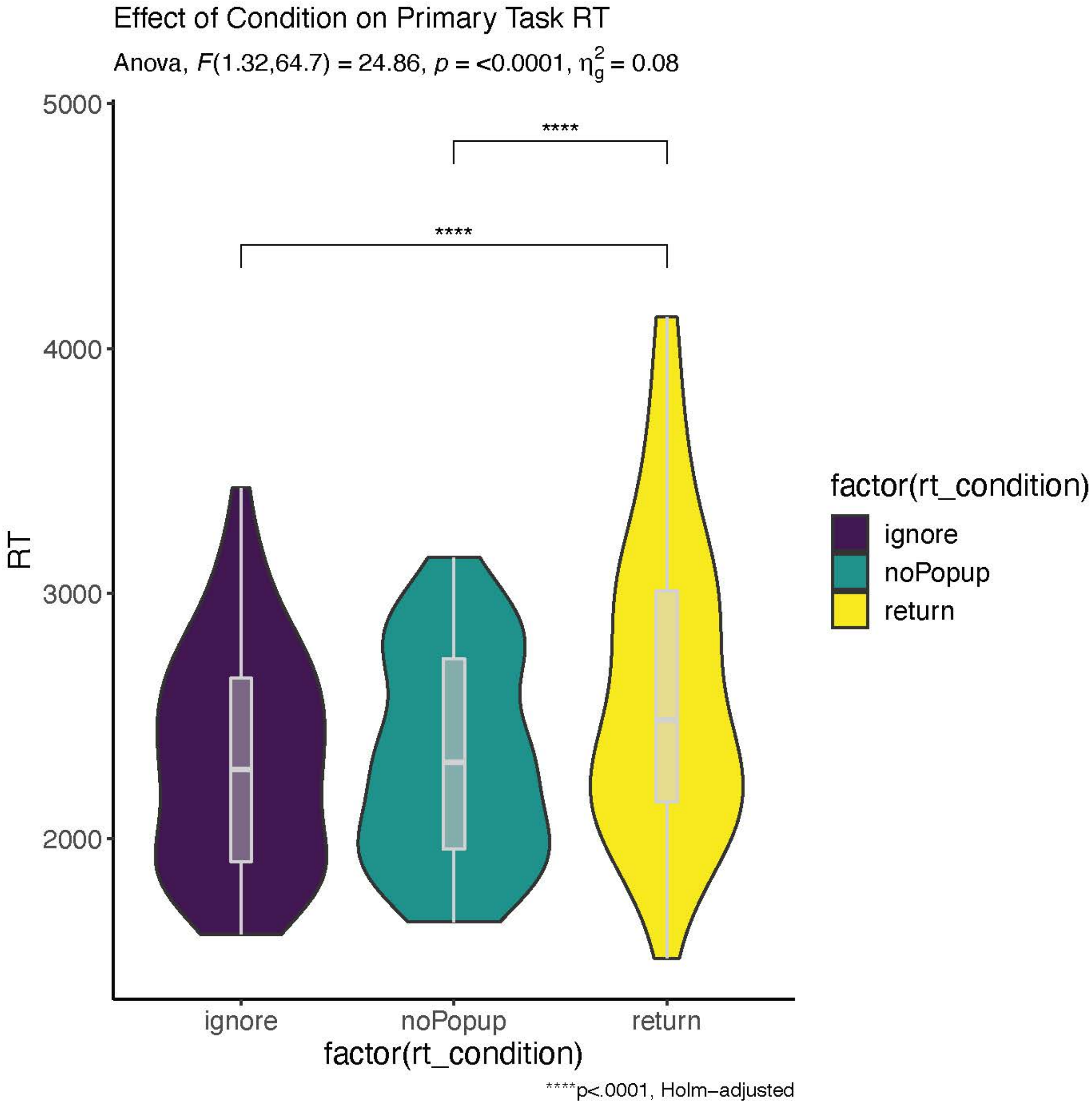


Figure 2.3 Effect of Condition on Primary Task RT

Next, we examined whether multitasking behavior was predicted by the multitasking and personality surveys. Table 2.3 (in appendix A) shows a breakdown of the main behavioral measures analyzed (switch rate, return cost, interference cost, and $Popup_{select}$) here. Figure 2.*4* shows correlational plots between the main behavioral measures analyzed and MMI score. Because we took a hierarchical regression modeling approach, we conducted three separate post hoc power analyses on the main analyses described using G*power (Faul et al.,2009), one for each separate model added.

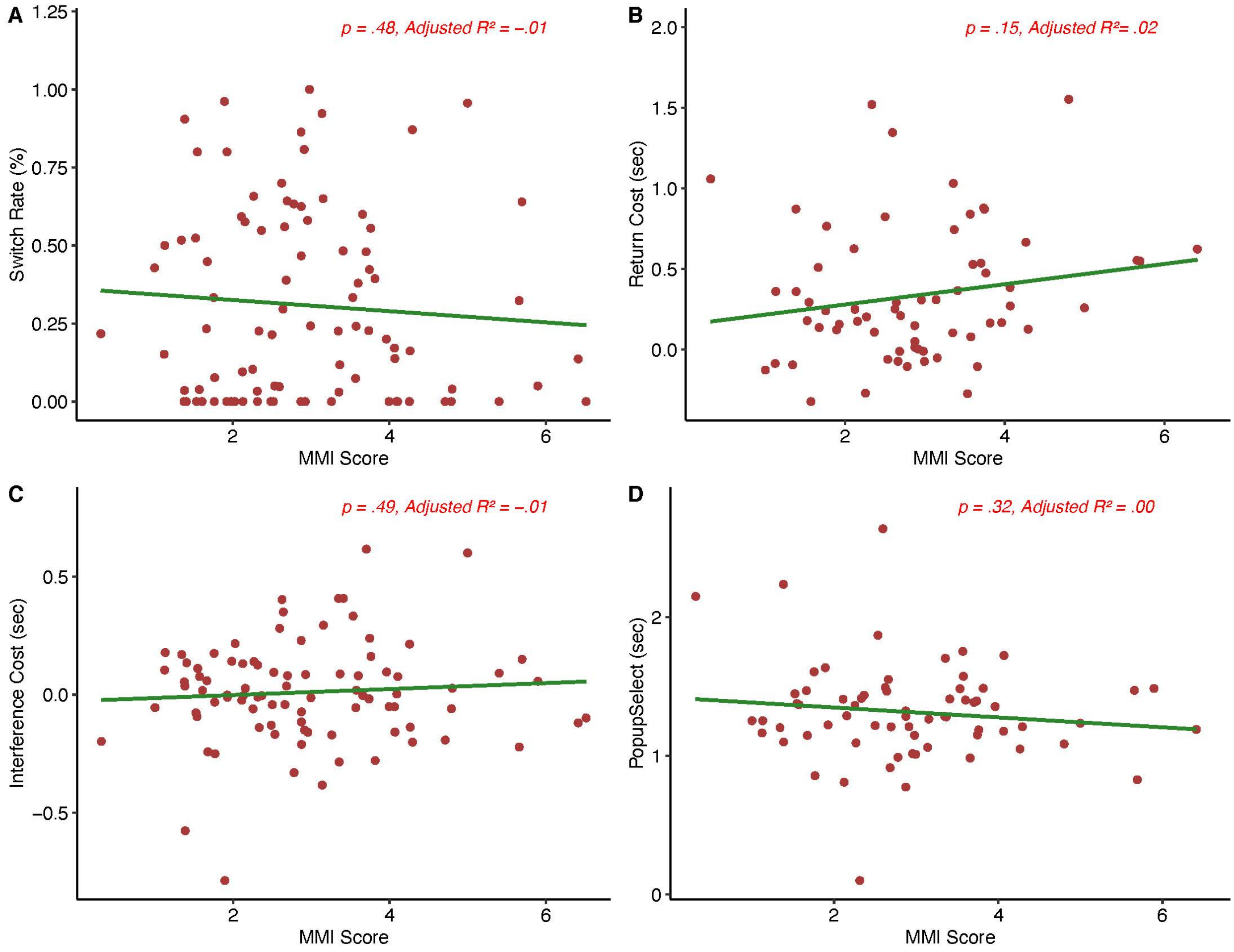


Figure 2.4 MMI Score vs. Main Behavioral Measures

Switch rate. The hierarchical model predicted switch rate (the percentage of trials in which a participant switched tasks across all trials in which a popup occurred) only in step 3 (Full model: $F(3, 86) = 5.6$, $p = .001$, Adjusted $R^2 = .13$). Only step 3 of the model achieved greater than 80% power according to a post-hoc power analysis. Individual predictors in the model were examined further, and only MPI score predicted switch rate ($B = 0.01$, $SE = 0.003$, t

= 3.8, *p* = <.001). Given that the MPI is thought to reflect the tendency or preference to multitask, we expected MPI to relate to switch rate, which was supported by our results. Table 2.4 (in appendix A) shows the hierarchical model at each step for this variable. To more directly relate MPI and switch rate, we correlated non-zero switch rate and MPI scores, and found a significant positive correlation (*r(*65) = .33, *p* = .007), suggesting that the tendency to multitask in day-to-day life, as indexed by the MPI, does indeed have at least a weak association with participants' choice to switch to the secondary task when given the opportunity.

Return cost. None of the steps in the hierarchical regression model were significant for return cost, or the difference in average reaction time for primary tasks following a switch to the secondary task minus the average reaction time for all other primary task trials without a popup (Full model: *F(*3,61) = 1.42, *p* =.25, Adjusted R^2 = .02). A post hoc power analysis also suggested that we did not reach the sample size necessary to achieve above 80% power on any of the three steps of the model. We expected return cost to be related to MMI score, in line with previous work suggesting that media multitaskers show a decrease in task performance, but this was not the case. Table 2.5 (in appendix A) shows the hierarchical model at each step for this variable.

Interference cost. The hierarchical model predicting interference cost, or the difference in average reaction time for primary task trials with a non-selected pop-up and average reaction time on primary task trials without a pop-up was not significant at any step (Full model: *F*(3, 85) = 0.69, *p* = .56, Adjusted R^2 = -.01). A post hoc power analysis also suggested that we did not reach the sample size necessary to achieve above 80% power on any of the three steps of the model. Table 2.6 (in appendix A) shows the hierarchical model at each step for interference cost.

Popup$_{select}$. Table 2.7 (in appendix A) shows the hierarchical model at each step for Popup$_{select}$. None of the three models predicting Popup$_{select}$, or the RT for participants to choose to switch after popup onset on relevant trials, were significant (Full model: *F*(3, 63) = 0.93, *p* = .43, Adjusted $R^2 < .001$). \Our pattern of results here suggests that there was no difference in the amount of time an individual took to elect to switch tasks in relevant trials in terms of degree of multitasking, impulsivity score, or preference for multitasking.

Exploratory Analyses

As this is a novel task with many components, we made several exploratory comparisons to examine the relationships between MMI and task performance. To this end we examined RT on trials in which the participant ignored the popup and completed the primary task (Popup$_{ignore}$), response time to elect to switch (i.e., time to respond to the prompt, “A New Task is Available! Press ‘Y’ to switch tasks”) Popup$_{select}$, response time on non-popup trials (Primary$_{nopopup}$), RT on primary trials following a switch, regardless of availability of a switch (Primary$_{return}$), RT on trials in which the individual repeated the primary task (Primary$_{repeat}$), and overall average RT on the primary and secondary tasks were also determined for each participant. As before, because some participants did not switch tasks at all, some of these measures could not be calculated for the entire sample. We again used a hierarchical multiple regression analysis to develop a model predicting each of these measures based on survey results. The first step of the model added MMI score to the model, while steps 2 and 3 added attentional impulsivity scores and MPI scores, respectively. Table 2.8 (in appendix A) shows a breakdown of the exploratory analyses described here. Additionally, we compared individuals who did not switch at all during the task to those who did on each task and survey measure (where possible) using both parametric and non-parametric t- tests (where appropriate, as some task measures were non-normally distributed) to examine for any differences in task performance between both groups. Figure 2.5 shows correlational plots between the exploratory behavioral measures analyzed and MMI score. We again note that the current study did not achieve the sufficient statistical power needed to detect the weak effect of media multitasking on task performance, which may explain the pattern of effects found.

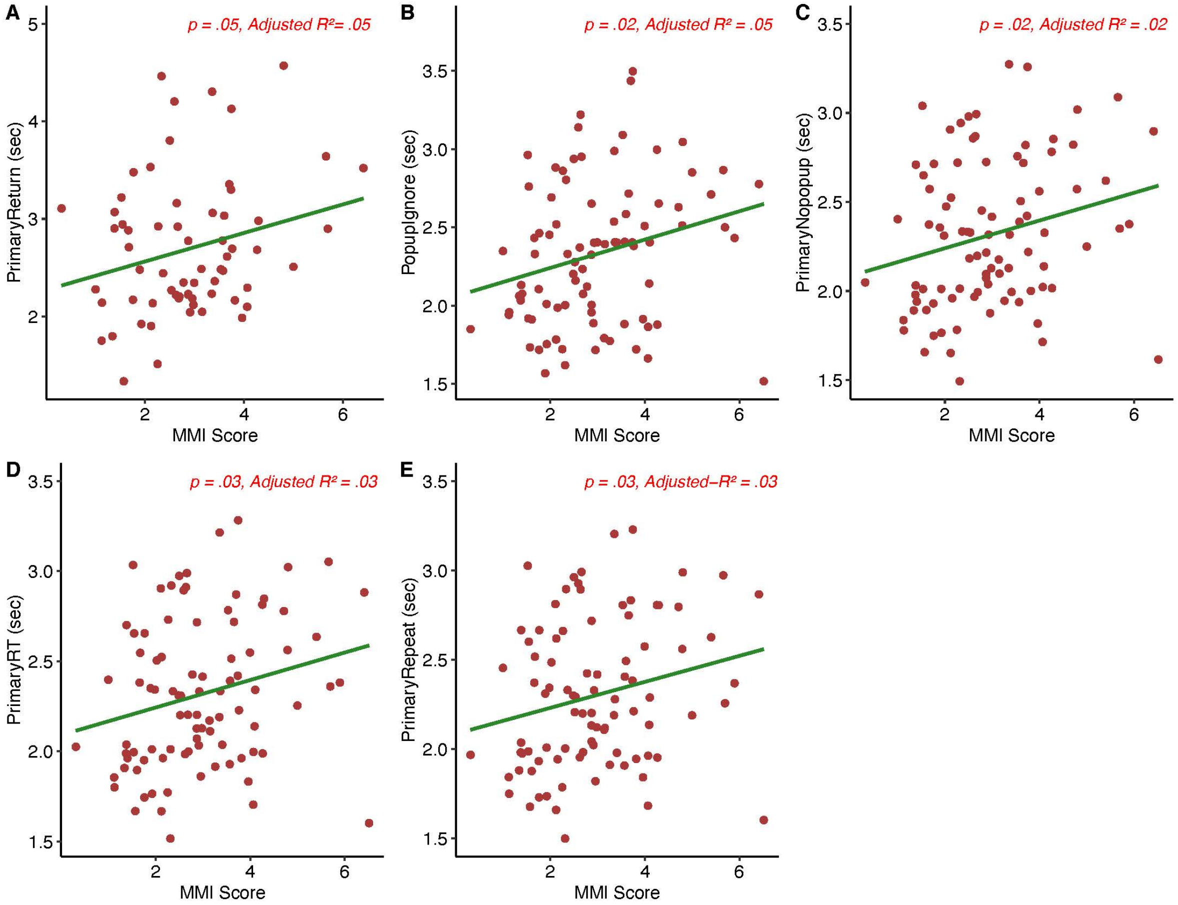


Figure 2.5 MMI score vs. Exploratory Behavioral Measures

Survey Results. A Wilcoxon Signed-Ranks test suggested that there was no difference in MMI scores between those who did not switch at all throughout the task (median = 2.52) and those who did(median = 2.87) $W = 847$, $p = .76$. There was a significant effect for switch group, $t(59.9) = -3.29$, $p = .001$, indicating that those who did not switch at all had a lower MPI score(*M*

= 33.4, *SD* = 8.17) than those who did switch (*M* = 40.5, *SD* = 11.27). A Wilcoxon Signed-Ranks test suggested that there was an effect of switch group on the attentional impulsivity sub-scale of the BIS, *W* = 562.5, *p* = .02, between those who did not switch at all throughout the task (median = 32) and those who did(median = 38). These results suggest that both attentional impulsivity and preference for multitasking are positively related to the act of switching throughout the task in the current study.

Primary$_{return}$. Table 2.9 (in appendix A) shows the hierarchical model at each step for this Primary$_{\text{return}}$. Step 1 of the model ($F(1, 63) = 4.1$, $p = .048$, Adjusted $R^2 = .05$) found that MMI score predicted Primary$_{\text{return}}$ ($B = 0.15$, $SE = 0.072$, $t = 2.02$, $p = .48$). Steps 2 and 3 were not significant (Full model: $F(3,61) = 1.47$, $p = .23$, Adjusted $R^2 = .02$). Our finding in step 1 of the model suggests that those who media multitask more often show a decrease in their ability to return to an initial task following a switch in task set, such that they are slower to respond to the initial task regardless of the availability of a switch on that given trial. The lack of a relationship between MPI score and Primary$_{\text{return}}$ also suggests that those who are more likely to choose to multitask do not show an increase in performance when switching back and forth between task sets.

Popup$_{ignore}$. Table 2.10 (in appendix A) shows the hierarchical model at each step for Popup$_{\text{ignore}}$ i.e., the reaction time on trials in which a popup occurred but was not attended to. The initial step in our hierarchical model predicting Popup$_{\text{ignore}}$ from MMI score was significant ($F(1, 87) = 6.08$, $p = .02$, $R^2 = .05$). MMI score positively predicted popup interference in the form of a longer RT, ($B = 0.09$, $SE = 0.037$, $t = 2.47$, $p = .02$). Step 2 in the model was also significant ($F(2, 86) = 3.15$, $p = .048$, Adjusted $R^2 = .05$), but the change in R^2 was not. The step 3 model was also significant ($F(3, 85) = 4.28$, $p = .007$, Adjusted $R^2 = .1$), as was the change in R^2 . A relationship between MMI score and $\text{Popup}_{\text{ignore}}$ RT suggests that the more an individual media multitasks, the slower they are on trials in which they decide to ignore popups, in line with the suggestion that heavy media multitaskers have difficulty filtering irrelevant information (Cain & Mitroff, 2011; Ophir et al., 2009). The relationship between MPI score and $\text{Popup}_{\text{ignore}}$ suggests that although individuals may have a preference for multitasking, they may still be unable to filter out irrelevant information during a task. There was no significant effect for switch group, $t(56.6) = -1.395$, $p = .018$, despite those who switched during the task($M = 2.36$, $SD = 0.48$) having a longer RT than those who did not switch at all ($M = 2.23$, $SD = 0.37$) on trials in which a popup occurred but was ignored.

$Primary_{nopopup}$. Table 2.11 (in appendix A) shows the hierarchical model at each step for this variable. The initial model predicting response time on tasks in which there was no popup prompt ($\text{Primary}_{\text{nopopup}}$) from MMI score was significant ($F(1, 88) = 5.32$, $p = .02$, Adjusted $R^2 = .05$). MMI score positively predicted RT on primary task trials with no popup prompt ($B = .08$, $SE = 0.034$, $t = 2.31$, $p = .02$). Step 2 of the hierarchical model was not significant, but step 3 was (Full model: $F(3, 86) = 3.34$, $p = .02$ Adjusted $R^2 = .07$). In this model, MPI score positively predicted RT on primary task trials with no popup prompt ($B = .008$, $SE = 0.004$, $t = 1.99$, $p = .05$), as did MMI score ($B = .08$ $SE = 0.03$, $t = 2.5$, $p = .01$). The relationship found between MMI score and $\text{Primary}_{\text{nopopup}}$ suggests that individuals who media multitask more often are generally slowed, while the relationship between MPI score and $\text{Primary}_{\text{nopopup}}$ suggests that preferential multitaskers show this same pattern of effects. A Wilcoxon Signed-Ranks test suggested that there was no difference in RT scores on trials in which no popup occurred between those who did not switch at all throughout the task (median = 2.18) and those who did(median = 2.33) $W = 660$, $p = .17$.

Primary RT. The initial step in the model predicting response time on all primary trials from MMI score was significant ($F(1, 88) = 5.16$, $p = .03$, Adjusted $R^2 = .04$). MMI score positively predicted Primary RT($B = 0.08$, $SE = 0.034$, $t = 2.27$, $p = .08$). Step 2 was not significant, but step 3 was, ($F(3, 86) = 3.41$, $p = .02$, Adjusted $R^2 = .08$). The individual predictors in the model were examined further, and both MPI score ($B = 0.01$, $SE = 0.004$, $t = 2.08$, $p = .04$) and MMI score ($B = 0.08$, $SE = 0.03$, $t = 2.49$, $p = .01$) positively predicted Primary RT. Higher MMI and MPI was associated with slower RT on the primary task, suggesting an overall slowing for heavier media multitaskers, as well as those who prefer to multitask in general. Table 2.12 (in appendix A) shows the hierarchical model at each step for this variable. A Wilcoxon Signed-Ranks test suggested that there was no difference in RT scores on trials in which the participant completed the primary task on the preceding trial between those who did not switch at all throughout the task (median = 2.2) and those who did(median = 2.33), $W = 664$, $p = .18$.

Secondary RT. All three steps of the models predicting RT on the secondary task were not significant (Full model: $F(3,60) = 0.26$, $p = .85$, Adjusted $R^2 = < .001$). Table 2.13 (in appendix A) shows the hierarchical model at each step for secondary RT.

Primary$_{repeat}$. Table 2.14 (in appendix A) shows the hierarchical model at each step for Primary$_{\text{repeat}}$. Finally, the first step in the model predicting RT on Primary$_{\text{repeat}}$ trials, or trials in which the participant completed the primary task on the preceding trial, from MMI score was significant ($F(1, 88) = 4.69$, $p = .03$, Adjusted $R^2 = .04$). MMI score positively predicted ($B = 0.07$, $SE = 0.034$, $t = 2.17$, $p = .03$) reaction times on trials in which the primary task was also completed on the preceding trial. Step 2 was not significant, but the final step, which added MPI score to the hierarchical model, was (Full model: $F(3,86) = 3.1$, $p = .03$, Adjusted $R^2 = .07$). MPI score positively predicted (*B* = 0.008, *SE* = 0.004, *t* = 2.04, *p* = .04) reaction times on trials in which the primary task was also completed on the preceding trial, as did MMI score (*B* = 0.08, *SE* = 0.03, *t* = 2.39, *p* = .02). This pattern of results suggests that those who media multitask as well as prefer to multitask more often are slower when attending to the same task for a prolonged period of time.

A Wilcoxon Signed-Ranks test suggested that there was no difference in RT scores on trials in which the participant completed the primary task on the preceding trial between those who did not switch at all throughout the task (median = 2.21) and those who did(median = 2.28) *W* = 698, *p* = .30.

Discussion

In this study we investigated the effects of self-reported media multitasking exposure on performance in a novel multitasking paradigm. This paradigm consisted of a volitional task switch prompted by random text popups during the primary task; critically, participants were able to ignore or choose to engage with the popup. If they chose to engage with it, they would then complete a different secondary task before returning to the primary task. Participants were not pre-selected for extreme degrees of media multitasking as in many previous studies; we took an individual difference approach using naïve participants. We used hierarchical regression models to predict task performance based on self-reported media multitasking exposure and preferences and the Attentional impulsivity subscale of the BIS-11.

We hypothesized that media multitasking exposure (MMI score) and preference (MPI score) would predict both the frequency at which participants would elect to switch to the secondary task (*switch rate), as* well as the RT to choose to switch on relevant trials ($\text{Popup}_{\text{select}}$). We also expected a "*return cost"* and an interference cost that would be positively predicted by media multitasking scores. In addition to these initial constructs of interest, we also performed several exploratory analyses between the survey constructs and several other behavioral measures. These included the effect of each survey measure on the RT on primary task responses following a task switch ($\text{Primary}_{\text{return}}$), primary task RT on trials where a pop-up was presented, but the secondary task wasn't chosen ($\text{Popup}_{\text{ignore}}$), RT on trials in which no popup was present ($\text{Primary}_{\text{nopopup}}$), RT on primary task trials in which the participant completed the primary task on the preceding trial ($\text{Primary}_{\text{repeat.}}$), and overall RT on the primary and secondary tasks.

We found mixed results. In line with our primary hypotheses, we found that MPI score predicted switch rate. However, we found no significant predictors of return cost. Several exploratory analyses yielded results supporting the hypothesis that media multitasking exposure relates to poorer executive function; we found that MMI score positively predicted $\text{Primary}_{\text{return,}}$ $\text{Popup}_{\text{ignore}}$, $\text{Primary}_{\text{nopopup}}$, $\text{Primary}_{\text{repeat}}$, and primary RT. We also found that MPI score positively predicted $\text{Popup}_{\text{ignore}}$, primary RT, $\text{Primary}_{\text{nopopup.}}$, and $\text{Primary}_{\text{repeat}}$. Attentional impulsivity scores on the BIS-11 subscale were not substantial, except for when comparing results across individuals who did not switch at all versus those who did. After comparing the survey scores of individuals who did not switch at all throughout the task versus those who did, we also found that those who switched tasks had higher MPI and attentional impulsivity scores than those who did not switch tasks at all. Although we found several significant models and predictors, it is crucial to underline the fact that the effect sizes for all findings were small and as such are likely not indicative of any greater underlying trend. In fact, according to a post-hoc power analysis using G*power (Faul et al., 2009), the current study did not achieve the sufficient statistical power needed to detect the weak effect of media multitasking on task performance.

Supporting the idea that high media multitaskers show less efficient executive functioning (Becker, Alzahabi, & Hopwood, 2013; Cain & Mitroff, 2011; Murphy & Creux, 2021; Ophir et al., 2009; Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013), we found that greater were an individual's MMI and MPI scores, the greater was their RT on primary trials following a switch, regardless of a popup being present. This suggests that media multitasking reduces one's ability to re-engage with the primary task. This has been demonstrated in applied domains such as multitasking while driving (Nijboer, Borst, van Rijn, Taatgen, 2016; Strayer, Watson, Drews, 2011). However, our results regarding return cost, or the difference in RT on primary trials with no popup available following a task switch, may contest this interpretation. In regard to return cost, we found no effects within the three steps of our model. This may suggest that although heavier media multitaskers are less effective when switching back to a task from a previous task set on average, this difference is not detectable when only taking into account primary task RT on trials following a switch in which another switch is not possible. Additionally, both MMI and MPI score predicted overall RT on all primary task trials. Here, those who media multitask more often, as well as those who prefer to multitask, responded to the primary task more slowly in general. These results point toward a general decrease in task performance for individuals who engage in media multitasking more often.

Heavy media multitaskers have been found to have an inability to efficiently filter out distractors (Lui & Wong, 2012; Murphy & Creux, 2021; Ophir et al., 2009). Our results suggest a similar relationship, with individual MMI score predicting reaction time during $\text{Popup}_{\text{ignore}}$ trials, or trials in which a popup occurred but the participant chose not to switch, such that responses to the primary task during these trials were slower for individuals who media multitask more often. In trials in which the participant chose not to switch, the popup can be seen as a distraction from completing the primary task. As such, a longer RT to complete the primary task here demonstrates an inability to effectively filter irrelevant stimuli to the task at hand. This pattern of effects is true regarding MPI score as well, suggesting that even preferential multitaskers may be distracted to a greater extent by a popup stimulus, even if they choose to ignore the option to switch tasks. However, our findings regarding interference cost, or the difference in RT on trials in which the participant ignored a popup and the RT on trials in which no popup occurred, may conflict with this interpretation. The lack of a relationship here may be attributed to the low number of overall switches, which are further elaborated on below. The weak effect size associated with the former finding may also account for this discrepancy.

Because greater impulsivity and worse inhibitory control have been linked to MMI scores (Gorman & Green, 2016; Sanbonmatsu et al., 2013; Murphy & Creux, 2021; Rogobete et al., 2021; Shin et al., 2019), we expected a greater switch rate among more impulsive and less inhibited individuals. However, we found no evidence that attentional impulsivity as indexed by the sub-scale of the BIS score predicts switch rate. We did, however, find that individuals who did not switch tasks at all had lower attentional impulsivity scores than those who did, along with a lower preference for multitasking. We found similar results for the RT for individuals to choose to switch tasks ($\text{popup}_{\text{select}}$). We reasoned that more impulsive individuals would switch tasks more quickly and frequently, again because of the greater possibility of reward due to completing more the secondary task.

Task Limitations

Several factors may have contributed to the low switch rate observed in the current study (~31%). For example, the popup prompts may not have been salient enough to entice a switch. Increasing the points earned for completing the secondary task or making the popup more prominent on the screen by changing the text color or including sound may make the popups more salient. Because there was no monetary incentive for a higher score other than the motivation to "beat" a "high score", participants may have had no motivation to maximize points earned, leading to less task switches. This is a limitation of the task we must acknowledge, as we have no way to be certain that this did not affect our participants' motivation and thus, our results.

Relatedly, the greater penalties for an error in the secondary task may have also disincentivized task switches. Interestingly, higher MPI score was related to switch rate, but MMI score was not. Individuals who switched tasks had higher MPI scores when compared to those who did not switch at all as well. These effects point towards a greater propensity for preferential multitaskers to opt to switch to a different task set, but not for individuals who report engaging in media multitasking to a greater degree. Finally, there was a non-trivial difference in overall participant accuracy between the primary task (93%) and the secondary task (69.7%); one possibility is that participants found the secondary task too difficult and not worth the increased effort (Inzlicht, Shenhav, Olivola, 2018). This was not analyzed further due to the even greater potential for incomparable data due to the overall low switch rate observed.

Survey Limitations

The changes we made to the Media Use Questionnaire may have also contributed to some of the findings, both null and significant, in this experiment. Many of the changes made to the original 2009 questionnaire devised by Ophir and colleagues were done to reflect changes in the media consumption landscape we see today. Nevertheless, our average MMI score was relatively in line with other studies that have used the original Ophir (2009) questionnaire. Despite this, we must still acknowledge that the changes made in the current study to the original questionnaire may limit the generalizability of our findings to other studies that used the original version. Since the original introduction of the media use questionnaire in 2009, there have been attempts to devise a more cohesive and briefer version of the questionnaire, with differing patterns of effects (Baumgartner et al., 2016; Pea, Nass, Meheula, Rance, Kumar, Bamford, Nass, Simha, Stillerman, Yang, Zhou, 2012.). This lack of uniformity in regard to screen time and media use measures in the overall literature points to a bigger problem recently emphasized by Kaye and colleagues (2020). They point out that the conceptualization of media use is far too broad and ambiguous in its current state in the literature, and vastly undermines the generalizability of the literature to a broader audience.

Despite the limitations discussed, the findings resulting from this novel multitasking paradigm are promising. Because the majority of current media multitasking literature has used paradigms designed to evaluate other domains of executive function such as working memory and inhibitory control, the implementation of a paradigm specifically designed to be analogous to the environment in which individuals frequently multitask is needed. This initial study serves as a first step to fill this gap in the literature. Further implementations to this paradigm to develop a task more analogous to real world multitasking should include a sound clip in conjunction with the popup notification. This would be reminiscent of many of the notifications we receive on our phones and laptops, as they too may sometimes include sound. Many of the notifications we receive on these same devices can be ignored as they are “spam” or of little interest to us. As such, the inclusion of uninformative or “distractor” popups mixed in with informative popups may serve to further emulate a real-world multitasking environment. It may be beneficial to include trials in the paradigm where a task switch is required to allow for a clear differentiation between an interference cost and trials in which a participant actively chooses to switch costs, as in our current design, this is not possible. Finally, a larger sample size is needed to provide for enough statistical power to detect effects our paradigm may uncover.

Conclusions

Using a novel, more ecologically valid paradigm, we expected to find a negative effect of media multitasking, multitasking preference, and attentional impulsivity on task performance. We found a number of significant, albeit weak, effects of media multitasking on task performance, including a general slowing effect on the primary task. We also found that self-reported multitasking preference related to how often participants chose to engage in the secondary task. These findings contribute to the now growing media multitasking literature showing some of the negative effects of frequent media multitasking. However, it is crucial to recognize that many of the effects we found were weak, and with a smaller than ideal sample size, may not persist given further testing. Further, the adjustments made to the Media Use Questionnaire use may limit the generalizability of our findings to the work done using the questionnaire in its original form. Future directions of this line of research include a modification to the paradigm to make the popup prompts more “enticing” to participants to more closely mirror a real-world multitasking environment. We also plan to collect EEG recordings to examine the event related potentials occurring as participants complete the tasks.

CHAPTER III

NULL FINDINGS OF VOLITIONAL MULTITASKING ON HUMAN ELECTROPHYSIOLOGY

Introduction

Media multitasking, or the use of two or more media types (Minear, Brasher, McCurdy, Lewis, & Younggren, 2013), is now a daily occurrence in today's society. Indeed, the 10% increase of an average individual's time spent multitasking with multiple information sources between 1999 and 2009 is indicative of society at large's need to be "always online" (Rideout, Ulla, Foehr, & Roberts, 2010). Multitasking in different settings, such as driving, has been found to have negative effects, such as an overall decrease in performance on both tasks being performed (Strayer, Watson, 2011; Nijboer, Borst, van Rijn, & Taatgen, 2016; Sanbonmatsu, Strayer, Biondi, Behrends, & Moore, 2016; Strayer & Johnston, 2001). As this phenomenon continues to develop, the need to investigate the costs and benefits of media multitasking has become quite clear.

To that end, Ophir and colleagues devised the Media Use Questionnaire (MUQ) to quantify the amount of time an individual media multitasks during a typical media-consumption hour (Ophir et al., 2009). Using this questionnaire, and an extreme groups approach, they found that heavy vs. low media multitaskers performed worse on several executive function tasks. Based on these findings, Ophir and colleagues suggested that heavy media multitaskers are less able to filter out irrelevant information than light media multitaskers, a finding that has since been corroborated by others in the literature (Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Heathcote et al., 2014.; Lottridge et al., 2015; Moisala et al., 2016; Murphy & Creux, 2021; Wiradhany & Nieuwenstein, 2017). Research into other domains of executive function has found that media use frequency has a negative effect on inhibitory control (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014; Schutten, Stokes, & Arnell, 2017), and sustained attention as well (Ralph & Smilek, 2017; Ralph, Thomson, Cheyne, & Smilek, 2014).

Mixed Effects of Media Multitasking

While a large proportion of the media multitasking literature has found negative effects on task performance, other studies have found mixed results. For example, Alzahabi and Becker (2013) found a positive relationship between heavy media multitaskers and task switching performance. Some researchers have also found no relationship between media multitasking and task performance at all (Baumgartner et al., 2014; Minear, Brasher, McCurdy, Lewis, & Younggren, 2013). Complicating matters further, recent findings from Rogobete, Ionescu, and Miclea (2020) suggested no linear relationship between media multitasking frequency and task switching performance, but once participants were categorized into heavy and light media multitaskers, heavy media multitaskers demonstrated better performance on the task. Further still, a meta-analysis by Wiradhany and Nieuwenstein (2017) found a weak association between media multitasking and distractibility. More recently, a meta-analysis by Parry and le Roux (2021) found a weak association between media multitasking and cognitive function in general. This lack of consensus in the literature demonstrates the need for further research into media multitasking and its effect on task performance.

Real world media multitasking often involves a form of dual tasking similar to what is seen in a Psychological Refractory Period (PRP) paradigm. The PRP task is often synonymous with dual tasking and involves the performance of two concurrent tasks, usually with a delay in the onset of each task (Fagot and Pashler, 1992). More specifically, the PRP paradigm introduces the aspect of a variable stimulus onset asynchrony (SOA) between Task 1 and Task 2 such that both tasks are temporally separate to different extents throughout the experiment. The typical effect seen here is that as the SOA decreases, the reaction time to Task 2 increases (Pashler, 1994). This is thought to be due to a “processing bottleneck” that occurs when several stimuli are presented to an individual, leading to a decrease in task performance. Because media multitasking involves the ongoing maintenance of different tasks completing several tasks with different media types, usually with different stimulus onsets, the bodies of literature have some overlap.

Following Lui and Wong (2012), who found that heavy media multitaskers showed greater accuracy when completing a multisensory (sound and vision) task, Shin and colleagues (2019) used a multisensory version of a PRP dual-task paradigm to examine for an effect of media multitasking exposure on task performance. They found that heavier media multitaskers were faster to respond to the tasks when they were presented with longer intervals between them, but this advantage disappeared as the intervals became shorter. Similarly, Alzahabi and Becker (2013) also found no difference in dual tasking performance between heavy and light media multitaskers. Taken together, these results point towards a deeper relationship between dual tasking and media multitasking that has yet to be fully investigated.

Introduction of the Novel Multitasking Paradigm

To approximate real-world multitasking, in a previous experiment, we designed a multitasking paradigm that allowed the participant to be in control of when they switched from a primary to a secondary task. While we aimed to differentiate this paradigm from lab-based studies of multitasking, it was designed with concepts and ideas taken from the Operation Span Task (OSPAN) devised by Turner and Engle (1989), which has been used previously by Sanbonmatsu and colleagues (2013) to examine multitasking ability. This paradigm consisted of a primary math verification task (as in the OSPAN) that featured randomly occurring “popup” prompts. These popups were designed to be like the notifications seen on most modern devices and gave participants the opportunity to switch to a different secondary task for the remainder of the trial. The secondary task consisted of a word stem completion to solve, and once this task was completed, they returned to the primary task.

Our paradigm also drew from the voluntary task switching (VTS) and dual tasking literature. We implemented the volitional aspect from VTS paradigms that was missing from the OSPAN to resemble daily multitasking more closely, albeit with critical deviations from both VTS and dual tasking. In our paradigm, the participant can only switch tasks when a popup informs them that another task is available, but in most VTS paradigms, the individual is given the choice to switch tasks on every trial (Arrington & Logan, 2004; Mayr & Bell, 2006; Orr & Weissman, 2011). Dual task paradigms involve the completion of two tasks, with one task usually given priority over the other task. Our paradigm features a primary task with an occasional, delayed option to engage in a secondary task. These deviations were both made to bring the paradigm more in line with a real-world multitasking scenario, as in most such cases, there is not a constant stream of notifications appearing on screen. Instead, they may appear sporadically, drawing attention away from the primary task at random, while also allowing the individual to switch tasks at their leisure. Further, a recent study by Lui and colleagues (2022) established the contrasts between the laboratory based multitasking paradigms and those specifically designed to emulate real-world multitasking. These include the ability for the individual to prioritize certain tasks while also switching between tasks as they choose. They also highlighted the need for a more ecologically valid paradigm due to the discrepancy in findings between studies that used these classical, laboratory-based paradigms and paradigms that more closely aim to emulate real-world multitasking, a discrepancy our line of experiments aims to dispel (Lui et al., 2022).

Purpose

We hoped that using this more ecologically valid paradigm would help to dispel some of the ambiguity in the current literature. We also deviated from the overall literature by foregoing an extreme groups approach and instead examining for a linear relationship between media multitasking and task performance. Using a modified version of Ophir and colleagues (2009) Media Use Questionnaire to estimate media multitasking frequency, we found several, small effects during our exploratory analysis, including evidence that as individuals media multitask to a greater extent, they are slower to return to the previous task set, and were generally slower on primary task performance. We also found that the more an individual media multitasks, the slower they are on trials in which they decide to ignore popups. Finally, we also found that those who media multitask more often are slower when attending to the same task for a prolonged period of time. However, we found no relationships in our main analyses between media multitasking frequency and the following: switch rate, return cost, (the difference in average reaction time for primary tasks following a switch to the secondary task minus the average reaction time for all other primary task trials without a popup), and interference cost (the difference in reaction time for primary task trials with a non-selected pop-up and primary task trials without a pop-up).

As our main analyses did not produce significant results, and the effects that we did find were weak at best, we aimed to replicate our original experiment, albeit with a number of changes and additions. We identified multiple shortcomings in our original paradigm design that we attempt to remedy here using two different iterations of the paradigm, including addressing an overall low number of task switches and incentivization to switch tasks. We discuss both iterations of the paradigm in detail further below. With these changes, we expected to find an effect of media multitasking frequency where we did not previously, such that as media multitasking frequency increases, the switch rate increases as well. We also expected to see a greater return cost and interference cost that would be positively predicted by media multitasking frequency. Additionally, we predicted that individuals who media multitask more often would choose to switch to the secondary task more quickly. Finally, we expected to replicate our previous exploratory analysis findings.

Transcranial Direct Current Stimulation (tDCS)

Along with changes to the paradigm design, we also examined the effect of non-invasive brain stimulation on task performance via transcranial direct current stimulation (tDCS). tDCS has been found to increase task performance when applied to relevant brain regions (Oldrati, Colombo, Antonietti, 2018; Ljubisavljevic, Oommen, Filipovic, Bjekic, Szolics, Nagelkerke, 2019; Scheldrup, Greenwood, McKendrick, Strohl, Bik-son, Alam, McKinley, Parasuraman, 2014; Leite, Carvalho, Fregni, Gonçalves, 2011). Interestingly, Nelson and colleagues found that tDCS improved multitasking capability (Nelson et al., 2016). tDCS has been proposed to increase neuronal excitability at the anode stimulation site and decrease excitability at the cathodal site (Nitsche & Paulus, 2000, 2001). However, much like the media multitasking literature, a growing body of literature exists contradicting tDCS' effects on task performance (Dawood, Dickinson, Aytemur, Howarth, Milne, Jones, 2020; Horvath, Forte, Carter, 2015). Due to these parallels, we included a tDCS manipulation in our design. We expected an effect of tDCS on task performance such that individuals in the active stimulation condition would show better task performance overall.

Electroencephalography (EEG)

Finally, we also collected EEG data to examine neural markers of preparatory control and decision making. The P300 ERP component has been identified as a positive deflection in EEG that usually follows a rare stimulus that appears among other more frequent stimuli (Polich, 2007). Previous findings also suggest that the amplitude of the P300 is reduced during dual-task paradigms, implying that P300 amplitude is a representation of processing capacity between concurrent tasks (Miyakoshi, Nomura, & Ohira, 2007; Isreal, Chesney, Wickens, & Donchin, 1980; Allison & Polich, 2007; Miller, Rietschel, McDonald, & Hatfield, 2011). In the task switching literature, P3 amplitude has been related to smaller switch costs (Elchlepp, Lavric. Mizon, Monsel, 2012). As such, the nature of the paradigm makes the addition of an EEG component in this experiment can only add to the growing body of EEG and multitasking literature.

Methods

Participants

A total of 104 participants fully completed the procedure. Six participants were dropped due to non-completion of the study. Participants were recruited from the Texas A&M Psychology Subject Pool and received course credit for participating. All participants were also entered into a drawing to win one of five $100 Amazon gift cards. No prior sample size was determined, with the intent being to collect as much data as was possible throughout a university semester. Participants were right-handed, neurotypical, between the ages of 18-30 years old, English-speaking individuals with full color vision. They were not informed of the topic of the study prior to consenting to participate. Study procedures were deemed “Not Greater than Minimal Risk” under 45 CFR 46 / 21 CFR56 by the Texas A&M Institutional Review Board, approval reference number IRB2019-0472D. The authors confirm that we have reported all measures, conditions, data exclusions, and the method of sample size determination.

Media Multitasking Index

As in our original study, participants first completed a revised version of the Media Use Questionnaire (MUQ), which asked participants to estimate how many hours per week they use each individual form of media (using a sliding scale ranging from 0-80 (in hours). Media types evaluated included computer-based applications (e.g., word processing, excel), web surfing (not including social media sites), text-based media such as print books, eBooks, magazines, newspapers (for school/work/pleasure), television programs (TV based or online streaming), streaming videos (e.g., YouTube, BuzzFeed, other short clips), listening to music, listening to nonmusic audio (e.g., audio books, podcasts, talk radio, etc.), video based games (console, computer, phone/tablet based), voice calls (landline, cellphone, skype), reading/writing emails, viewing social media (Facebook, Instagram, snapchat, twitter, etc.), and “other” media types. “Social media” replaced “instant messaging” in this revised version to be consistent with the rise of social media platforms and the decline in instant messaging programs. “Text messaging” was also removed as it did not contribute substantially to the total hours spent consuming media and was instead included under “social media. Additionally, several media types were renamed to be consistent with current media trends as follows: to reflect the popularity of e-readers, “print media” was changed to “text media” “telephone and mobile phone voice calls” was changed to “voice calls,” “computer-based video” was renamed to “streaming video” (to reflect current trends in video consumption), and “video or computer games” was renamed to “video games.”

After participants indicated the number of hours they spent using each of the above media types, they were then given a matrix asking, for each media type they use, how often they concurrently used each of the other mediums using a 5-point Likert scale (“Always,” “Most of the time,” “Some of the time,” “A little of the time,” or “Never”). The original MUQ used only a 4-point Likert scale ranging from “Most of the time” to ‘‘Never’’. We added the additional answer choice of “Always” to get a more precise measure of media multitasking occurrence. We added “Always” answer choice to counterbalance the already existing “Never” answer choice.

To calculate a Media Multitasking index (MMI) score for each participant, numeric values were assigned to each of the above matrix answers, such that “1.0” represented “Always”, “0.75” corresponded to “Most of the time,” “0.5” to “About half the time”, “0.25” to “Sometimes,” and “0” to “Never.” The sum of the above values across each primary medium used is then weighted by the percentage of time spent with the corresponding primary media type. This final MMI score quantifies the amount of media multitasking the participant is engaged in during a typical media-consumption hour so that as the score increases, the amount of time spent multitasking during that hour increases.

tDCS Setup

After the questionnaire, participants underwent tDCS stimulation. tDCS was administered using a Soterix 1x1 TES system. Following prior research regarding tDCS stimulation to the DLPFC (Cerrutti & Schlaug, 2009), which has been implicated in executive function (Antal, Kincses, Nitsche, Bartfai, Paulus, 2004; Fecteau., Pascual-Leone, Zald, Liguori, Théoret, Boggio, 2007) we placed the anode at F3 and the cathode at F4 (according to the 10-20 EEG Placement System). Participants were randomly separated into two stimulation conditions, active and sham. During active stimulation, participants underwent 20 minutes of 2 mA stimulation. During the sham condition, participants experienced the active stimulation only for the first and last 30 seconds of the 20-minute stimulation period. Stimulation blindness was checked by asking participants if they thought they received active or sham stimulation, or if they did not know enough to guess. A chi-square test of independence was performed to examine the relation between a participant’s answer and their stimulation condition. The relation between these variables was not significant, X^2 (1, $N = 104$) = 0.52, p > .05. This indicates that participants were blind to their stimulation condition.

EEG Setup

EEG preparation followed after the tDCS system was set up, using a 32-channel montage based on the 10/20 system. Continuous EEG was recorded using an ActiCap and the ActiCHamp amplifier system (Brain Products, Munich, Germany) and was sampled at 1000 Hz using FCz as an online reference. The preprocessing pipeline is described further below.

Multitasking Paradigm

As mentioned above, we devised and tested two iterations of the task paradigm. For simplicity, we refer to them as “Task Iteration 1” and “Task Iteration 2”, and the ensuing sections will be ordered as such. Figure 3.1 shows a representation of the task paradigm 1, and Figure 3.2 is a representation of task iteration 2.

Once EEG was set up, participants completed the multitasking task, created using PsychoPy version 3.0.6 (Peirce et al., 2019). All participants completed the task on a 21-inch, with default monitor settings as defined by PsychoPy.

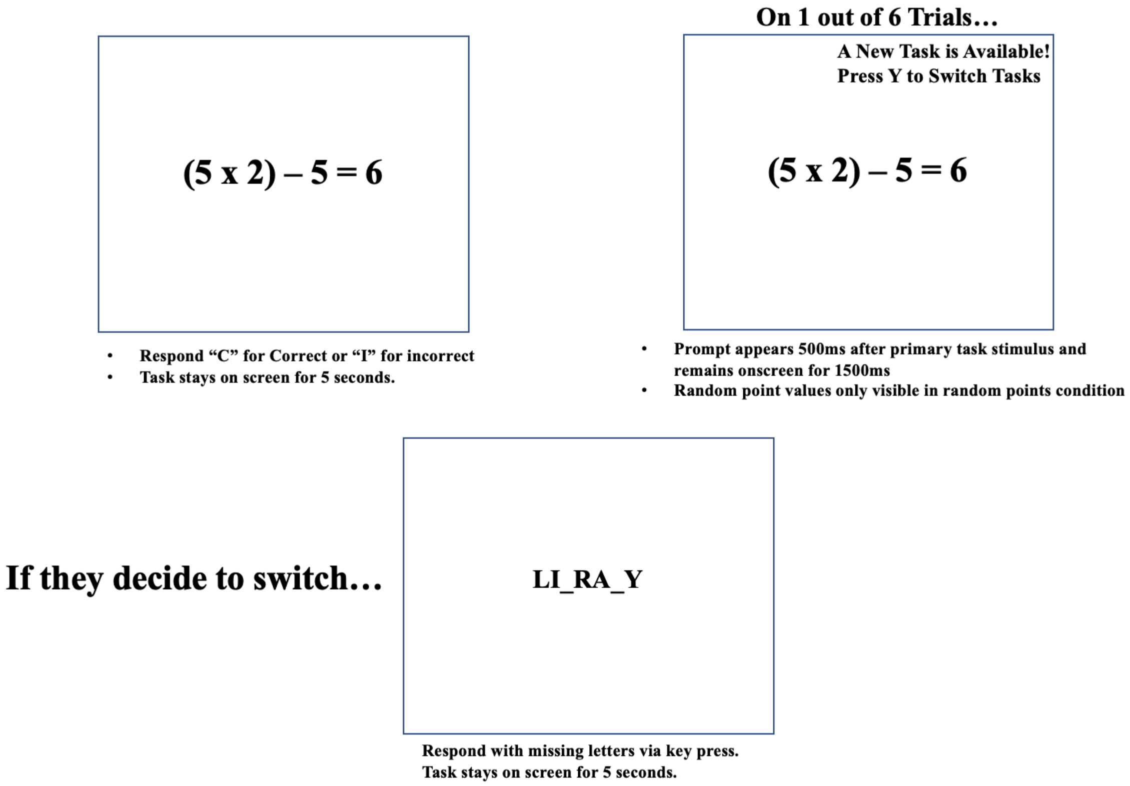
Task Iteration 1—Primary Task

As in our original design, participants had a primary task and secondary task to attend to. During the primary task, participants were instructed to check the validity of math problems (e.g., ‘(3–2) × 1 = 4’) via key press, with “C” indicating the math problem was correct, and “I” to indicate an incorrect problem. The math operations were on the screen for 5 seconds. To incentivize good performance, the task featured a point system for responses, and participants were told that a higher score would result in a higher chance to win a $100 Amazon gift card. However, it was later explained during the debriefing portion of the experiment that all participants were entered into the drawing with equal chances to win. Nevertheless, a correct response to the primary task was worth 3 points, with an incorrect or missed response would deduct this same amount from the total. A participant's running total was shown to them at the conclusion of each trial. To further incentivize participants to perform as well as possible during the task, they were shown a "high score" at the end of each block. This high score was the same for each participant.

Task Iteration 1—Secondary Task

On one out of every four primary task trials, a text "popup" would appear on the screen 500 ms after the primary task appeared, reading "A New Task is Available! Press 'Y' to switch tasks". This differed from our original design, as in the original paradigm, the popup prompt appeared in one out of every six trials. This popup would appear on the top right corner of the screen. The position of the popups was chosen so that they would be reminiscent of the notifications seen on computers and cell phones. The popup would appear on screen for 2 seconds, then disappear. If participants elected to switch tasks, the primary task would disappear from the screen. They would then be shown a word fragment with two letters missing (e.g., "HI_TO_Y"). Participants would then indicate which letters were missing via key press. A correct response to this secondary task was worth 10 points, while an incorrect or response not made in time would deduct this same amount from the total. This point difference was implemented to encourage multitasking by making a greater reward possible for switching tasks. Their total points were shown at the end of each trial of this task as well.

The full task consisted of 8 blocks of 20 trials each for a total of 160 trials. The number of blocks was chosen so that the task would be broken up into intervals allowing the participant to take breaks regularly while still being able to complete the experiment in under an hour. The number of pop-ups was not consistent across participants due to the randomization procedure, with an average of 39.4 (*SD* = 4.8) pop-ups per participant for task iteration 1. A total of 51 participants completed this version of the task.



- Respond "C" for Correct or "I" for incorrect
- Task stays on screen for 5 seconds.

- Prompt appears 500ms after primary task stimulus and remains onscreen for 1500ms
- Random point values only visible in random points condition

Respond with missing letters via key press.
Task stays on screen for 5 seconds.

Figure 3.1 Visual Representation of Task Iteration 1

Task Iteration 2—Differences from Iteration 1

Task iteration 2 was very similar to the first iteration of the task. The first main difference between the two versions was the number of possible points for the secondary task. The possible point gain for a correct response during the secondary task was randomized each trial and would range from 10 to 25. Participants were informed of the number of points possible for completing the secondary trial via an additional line of text below the popup prompt during relevant primary task trials. The second main difference was the removal of any loss of points for an incorrect or missed response during any trial. Both changes were implemented to further incentivize task switches and good performance during the task. No other changes were made to this version of the task.

An average of 40.3 (*SD* = 5.2) pop-ups occurred for each participant during task iteration 2, with 53 total participants completing this version of the paradigm.

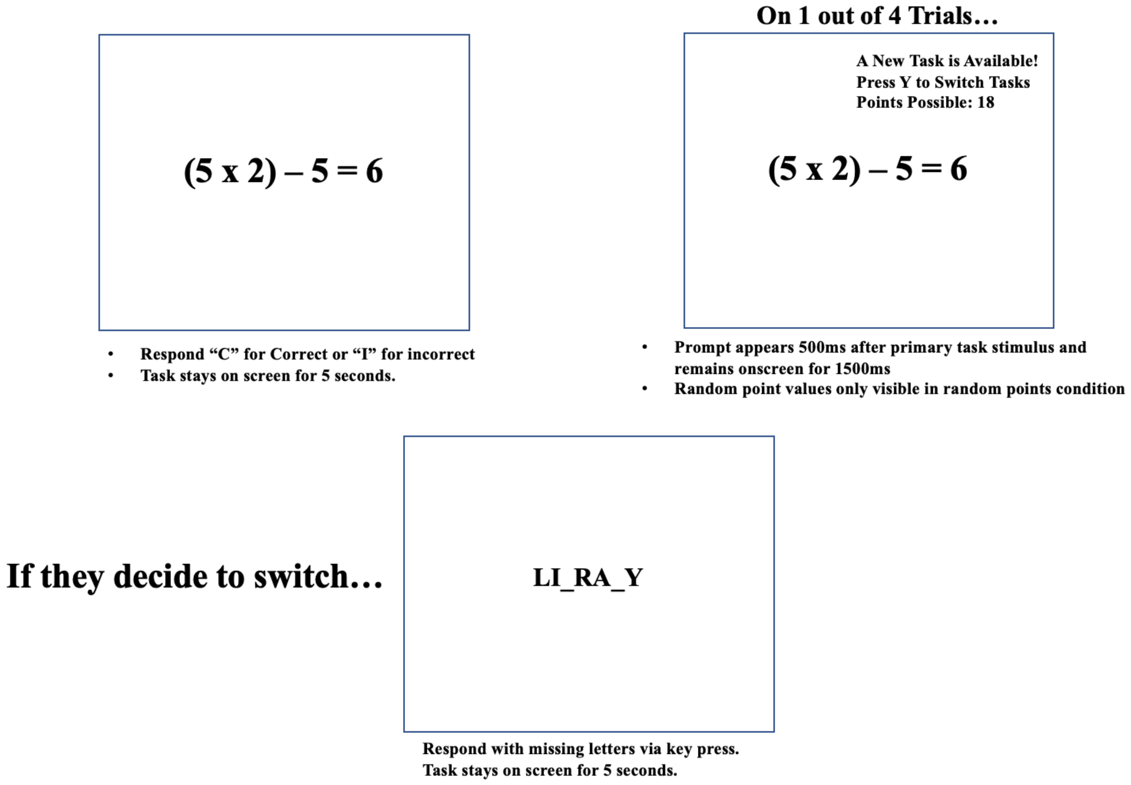


Figure 3.2 Visual Representation of Task Iteration 2

Procedure

After providing consent via a written consent form, participants completed an online version of the Media Use Questionnaire and a demographics questionnaire. tDCS and EEG were set up following the completion of the surveys. Then, participants were introduced to the multitasking paradigm via a short practice version of the task. The practice tasks consisted of three distinct blocks. In the first block, participants completed 5 trials of only the primary task. In the second block, they then completed 5 trials of only the secondary task in the second block. Finally, participants completed 6 trials of the full task during the final practice block. Point values were identical to the full task according to the task iteration (random vs non-random point values). The total experiment duration was about 2 hours.

Behavioral Data Analysis

We examined the same behavioral performance measures, both exploratory and otherwise, as in our original experiment. Switch rate was defined as the percentage of trials in which a participant switched tasks across all trials in which switches were possible. *Return Cost* was the average difference between RT on primary task trials following a switch and primary task trials during which no popup occurred. *Interference Cost* was the average difference in reaction time for primary task trials with a non-selected pop-up and primary task trials without a pop-up. $\text{Popup}_{\text{ignore}}$ referred to the average RT on trials in which the participant ignored the popup and completed the primary task. We defined $\text{Popup}_{\text{select}}$ as the response time to choose to switch (i.e., time to respond to the popup prompt). We also examined the average response time on non-popup trials ($\text{Primary}_{\text{nopopup}}$), $\text{Primary}_{\text{return, or}}$ RT on primary trials following a switch, regardless of availability of a switch, RT on trials in which the individual repeated the primary task ($\text{Primary}_{\text{repeat}}$), and finally, overall average RT on the primary and secondary tasks. As before, because some participants did not switch tasks at all, some of these measures could not be calculated for the entire sample.

In our original study, we used frequentist methods to analyze our data. Here, we used Bayesian statistics to examine our findings and, given the trend of previous null findings, be able to assess support for the null and alternative hypotheses. More specifically, we used a series of simple Bayesian regressions to predict each of the behavioral measures described above from media use frequency. We then used Bayesian independent samples t-tests to test for an effect of tDCS condition (anodal or sham) on each of the task performance metrics. For each analysis, an uninformed uniform prior [P(M)] of 0.5 was set for each possible model. All analyses and plots were created using JASP version 0.16 (JASP Team, 2021). Bayes factor cutoffs and reporting were based on Dienes (2014). Post hoc power analysis was conducted using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009), finding that the study was underpowered. Because some participants did not switch at all throughout the task (14 during task iteration 1, 10 during task iteration 2), it was not possible to calculate some measures for the entire sample, including switch rate, return cost, interference cost, and measures of switch RT.

EEG Preprocessing

We used the MATLAB toolbox, EEGLAB, to analyze the EEG data. We preprocessed it using a standard pipeline as suggested by Makoto Miyakoshi (n.d.); data was re-referenced to the average, band-pass filtered with high-pass and low-pass filters of 0.1 Hz and 30 Hz respectively, visually inspected for large amounts of noise, and artifact rejected using the fastICA EEGLAB algorithm. Following ICA artifact rejection, we visually inspected the data and removed any remaining artifacts. Due to a coding error, some event markers for iteration 1 were not recorded, so analyses regarding trials in which a popup was ignored, as well as popup onset were not possible.

Results

Behavioral Results

For Task Iteration 1, using a series of simple Bayesian regressions, we found a mix of anecdotal and moderate evidence in favor of the null hypotheses, with no BF_{01} being greater than 3.44 or less than 1.42. This suggests that media use frequency does not predict switch rate, how quickly an individual decides to switch tasks, the individual's return cost, interference cost, d RT on repeat trials, RT trials in which a prompt to switch tasks was ignored, RT on trials with no popup present, or overall secondary and primary RT. We saw a very similar pattern of results regarding the effect of tDCS on task performance, with all BF_{01}s ranging from 3.13 to 1.23, suggesting that tDCS has little to no effect on executive function as indexed by task performance. Tables 3.1 and 3.2 show a breakdown of each task performance measure examined and the related $BF_{01}$for each Bayesian Regression for behavioral and tDCS analyses.

	MMI Score	Switch Rate(%)	Return Cost	Interference Cost	$\text{Popup}_{\text{select}}$
Mean	2.37	0.34	0.18s	0.02s	1.29s
SD	0.97	0.30	0.28s	0.21s	0.28s
BF_{01}	N/A	2.12	1.53	3.44	1.65
tDCS BF_{01}	N/A	3.13	2.79	2.06	1.65

Table 3.1 Task Iteration 1 Descriptive statistics and BF01 for main behavioral and tDCS analyses

	$\text{Primary}_{\text{return}}$	$\text{Popup}_{\text{ignore}}$	$\text{Primary}_{\text{nopopup}}$	Primary RT	Secondary RT	$\text{Primary}_{\text{repeat}}$
Mean	2.6s	2.36s	2.35s	2.35s	2.83s	2.33s
SD	0.42s	0.43s	0.38s	0.38s	0.46s	0.38s
BF_{01}	1.42	2.64	2.69	2.76	3.02	2.72
tDCS BF_{01}	3.06	1.23	1.75	1.64	3.1	1.75

Table 3.2 Task Iteration 1 Descriptive statistics and BF01 for exploratory behavioral and tDCS analyses

Results were very similar during task iteration 2. We again found a mix of anecdotal and moderate evidence in favor of the null hypotheses, with all BF_{01}s ranging from 1.43 to 3.55. This further suggests that media use frequency does not predict switch rate, how quickly an individual decides to switch tasks, the individual's return cost, interference cost, RT on repeat trials, RT trials in which a prompt to switch tasks was ignored, RT on trials with no popup present, or overall secondary and primary RT. We saw a very similar pattern of results regarding the effect of tDCS on task performance, with all BF_{01}s ranging from 3.41 to 1.58, suggesting that tDCS has little to no effect on performance in the current task. Tables 3.3 and 3.4 show a breakdown of each task performance measure examined and the related BF_{01} for each Bayesian Regression for behavioral and tDCS analyses.

	MMI Score	Switch Rate(%)	Return Cost	Interference Cost	$\text{Popup}_{\text{select}}$
Mean	2.37	0.34	0.18s	0.02s	1.29s
SD	0.97	0.30	0.28s	0.21s	0.28s
BF_{01}	N/A	3.33	3.11	2.3	3.34
tDCS BF_{01}	N/A	1.58	2.73	3.41	3.33

Table 3.3 Task Iteration 2 Descriptive statistics and BF01 for main behavioral and tDCS Analyses

	$\text{Primary}_{\text{return}}$	$\text{Popup}_{\text{ignore}}$	$\text{Primary}_{\text{nopopup}}$	Primary RT	Secondary RT	$\text{Primary}_{\text{repeat}}$
Mean	2.6s	2.36s	2.35s	2.35s	2.83s	2.33s
SD	0.42s	0.43s	0.38s	0.38s	0.46s	0.38s
BF_{01}	3.29	3.48	3.48	3.55	1.43	3.42
tDCS BF_{01}	2.73	3.36	2.97	2.99	2.88	2.51

Table 3.4 Task Iteration 2 Descriptive statistics and BF01 for exploratory behavioral and tDCS analyses

EEG Results

Task Iteration 1, Target Locked

We first examined the effect of previous trial conditions on primary task representation. This mirrored our behavioral investigation of return costs. In ERP studies of traditional task switching, investigators have identified an effect of task switching on P3 amplitude, such that a larger amplitude is related to smaller switch costs (Elchlepp, Lavric. Mizon, Monsel, 2012). Further, the existence of a Target P3 between 400 and 600ms post target has been found to be related to a smaller amplitude on switch trials, suggesting an increase in working memory load (Kariyanidis et al, 2003). To this end we created bins time-locked to the primary task following a previous task switch. Data was epoched from 500 ms prior to primary task onset to 2000 ms after the stimulus, with a baseline of -200–0ms. To identify components of interest we examined plots of the grand averaged ERPs. We identified a P2 at 120–240 ms, a P300 at 300–450 ms, and a late component 500–800 ms along the averaged frontal (FC1, Fc2, Fz) and parietal midline sites (CP1, Pz, and CP2). Based on the shape of the components (isolated peak or slower drift), the mean amplitude was extracted for each participant from each site across the two later time frames, while the peak amplitude was extracted for the earliest. Each component was analyzed separately using Bayesian repeated measures (RM) ANOVA with condition and site (parietal or frontal) as repeated factors, and MMI as a covariate.

P2. We first examined the P2 at 120–240ms. The best model included Site, Condition, and the interaction (BF_M =11.78), with no other model being supported (all $BF_{10} < 0.34$). When comparing across matched models, there was very strong evidence for the effect of site (BF_{incl} = 4.227e+11) and for the effect of condition (BF_{incl} = 39100), with moderate evidence for a null effect of MMI (BF_{excl} = 3.14), and weak evidence for a null effect of the interaction of site and condition (BF_{excl} = 2.94). In line with Figures 3.3 and 3.4, post hoc comparisons showed that amplitude was greatest over frontal sites at this time period, with robust differences between frontal and parietal sites (BF_{10} 1.680e+10). Post-hoc comparisons between conditions supported the finding that amplitude for the current primary task was largest when preceded by a switch trial (BF_{10} = 657530). A frontal P200 has been suggested to be involved in attentional recruitment, including selective (Hilyard, Hink, Schwent & Picton, 1973) and executive attention (Zhao, Zhou, & Fu, 2013). As such, the elicitation of this component during the multitasking paradigm may be attributed to the previous appearance of the switch popup, or more simply, to the primary stimulus onset. However, In the task switching literature, the P2 has also been related to task-set activation (Finke et al, 2011), with a larger amplitude and later latency being related to decreased performance on switch trials. Because of the effect of condition, this may suggest that the elicited component is related to the previous switch task.

P3. We then examined the P3 at 300–450 ms. The best model included only Site (BF_M = 11.28), with no other model being supported (all $BF_{10} < 1.86$). When comparing across matched models, there was very strong evidence for the effect of site (BF_{incl} = 9.901e+21) but weak evidence for a null effect of condition, MMI, and the interaction of site and condition (BF_{01} <

3.51). In line with Figures 3.3 and 3.4, post hoc comparisons showed that amplitude was greatest over parietal sites at this time period, with robust differences between frontal and parietal sites (BF_{10} = 3.539e+16). Planned comparisons between conditions found that amplitude for the current primary task did not differ after switch trials (BF_{10} = 0.34). The observation of an increased amplitude at 300 ms post stimulus has been related to the evaluation of a stimulus (Allison, Polich, 2007). As such, this is likely a product of the onset of the primary task and was not influenced by previous trial conditions.

Visual inspection of grand averaged ERP also identified a slow component at 500–800ms. When examining amplitude from this component, however, the best model included Site (BF_M = 15.56), with no other model being supported (all BF_{10} < 0.29). When comparing across matched models, there was very strong evidence for the effect of site (BF_{incll} = 3.221e+8), moderate evidence for a null effect of condition (BF_{excl} = 5.59), moderate evidence for a null effect of MMI (BF_{excl} = 3.52), weak evidence for a null effect of the interaction of site and condition (BF_{excl} = 3.72). In line with Figures 3.3 and 3.4, post hoc comparisons showed that negative amplitude was greatest over frontal sites and positive at parietal areas at this time period, with robust differences between frontal and parietal sites (BF_{10} 1.519e+6). Post-hoc comparisons between conditions found that amplitude for the current primary task did not differ after switch trials (BF_{01} < 6.8). An ERP component at 600 ms post stimulus onset has been attributed to syntactic processing of language, such as with garden path sentences or when processing syntactic violations (Frisch, Schlesewsky, Saddy, & Alpermann, 2002; Osterhout and Holcomb, 1992). Further, a frontal N400 has also been suggested to be related to semantic priming (Voss & Federmeier, 2011). As these are not components of the multitasking paradigm, this ERP activity may be attributed to the variability throughout the ERP waveforms (e.g., noise).

However, it is also possible that this component is related to the onset of the popup switch prompt, as it occurs 500 ms post primary stimulus onset.

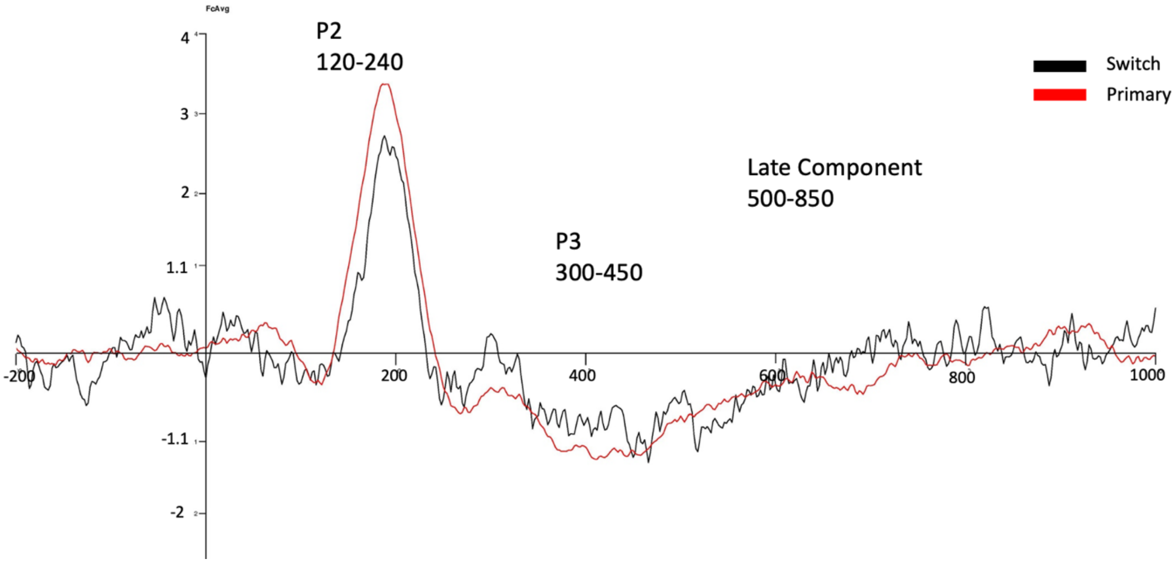


Figure 3.3 Average Waveform Over Frontal Sites During Primary Task Processing

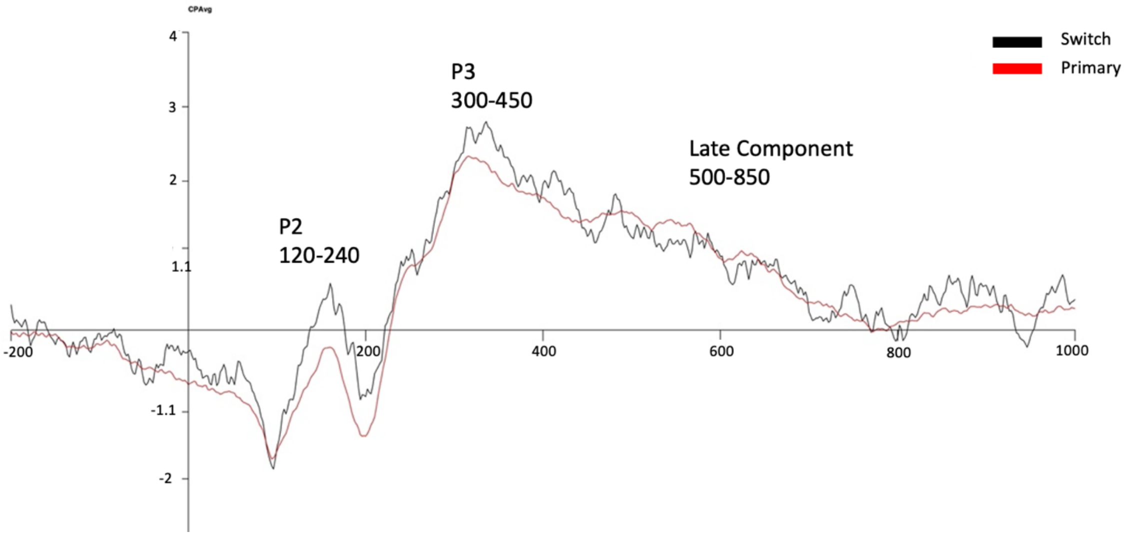


Figure 3.4 Average Waveform Over Central Sites During Primary Task Processing

Task Iteration 1, Popup Stimulus Processing

As the time period preceding the onset of the popup stimulus was contaminated by the ongoing response to the primary task stimulus, we examined popup processing by time-locking to the primary task stimulus but examined activity starting after the popup onset (i.e., 500 ms). We once again examined plots of the grand averaged ERPs to identify components of interest. We identified a later component at 700–850 ms along the averaged frontal (FC1, Fc2, Fz) and parietal midline sites (CP1, Pz, and CP2). Based on the shape of the components, the peak amplitude was extracted for this component. It was then analyzed separately using Bayesian repeated measures (RM) ANOVA with condition and site (parietal or frontal) as repeated factors, and MMI as a covariate.

The last component examined was the late component at 700–850ms. The best model included Condition ($BF_M = 10.97$), with no other model being supported (all $BF_{10} < 2.86$). When comparing across matched models, there was very strong evidence for the effect of condition ($BF_{incl} = 1.423e+7$) with only moderate evidence for a null effect of site ($BF_{excl} = 5.97$), weak evidence for a null effect of MMI ($BF_{excl} = 2.26$), and weak evidence for a null effect of the interaction of site and condition ($BF_{excl} = 1.72$). In line with Figures 3.5 and 3.6, post hoc comparisons showed that amplitude did not differ between parietal or frontal sites at this time period ($BF_{01} =7.82$). Post-hoc comparisons between conditions supported the finding that negative amplitude for the current primary task was largest when preceded by a switch trial ($BF_{10} = 88359$). As this is approximately the time frame in which a popup would appear during any trial, the component observed here may have been more prominent following a switch trial due to the expectation of a popup around this time.

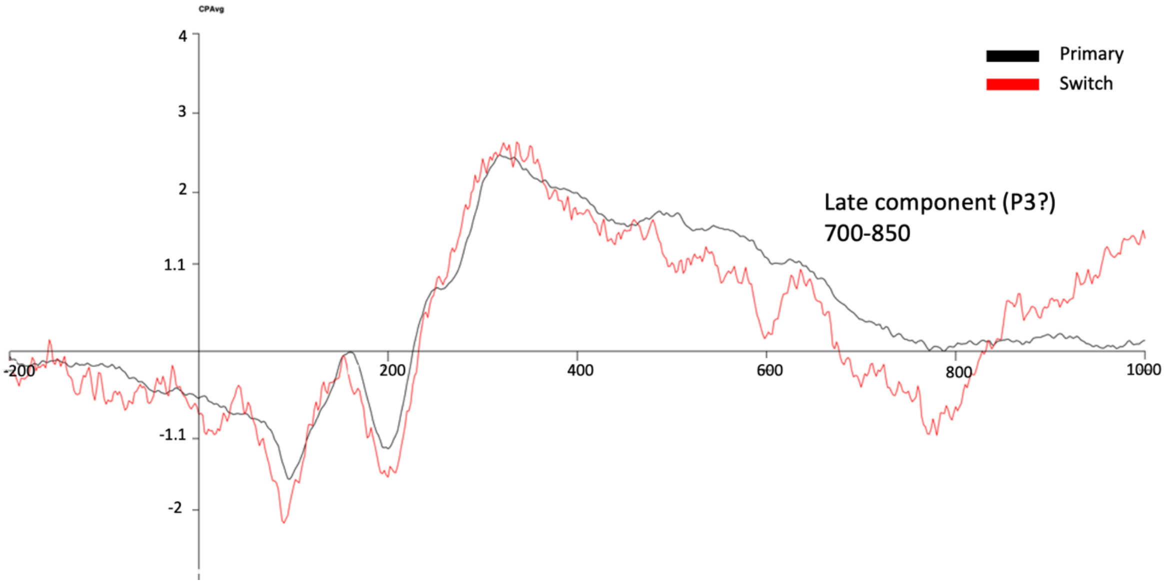


Figure 3.5 Average Waveform Over Central Sites During Popup Processing

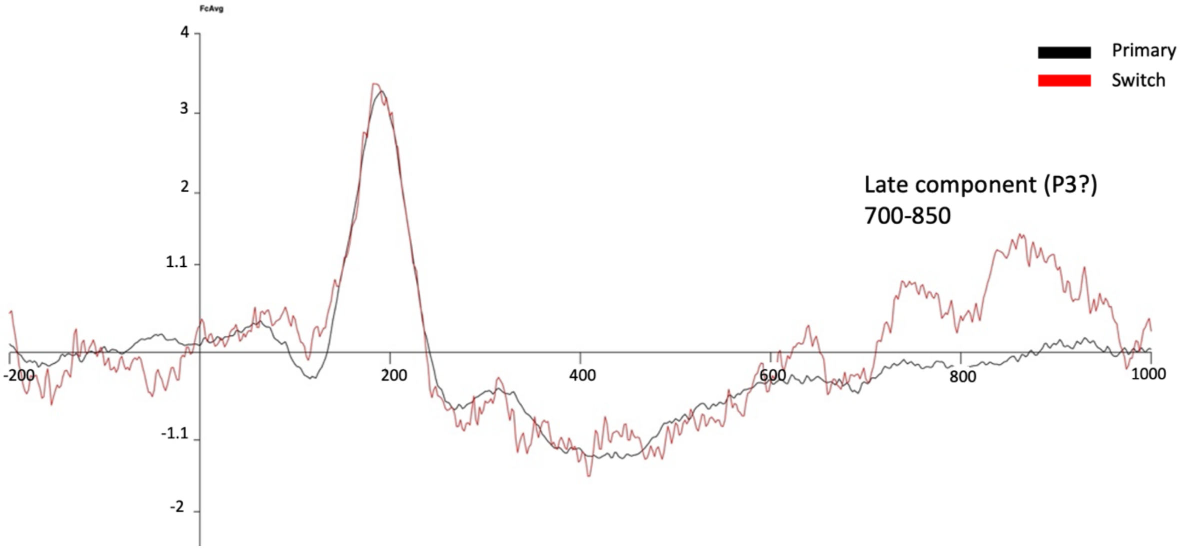


Figure 3.6 Average Waveform Over Frontal Sites During Popup Processing

Task Iteration 2, Primary Task Stimulus Locked

Just as in task iteration 1, we first examined the effect of previous trial conditions on primary task representation to mirror our behavioral investigation of return costs. We created bins time-locked to the primary task stimulus as a function of whether the previous trial was a task switch or included an ignored popup. Data was epoched from 500 ms prior to primary task onset to 2000 ms after the stimulus, with a baseline of -200–0ms. To identify components of interest we examined plots of the grand averaged ERPs. We identified a P2 at 160-240 ms, and P300 at 270-420 ms along the averaged frontal (FC1, Fc2, Fz) and parietal midline sites (CP1, Pz, and CP2). Based on slower drift of the components, the mean amplitude was extracted for each participant from each site across the two later time frames. Each component was analyzed separately using Bayesian repeated measures (RM) ANOVA with condition and site (parietal or frontal) as repeated factors, and MMI as a covariate.

P2. We first examined the P2 at 160-240ms. The best model included Site ($BF_M = 16.66$), with no other model being supported (all $BF_{10} < 1.65$). When comparing across matched models, there was very strong evidence for the effect of site ($BF_{incl} = 644$) and moderate evidence for null effects of condition ($BF_{excl} = 4.77$), MMI ($BF_{excl} = 4.17$), and the interaction of site and condition ($BF_{excl} = 6.6$. In line with Figures 3.7 and 3.8, post hoc comparisons showed that amplitude was greatest over frontal sites at this time period, with robust differences between frontal and parietal sites ($BF_{10} = 66.32$). Planned comparisons between conditions supported the finding that amplitude did not differ across conditions ($BF_{10} < 1.04$).

P3. We then examined the P3 at 270-420ms. The best model included Site ($BF_M = 21.69$), with no other model being supported (all $BF_{10} < 2.27$). When comparing across matched models, there was very strong evidence for the effect of site ($BF_{incl} = 1.179e+28$) and strong evidence for a null effect of condition ($BF_{excl} = 10.29$), with weak evidence for a null effect of MMI ($BF_{excl} = 3.54$, and moderate evidence for a null effect of the interaction of site and condition ($BF_{excl} = 9.15$). In line with Figure 3.4, post hoc comparisons showed that amplitude was greatest over parietal sites at this time period, with robust differences between frontal and parietal sites (BF_{10}

9.114e+18). Planned comparisons between conditions supported the finding that amplitude did not differ across conditions ($BF_{10} < 0.27$).

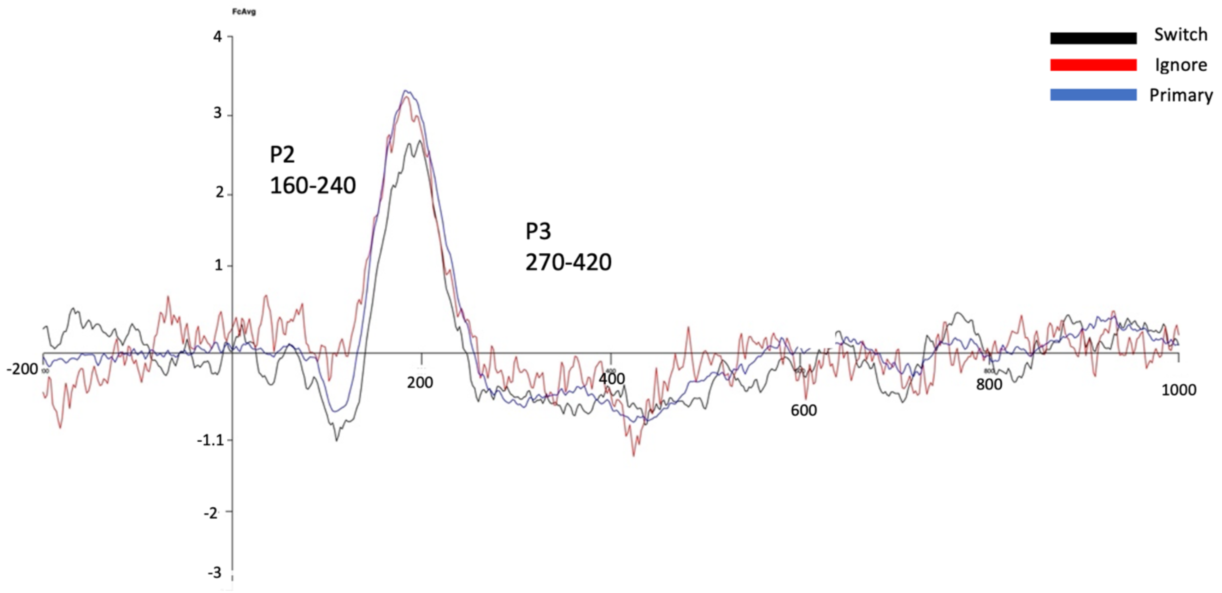


Figure 3.7 Average ERP Waveform Over Frontal Sites During Primary Task Processing

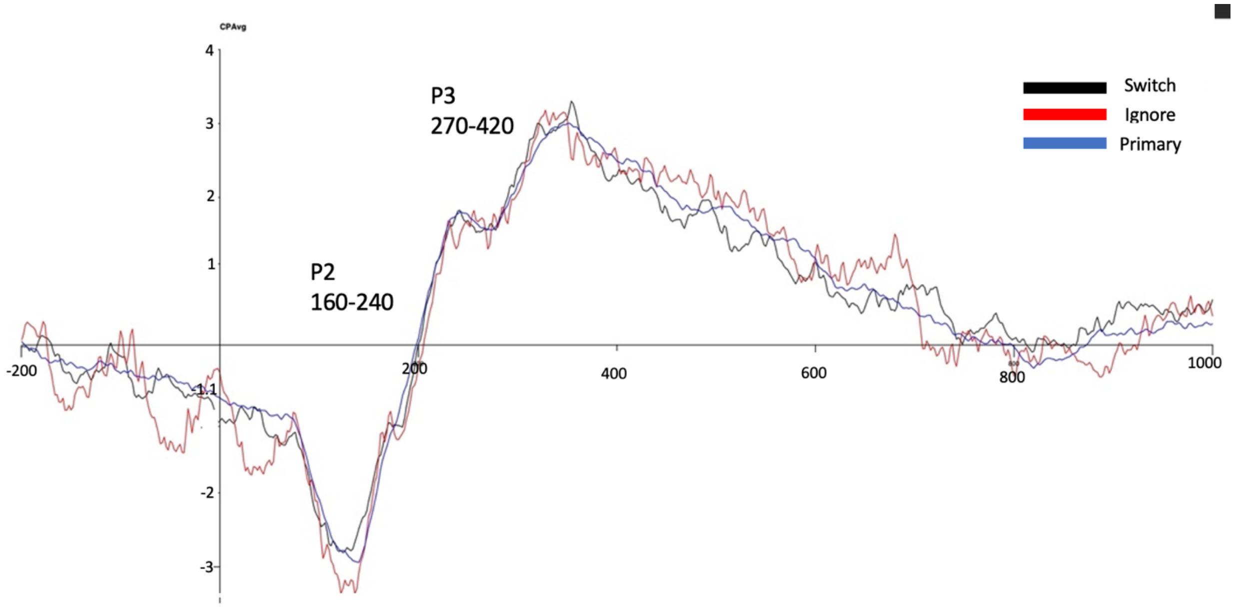


Figure 3.8 Average ERP Waveform Over Central Sites During Primary Task Processing

Task Iteration 2, Popup Stimulus Processing

To examine the differences in popup processing, we created bins time-locked to the primary task stimulus onset that included the following switch trial, as well as the following ignored popup. We once again examined plots of the grand averaged ERPs to identify components of interest. We did not identify any components of interest from 500 ms to 1000ms post primary task onset, which is when the popup appears on screen as shown in Figures 3.9 and 3.10.

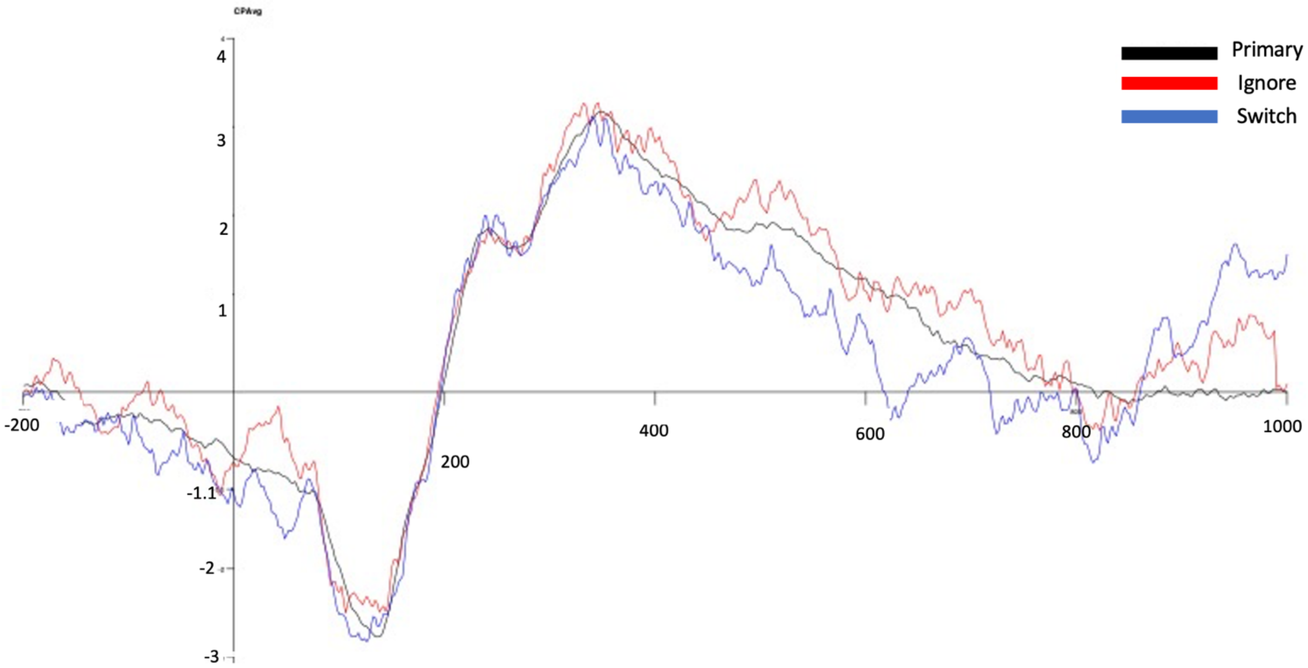


Figure 3.9 Average ERP Waveform Over Central Sites During Popup Processing

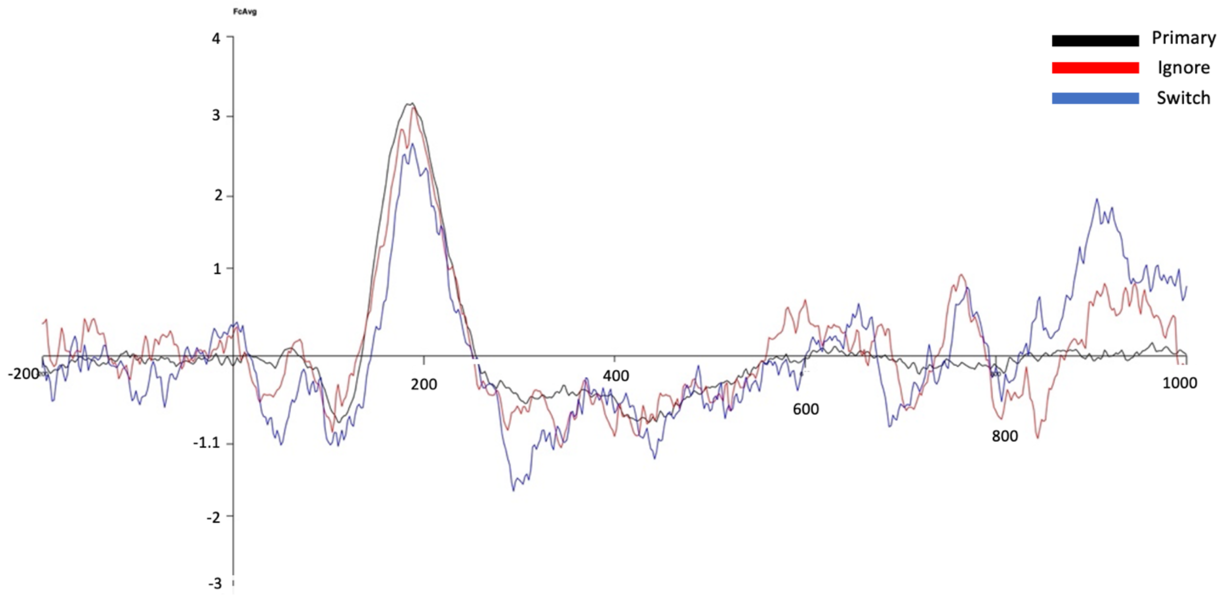


Figure 3.10 Average ERP Waveform Over Frontal Sites During Popup Processing

Discussion

In this study, we attempted to replicate our previous findings on the effects of media use frequency and task performance with two revisions of the novel volitional task switching paradigm used in the original experiment. These revisions were intended to increase the number of available chances to switch tasks, as well as further incentivize the act of switching. We also examined for an effect of tDCS on task performance, as well as EEG markers of decision making, including the P300 ERP component. Briefly, using Bayesian statistics, we failed to replicate our original results by only finding anecdotal to moderate evidence of an effect of media use frequency on task performance, with a similar pattern of effects regarding an effect of tDCS on task performance. We also found no difference in ERP component amplitude between primary task representation and popup processing, with or without MMI score as a covariate.

Behavioral and tDCS Results

Switch rate, Popup$_{select}$, Primary$_{repeat}$. In line with our original hypothesis, we expected a higher switch rate among individuals who reported greater media frequency use due to the previously proposed link between greater impulsivity and worse inhibitory control have been linked to MMI scores (Gorman & Green, 2016; Sanbonmatsu et al., 2013; Murphy & Creux, 2021; Rogobete et al., 2021; Shin et al., 2019). Similarly, we expected Popup$_{select}$, or the average RT for an individual to choose to switch tasks in relevant trials, to be related to MMI scores. Our reasoning was that the link between frequent media use and impulsivity would present itself in the form of frequent media multitaskers choosing to switch tasks more quickly and frequently, due to the greater reward for completing the secondary task. Instead, we found very little evidence to support this suggestion in both iterations of the task. Moreover, we found little evidence to suggest that active tDCS had any effect on switch rate or time to elect to switch tasks.

Previously, we suggested that the tendency to engage in frequent media multitasking may be due to difficulty staying on task over time, leading to worse performance (Cain & Mitroff, 2011). Along these lines, we expected to replicate our original findings regarding Primary$_{repeat}$, or primary task trials following a previous primary task trial. We again found very little evidence in either task iteration to support these predictions. Similarly, we found no evidence of an effect of tDCS here.

Primary$_{return}$, Return Cost, Primary RT, and Primary$_{nopopup}$. Again, we expected to find evidence to support our original findings that suggest that high media multitaskers show less efficient executive functioning (Becker, Alzahabi, & Hopwood, 2013; Cain & Mitroff, 2011; Murphy & Creux, 2021; Ophir et al., 2009; Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). In line with this, we expected to find that more frequent media multitasking would be associated with slower primary trial RTs on trials following a switch (Return cost) as well as on all primary task trials following a task switch, regardless of the presence of a popup ($\text{Primary}_{\text{return,}}$). Our original design found the latter but not the former, however, in the current study, we found no evidence of an effect of media use frequency on these measures in both task designs, regardless of tDCS condition. This suggests that media use frequency has no effect on the effectiveness of one's executive function.

In line with our original findings as well as with research suggesting less efficient executive functioning in high media multitaskers, we expected to find a general slowing for more frequent media multitaskers during the primary and secondary task overall as well as on primary task trials with no popup present ($\text{Primary}_{\text{nopopup}}$). However, we found no evidence to support these claims in both of the paradigm designs, again casting doubt on the previously found effects of media use incidence on executive function. tDCS condition also had no effect on this measure.

Viewed through Altmann and Trafton's goal-activation model (2002), our pattern of results here was especially interesting. In their model, they describe a distraction as consisting of several events. Namely, the alert that a distraction is imminent is but the first component of a distraction, then followed by the interruption event. The time between these two events, called the interruption lag, can then affect the resumption lag, defined as the time between the end of the interruption and the point in time in which the previous task is resumed. Our paradigm fits nicely into the model, with the switch prompt being the "alert", the time it takes for an individual to switch tasks is the interruption lag, and the interruption event, or the secondary task, follows immediately after. In an examination of this model, Altmann and Trafton found that the average resumption lag was much longer than the average time between primary task trials, a measure not unlike our representation of return cost here. Altmann and Trafton also suggest that the length of the resumption lag is also affected by the training of an individual, which is represented by the rate of media multitasking an individual reported engaging in. However, despite these parallels, we found no effect of media multitasking on resumption lag, or return cost.

***Popup$_{ignore}$* and Interference cost.** We previously found evidence supporting the notion that heavy media multitaskers are less able to filter out distractors (Lui & Wong, 2012; Murphy & Creux, 2021; Ophir et al., 2009) in the form of a relationship between MMI score and RT on Popup$_{\text{ignore}}$ trials, or trials in which a popup occurred but the participant chose not to switch. Our results suggested that responses to the primary task during these trials were slower as a function of more frequent media multitasking. We interpreted this longer RT as the inability to filter irrelevant stimuli (the popup being ignored) on trials in which they did not intend to switch tasks. At the same time, our lack of an effect between interference cost, or the difference in RT on trials in which the participant ignored a popup and the RT on trials in which no popup occurred, and MMI score conflicted with this interpretation. In the current study, we found no evidence to support our earlier predictions, suggesting that media multitasking is not related to distractor filtering. Again, we found no evidence to support an effect of tDCS here as well.

EEG Results Discussion

In the task switching literature, a relationship between P3 amplitude has been found, such that a larger amplitude is related to smaller switch costs (Elchlepp, Lavric. Mizon, Monsel, 2012). This component has also been observed with a positive deflection that usually follows a rare stimulus that appears among other more frequent stimuli (Polich, 2007). Due to the nature of the popup component in our paradigm, we then expected to see this deflection on switch trials.

We found very few differences in task representation between switch and ignore (in task iteration 1 only) trials. However, the difference in P200 amplitude found between switch and primary task trials may be attributed to task-set activation (Finke et al, 2011) as the individual prepares to switch tasks. That being said, as this P2 occurred before any popup stimulus onset, it this may not be due to task set activation. The overall lack of difference in average ERPs between trial types may be attributed to the reconfiguration of the task set being completed prior to the beginning of the following trial. The time between each subsequent task trial, regardless of task type, is often approximately 5 seconds, allowing more than enough time for a reconfiguration to take place before the following trial. We also only found evidence for an effect of switching on popup processing during task iteration 1.

Further, due to the volitional aspect of the paradigm, allowing participants to be in control of what task type follows, this long amount of downtime between trials also contributes to their ability to reconfigure task sets (Imburgio & Orr, 2021). The long and extremely variable time period between most components of the tasks also makes it difficult to use traditional ERP averaging techniques to examine the inter-trial period. A multivariate pattern analysis (MVPA) may be necessary to further decode the time course of this time period. Recent research suggests that MVPA can be used to infer cognitive stages (Berberyan et al., 2021). Another approach may be the incorporation of multi-level modeling in conjunction with ERP analysis to help elucidate ERP variation across trials throughout a task. (Volpert-Esmond, Page-Gould, Bartholow, 2021). Such a method may be helpful to further examine the neural mechanisms at play in the current study.

ERP Amplitude and MMI. Finally, the uniform lack of any effect of MMI on any component further provides evidence for the largely inconsequential effect of media use frequency on task performance. This pattern of results mirrors our behavioral results.

MUQ Limitations

We did not make any further changes to the Media Use Questionnaire beyond our original experiment design. As such, the changes made to it may be contributing to our pattern of effects. Despite these changes, however, our average MMI score was relatively in line with other studies that have used the original questionnaire, albeit they themselves tend to greatly vary in range. As in our original study however, we must still acknowledge that the changes made to the questionnaire may limit the generalizability of our findings to other studies that used the original version. Even then, the literature remains divided in terms of the development of a ubiquitous media use questionnaire, with several different iterations being devised over the years, each resulting in their own patterns of effects (Baumgartner et al., 2016; Pea, et al, 2012.). Kaye and colleagues (2020) point to this lack of uniformity between screen time and media use measures, as well as the ambiguous definition of media use, as a major reason for the lack of generalizability of findings in the literature to the population.

Paradigm Discussion and Limitations

Both iterations of the novel paradigm aimed to fix the issue of secondary task incentivization from our original experiment. Originally, we proposed that there were simply not enough opportunities to switch, as well as no real reason for participants to actively engage with the switching component of the task other than reducing boredom. Thus, we increased the popup frequency from 1 out of every 6 primary task trials, to 1 out of every 4. This resulted in a meager

3% increase from 31% to 34% in switch rate between the original design and task iteration 1 of the current experiment, respectively. This suggests that the original finding was not due to low opportunities to engage in switching. However, the removal of point deductions and the introduction of random point values during task iteration 2 increased the overall switch rate from 34% to 69%. We chose the random points design as a necessary change to our paradigm, as the "reward" one receives from switching tasks in the real-world environment we are seeking to emulate is likely random as well. An individual may not always be aware of what the notification they are attending to and subsequently switching to may bring. To further drive this point in our design, it may be pertinent to only inform participants of the randomization of the point rewards, but to not inform them of the exact value until after the task has been switched to.

Interestingly, these switch rate differences came along with an increase in secondary task performance in the second vs. the first iteration (63% and 59%, respectively). The admittedly still low accuracy rate of the secondary task may be due to said task still being too difficult for most participants and may be an issue to be addressed in future implementations of the design.

The introduction of sound in conjunction with the popup notification would help to further bring this paradigm in line with a typical real world multitasking environment, as many of the notifications we are aiming to emulate are accompanied with sound. Research into the field of cross-modal spatial links has emphasized the importance of such a task design in the pursuit of the establishment of a more complex environment not unlike the one we aim to replicate (Ferris and Sarter, 2008).

Further, because many of the notifications we receive are ignored as either "spam" or of little interest to us, including uninformative popups within the "useful" switch prompts may also help to emulate a real-world environment. These uninformative popups can then be deemed as a “distractor” and can be used to investigate the link between inhibition and media use frequency. Research by Hammed and colleagues (2009) has found that more “informative” cues lead to more effective interruption management, but an investigation of the effect media multitasking may have on this skill has been carried out in a real-world multitasking environment. A design such as this would operationalize the “informative” cues as the switch prompt with the number of points possible, and the “distractor” popups as the uninformative cues.

As most of the current research on the effects of media use frequency on cognitive performance has relied on tasks unrelated to multitasking, e.g., working memory and inhibitory control tasks, a paradigm specifically designed to emulate a real-world volitional multitasking environment is necessary to demonstrate broad cognitive deficits in frequent multitaskers. Indeed, a recent study by Lui and colleagues (2022) pointed out the need for a more ecologically valid paradigm to investigate real-world multitasking due to the discrepancy in findings between studies that used these classical, laboratory-based paradigms and paradigms that more closely aim to emulate real-world multitasking, a discrepancy our line of experiments has exemplified. Despite the limitations discussed, our pattern of results here adds to the growing body of literature suggesting that media use frequency does not influence executive function (Imren & Tekman, 2019; Parry & Le Roux, 2021). Although these effects contrast with our original study’s, the original effects found were extremely weak, and were derived from a version of the paradigm that was lacking in several aspects, as discussed above.

Conclusion

Although our original study found some negative effects attributed to media use frequency, they were very weak and were not replicated. Overall, our behavioral and EEG findings lend support to more recent meta-analyses (Imren & Tekman, 2019; Parry & Le Roux,

2021) suggesting that media use frequency does not affect cognitive processes. Finally, our tDCS behavioral findings also point towards tDCS having no effect on executive functioning that can be detected in task performance.

CHAPTER IV

AN EXAMINATION OF DISTRACTION DURING VOLITIONAL MULTITASKING

Introduction

Between 1999 and 2009, there has been a 10% increase in an average individual's time spent multitasking with several media types(Rideout, Ulla, Foehr, & Roberts, 2010). Due to this widespread increase in incidence, researchers have been increasingly searching for associations between cognitive abilities and frequent media use, as well as media multitasking (Minear, Brasher, McCurdy, Lewis, & Younggren, 2013). Originally, this work focused on identifying negative consequences of frequent media multitasking, but recent work cast doubt on these original findings (Parry & Le Roux, 2021).

Early Multitasking Research

Early research led by Ophir and colleagues (2009) found that frequent media multitaskers showed worse performance compared to light multitaskers on a number of tasks designed to assess executive function. These findings lead to the suggestion that heavy media multitaskers are less able to filter out irrelevant information. As part of this initial study, they devised a survey to quantify the amount of time an individual multitasks with different media types, the Media Use Questionnaire (MUQ). Much of the research that followed this original 2009 study was predicated on these original findings, with many finding evidence to support their suggestion that frequent media users are less able to filter out irrelevant stimuli(Cain & Mitroff, 2011; Cardoso-Leite et al., 2016; Heathcote et al., 2014.; Lottridge et al., 2015; Moisala et al., 2016; Murphy & Creux, 2021; Wiradhany & Nieuwenstein, 2017). Additionally, other negative effects of media multitasking frequency have been found in regard to inhibitory control (Baumgartner, Weeda, van der Heijden, & Huizinga, 2014; Schutten, Stokes, & Arnell, 2017), and sustained attention (Ralph & Smilek, 2017; Ralph, Thomson, Cheyne, & Smilek, 2014), suggesting that media use frequency can affect many different aspects of cognitive function.

Dual-Tasking Vs. Multitasking

Because media multitasking will often involve the active maintenance of more than one task across a number of media types, it can be best described as a form of dual tasking reminiscent of the Psychological Refractory Period (PRP) paradigm. This dual tasking paradigm was described by Fagot and Pashler (1992) as a paradigm requiring participants to complete two tasks concurrently, albeit with a temporal delay between each task. The "processing bottleneck" that occurs when several stimuli are presented to an individual in temporal proximity leads to a decrease in overall task performance (Fagot & Pashler, 1992). Due to the parallels between the PRP paradigm and media multitasking, researchers have sought to establish a link between media use frequency and dual tasking.

For example, Alzahabi and Becker (2013) have found no difference in dual tasking performance between heavy and light media multitaskers. More recently, Shin, Webb, and Kemps (2019) examined for an effect of media multitasking exposure on task performance using a multisensory version of the PRP paradigm. They found a positive effect of media multitasking in task performance when the second task was presented with a longer delay from the initial task. Further still, a recent meta-analysis by Parry and le Roux (2021) found an overall weak effect of media multitasking on cognitive function. It is clear that there is a deeper relationship at play between media multitasking and dual task performance that still warrants investigating. Further still, a recent meta-analysis by Parry and le Roux (2021) found an overall weak effect of media multitasking on cognitive function.

Limitations in Media Multitasking Literature

As the true nature of the effects of media multitasking remains unclear, further research is needed to bridge the gap between real world multitasking and lab-based studies of multitasking. In our previous studies, we proposed that a more ecologically valid task paradigm is necessary to advance the literature, due to the bulk of research in this area focusing on task performance measures derived from paradigms that may not be well suited to examine the effects of multitasking. The field of media multitasking has mostly relied on empirical findings predicated only on laboratory-based multitasking paradigm, often using tasks originally designed to assess aspects of cognitive function, such as working memory and inhibitory control. Indeed, a recent study by Lui and colleagues (2022) pointed out the need for a more ecologically valid paradigm to investigate real-world multitasking due to the discrepancy in findings between studies that used these classical, laboratory-based paradigms and paradigms that more closely aim to emulate real-world multitasking, a discrepancy our line of experiments has exemplified. The main differences between the classical paradigms used to index multitasking and paradigms specifically examining real-world multitasking include the ability for the individual to prioritize certain tasks and switch back and forth at their leisure, as well as the scope of the tasks actually being used. Lui and colleagues also argue that laboratory-based tasks usually consist of much more simple tasks, a stark contrast from real-world multitasking (Lui et al., 2022).

Purpose

To that end, we devised an original volitional multitasking paradigm that took cues from several different bodies of literature, including studies of working memory, dual tasking, and voluntary task switching. The paradigm consisted of a primary task modeled after Turner and Engle's operation span task (1989) with occasional prompts designed to be analogous to the "popups" we see in most of the devices that are in wide use today. The prompts allowed the individual to switch tasks to a secondary task via a key press. As in PRP paradigms, these popup prompts appeared only after the primary task had been on screen for some time. Individuals were incentivized to maximize performance on both tasks by assigning point values to each, with the secondary task being worth more, so that the act of switching would be more alluring, as in the real world, switching from a monotonous, boring task to a different, more exciting one (that is also more sporadic) may provide for a breath of fresh air.

Using this paradigm, along with a modified version of Ophir and colleagues MUQ, we have largely found evidence to suggest that there is little to no effect of media multitasking on task performance. More specifically, we found very weak negative effects between media use frequency and task performance with the original version of our paradigm, but these effects were largely absent in the following experiment featuring two deviations from the original design that were intended to increase engagement with the popup prompts. Nonetheless, we aim to further refine the task paradigm to achieve our goal of a more ecologically valid paradigm for the media multitasking literature.

To further examine the negative link between media multitasking and distractor filtering (Lottridge et al., 2015; Moisala et al., 2016; Wiradhany & Nieuwenstein, 2017), we have modified the existing paradigm to include "distractor" popups that sporadically take the place of a "normal" popup that allows the participant to switch tasks. This version of the task paradigm will carry over the changes made during our previous experiment, featuring randomized point values for the secondary task, no point deductions for incorrect or missed responses, and an increased chance for a primary trial to include a popup prompt (1 out of 4). The distractor popups will be integrated into the randomization of the popup prompt's appearance, such that the distractor message has an equal chance to replace the prompt to switch tasks. These distractor messages will consist of encouraging messages (e.g., “Great job!”, “Keep it up!”), but will not have any interactions tied to its appearance. On trials in which these distractor popups appear, participants will not have the option to switch tasks and will instead have to remain on task by completing the primary trial on screen.

We expect to replicate our previous results indicating a limited, almost nonexistent effect of media multitasking frequency (as indexed by our modified version of the MUQ, detailed below) and task performance. However, in line with previous research regarding distractor filtering, we expect to see a more marked effect of media use on trials in which a distractor popup occurred, such that more frequent media multitaskers will spend more time on said trials due to an inability to filter out irrelevant stimuli (Cain & Mitroff, 2011; Cardoso-Leite et al., 2016).

As with our previous experiment, we also collected EEG data to examine for markers of decision making. More specifically, we were interested in examining for the P300 ERP component. Because the P300 component has been shown to be a positive deflection in EEG that usually follows a rare stimulus that appears among other more frequent stimuli (Polich, 2007), our paradigm design presents (more specifically, the popup prompts) a perfect opportunity to examine for this marker. Further, it has also been suggested that P300 amplitude is reduced during dual-task paradigms, creating a link between the link and processing capacity between tasks (Makoto, Nomura, & Ohira, 2007; Isreal, Chesney, Wickens, & Donchin, 1980; Allison & Polich, 2007; Miller, Rietschel, McDonald, & Hatfield, 2011). In the task switching literature, a relationship between P3 amplitude has been found, such that a larger amplitude is related to smaller switch costs (Elchlepp, Lavric. Mizon, Monsel, 2012). This component has also been observed with a positive deflection that usually follows a rare stimulus that appears among other more frequent stimuli (Polich, 2007). Due to the nature of the popup component in our paradigm, we then expected to see this deflection in distractor or switch trials.

Methods

Participants

A total of 64 participants (32 female, 32 male) with ages ranging from 18-23 years (*M* = 19.2, *SD* = 1.2) completed the full procedure. Four participants were dropped due to non-completion of the study. Participants were recruited from the Texas A&M Psychology Subject Pool and received course credit for participating. All participants were also entered into a drawing to win one of five $100 Amazon gift cards. We did not determine a target sample size a priori. Instead, we aimed to collect as much data as possible during the semester. Eligibility requirements for participants included the following: right-handedness, neurotypicality, between the ages of 18-30 years old, English-speaking, full color vision.

Study procedures were deemed “Not Greater than Minimal Risk” under 45 CFR 46 / 21 CFR56 by the Texas A&M Institutional Review Board, approval reference number IRB2019-1468D. The authors confirm that we have reported all measures, conditions, data exclusions, and the method of sample size determination.

Media Multitasking Index

We used the same modified version of the Media Use Questionnaire (MUQ) as in our previous studies. The survey asks participants to estimate how many hours per week they use each individual form of media (using a sliding scale ranging from 0-80 (in hours). Twelve distinct media types were evaluated, including computer-based applications (e.g., word processing, excel), web surfing (not including social media sites), text-based media such as print books, eBooks, magazines, newspapers (for school/work/pleasure), television programs (TV based or online streaming), streaming videos (e.g., YouTube, BuzzFeed, other short clips), listening to music, listening to non-music audio (e.g., audio books, podcasts, talk radio, etc.), video based games (console, computer, phone/tablet based), voice calls (landline, cellphone, skype), reading/writing emails, viewing social media (Facebook, Instagram, snapchat, twitter, etc.), and "other" media types.

As mentioned, our version of the survey was updated to match current media trends that were either not present or have changed in popularity in 2009, when the questionnaire was devised. We replaced the original media type of "instant messaging" with "social media" to be consistent with the rise of social media platforms and the decline in popularity of instant messaging programs. Along with this change, several media types were renamed. "Print media" was renamed to "text media" because of the rise in popularity of e-readers, "telephone and mobile phone voice calls" was changed to "voice calls," "computer-based video" was renamed to "streaming video" due to the influx and popularity of services such as "Netflix", "YouTube", and "Hulu", and "video or computer games" was renamed to "video games".

After indicating the number of hours per week spent using each media type, participants were then asked, for each media type they use, how often they concurrently used each of the other mediums using a 5-point Likert scale ("Always," "Most of the time," "Some of the time," "A little of the time," or "Never"). The original MUQ used only a 4-point Likert scale ranging from "Most of the time" to ''Never''. We added the additional answer choice of "Always" to get a more precise measure of media multitasking occurrence. We added "Always" answer choice to counterbalance the already existing "Never" answer choice.

To calculate a participant’s Media Multitasking Index (MMI) score, numeric values were assigned to each of the aforementioned matrix answers, such that “1.0” represented “Always”, “0.75” corresponded to “Most of the time,” “0.5” to “About half the time”, “0.25” to “Sometimes,” and “0” to “Never.” The sum of these values across each primary medium are then weighted by the percentage of time spent with the corresponding primary media type, yielding the individual’s MMI score. This final score is then interpreted as the amount of media multitasking the participant is engaged in during a typical media-consumption hour so that the higher the MMI, the greater the amount of time that participant spends media multitasking during that hour.

EEG Setup

After the MUQ, the EEG system was set up for each participant. The set-up consisted of the fitting of an EEG cap with 64 electrodes. EEG data was recorded using Brain Vision Recorder (needs reference) and was sampled at 1000 Hz using FCz as an online reference. The preprocessing pipeline is described further below.

Multitasking Paradigm

After EEG setup, participants completed the practice and full versions of the multitasking task, both created using PsychoPy version 3.0.6 (Peirce et al., 2019). All participants completed the task on a 21-inch, with default monitor settings as defined by PsychoPy. Figure 4.1 shows a representation of the task paradigms used.

As in our original design, participants had a primary task and secondary task to attend to. During the primary task, participants were instructed to check the validity of math problems (e.g., ‘(3–2) × 1 = 4’) via key press, with “C” indicating the math problem was correct, and “I” to indicate an incorrect problem. The math operations were on screen for 5 seconds. To incentivize good performance, the task featured a point system. Participants were also led to believe that a higher score would result in a higher chance to win a $100 Amazon gift card. It was later clarified that all participants were automatically entered into the drawing with equal odds. Regardless, a correct response to the primary task was worth 3 points, with no penalty for failing to respond on time or for an incorrect response. Participants were shown their running total after every trial and were also shown a “high score” at the end of each block. This high score was the same for each participant.

On 33% of the trials, a popup would appear 500 ms after the primary task stimuli, located in the top right corner in order to mimic standard notifications on computers. The popup remained on screen for 2 seconds and signaled that a secondary task was available, i.e., “A New Task is Available! Press ‘Y’ to switch tasks”. In addition, the number of points possible for completing the secondary task would appear below the popup message. The possible points ranged from 10 to 25 and were randomized per trial.

However, on 33% of the trials, instead of a switch prompt, a popup would consist of an irrelevant, positively valanced message (e.g., “Great job!”). This popup would occur at the same time that a “normal” popup would, and in the same position.

If participants elected to switch tasks (i.e., they pressed the Y key before either responding to the primary task or the allowed time elapsed) , the primary task would be replaced with the secondary task stimuli. A word fragment with two letters missing (e.g., “HI_TO_Y”) would appear and participants were instructed to respond via keyboard with the letters needed to complete the word. No point deductions occurred for missed or incorrect responses, and the running total for each participant was shown at the end of each trial. No additional accuracy feedback was provided.

The task consisted of 8 blocks of 20 trials each for a total of 160 trials. The number of blocks was chosen so that the task would be broken up into intervals allowing the participant to take breaks regularly while still being able to complete the experiment in under an hour. The number of pop-ups was not consistent across participants due to the randomization procedure, with an average of 39.4 (*SD* = 4.8) pop-ups and 52.9 (SD = 4.95) distractor popups per participant.

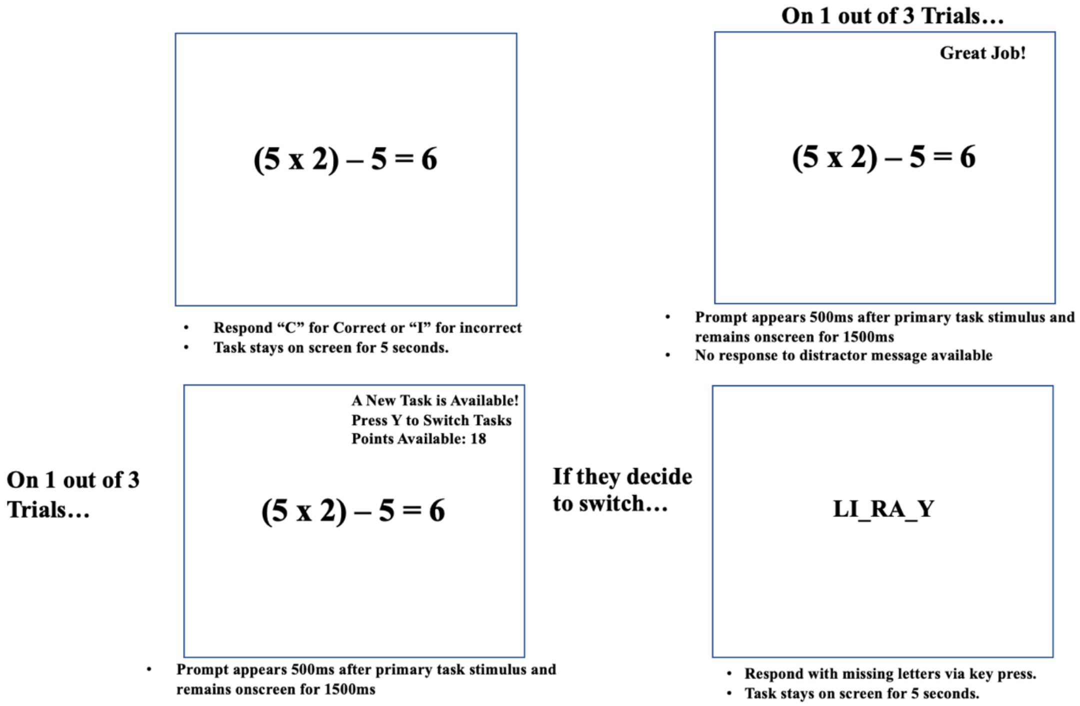


Figure 4.1 Visual Representation of Task Paradigm

Procedure

After providing consent via consent form, participants completed an online version of the MUQ and a demographics questionnaire. EEG setup followed the completion of the surveys. Once EEG setup was complete, participants completed a practice version of the multitasking paradigm, consisting of three separate blocks. The first two blocks of the practice consisted of 5 trials each of the primary and secondary tasks. The final practice block consisted of 6 trials of the full task. Point values were identical to the full task. Participants then completed the full version of the task immediately after the practice sessions were completed. Total experiment duration was about 2 hours.

Behavioral Data Analysis

Following our previous study, we used a series of simple Bayesian regressions to predict task performance across every measure from media multitasking incidence. For each analysis, an uninformed uniform prior [P(M)] of 0.5 was set for each possible model. We used JASP version 0.16 to run all analyses and create all plots (JASP Team, 2021). All Bayes Factor cutoffs and reporting was done in accordance with Dienes (2014). In addition, we performed a *post hoc* power analysis using G*Power (v3.1.9.6; Faul, Erdfelder, Buchner, & Lang, 2009), with the finding that the study was underpowered. Because some participants did not switch at all throughout the task (n = 6), it was not possible to calculate some measures for the entire sample, including switch rate, return cost, interference cost, and measures of switch RT.

Behavioral Measures Assessed

Following our previous studies, the same behavioral measures were examined. A description of each measure examined follows. Switch rate was defined as the percentage of eligible trials a participant chose to switch tasks. $\text{Popup}_{\text{select}}$, was the average reaction time for individuals to indicate their decision to switch tasks on relevant primary task trials. We defined *Return Cost* as the average difference between RT on primary task trials following a switch and primary task trials during which no popup occurred. *Interference Cost* was the average difference in reaction time for primary task trials without a pop-up and primary task trials with an ignored pop-up. $\text{Popup}_{\text{ignore}}$ referred to the average RT on trials in which the participant chose to complete the primary task while ignoring the popup prompt. We also examined the average response time on primary task trials in which no popup occurred,($\text{Primary}_{\text{nopopup}}$), $\text{Primary}_{\text{return,}}$ or average RT on primary trials following a switch, regardless of availability of a switch, RT on trials in which the individual repeated the primary task ($\text{Primary}_{\text{repeat}}$), and finally, overall average RT on the primary and secondary tasks. As before, because some participants did not switch tasks at all, some of these measures could not be calculated for the entire sample.

However, the inclusion of a distractor popup allowed for a number of additional analyses including $\text{Primary}_{\text{Distract}}$, the average RT on primary task trials in which a distractor popup occurred, $\text{Primary}_{PostDistract}$, the average RT on primary task trials following a trial in which a distractor popup occurred, and a *Distraction Cost*, or the average difference between RT on primary task trials in which no popup occurred and average RT on trials with a distractor popup.

EEG Preprocessing

All EEG preprocessing steps were done in EEGLAB, a MATLAB toolbox. Data was preprocessed using a standard pipeline as suggested by Makoto Miyakoshi (n.d.); data was re-referenced to the average, band-pass filtered with a high-pass filter of 0.1 Hz and a low-pass filter of 30 Hz, It was then visually inspected for excess noise artifacts and artifact rejected using the fastICA EEGLAB algorithm. Following ICA artifact rejection, we visually inspected the data and removed any remaining artifacts.

Results

Behavioral Results

Briefly, we found a mix of anecdotal and moderate evidence in favor of the null hypotheses, with no BF_{01} being greater than 3.65. This suggests that media use frequency does not predict switch rate, how quickly an individual decides to switch tasks, the individual’s return cost, interference cost, distraction cost, RT on repeat trials, RT trials in which a prompt to switch tasks was ignored, RT on trials with no popup present, trials in which a distractor was present, trials following a distractor trial, or overall secondary and primary RT. Taken together, this pattern of results is consistent with our previous studies and adds evidence to suggest that the amount of media multitasking does not have any effect on cognitive processes. Tables 4.1 and 4.2 show a breakdown of each task performance measure examined and the related BF_{01} for each Bayesian Regression.

	MMI Score	Switch Rate(%)	Return Cost	Interference Cost	$Popup_{select}$	Distraction Cost	$Primary_{PostDistract}$
Mean	2.48	0.67	0.15s	0.02s	1.38s	0.17s	2.38s
SD	1.17	0.35	0.37s	0.21s	0.36s	0.18s	0.32s
BF_{01}	N/A	3.13	2.79	3.08	2.16	2.22	3.4

Table 4.1 Descriptive statistics and BF01 for main behavioral analyses

	$Primary_{return}$	$Popup_{ignore}$	$Primary_{nopopup}$	Primary RT	Secondary RT	$Primary_{repeat}$
Mean	2.55s	2.44s	2.49s	2.49s	2.67s	2.46s
SD	0.51s	0.37s	0.31s	0.31s	0.4s	0.31s
BF_{01}	3.2	2.39	0.26	0.26	3.65	0.26

Table 4.2 Descriptive statistics and BF01 for exploratory behavioral analyses

EEG Results

We first examined the effect of previous trial conditions on primary task representation. This mirrored our behavioral investigation of return costs, but also examined whether primary task representations were influenced by a previous trial distractor or ignored popup. In ERP studies of traditional task switching, investigators have identified an effect of task switching on the P3 amplitude, such that a larger amplitude is related to smaller switch costs (Elchlepp, Lavric. Mizon, Monsel, 2012). Further, the existence of a Target P3 between 400 and 600ms post target has been found to be related to a smaller amplitude on switch trials, suggesting an increase in working memory load (Kariyanidis et al, 2003). To this end we created bins time-locked to the primary task as a function of the following previous task conditions: primary task without a distractor or popup (i.e., a pure task repeat), distractors, ignored popups, and switch or secondary task trials. Data was epoched from 500 ms prior to primary task onset to 2000 ms after the stimulus, with a baseline of -200–0ms. To identify components of interest we examined plots of the grand averaged ERPs. We identified a P2 at 150-250 ms, a P300 (or P3b) at 270-430 ms, and a possible P600 at 450-700 ms along the averaged frontal (F1, Fz, F2, FC1, and FC2) and parietal midline sites (CP1, CPz, CP2, P1, Pz, P2). Based on the shape of the components (isolated peak or slower drift), the mean amplitude was extracted for each participant from each site across the two later time frames, while the peak amplitude was extracted for the earliest. Each component was analyzed separately using Bayesian repeated measures (RM) ANOVA with condition and channel (parietal or frontal) as repeated factors, and MMI as a covariate.

Primary Task Stimulus Locked

P2. We first examined the P2 at 150-250ms. The best model included Channel and Condition, without the interaction ($BF_M = 19.72$), with no other model being supported (all $BF_{10} < 0.41$). When comparing across matched models, there was very strong evidence for the effect of channel ($BF_{incl} = 5.797e+41$) and condition ($BF_{incl} = 1.219e+11$), with weak evidence for a null effect of MMI ($BF_{excl} = 2.43$), and strong evidence for a null effect of the interaction of channel and condition ($BF_{excl} = 30.95$). In line with Figure 4.2, post hoc comparisons showed that amplitude was greatest over frontal sites at this time period, with robust differences between frontal and parietal sites (BF_{10} 1.318+e31). Post-hoc comparisons between conditions supported the finding that amplitude for the current primary task was different between all conditions except for between distractor and repeat trials($BF_{10} > 0.12$). The P200 elicited in the frontal area has been suggested to be involved in selective and executive attention (Hilyard, Hink, Schwent & Picton, 1973; Zhao, Zhou, & Fu, 2013). In the task switching literature, the P2 is related to task-set activation (Finke et al, 2011), with a larger amplitude and later latency being related to decreased performance on switch trials. However, as this P2 occurred before any popup or distractor stimulus onset, it is likely not due to a difference in task set activation and may instead be due to previous task trial interference.

P3. We then examined the P3 at 270-430 ms. The best model included only Channel ($BF_M = 19$), with no other model being supported (all $BF_{10} < 0.38$). When comparing across matched models, there was very strong evidence for the effect of channel ($BF_{incl} = 3.978e+78$) but weak evidence for a null effect of condition, MMI, and the interaction of channel and condition (BF_{excl} from 16.42 to 2.6). In line with Figure 4.1, post hoc comparisons showed that amplitude was greatest over parietal sites at this time period, with robust differences between frontal and parietal sites (BF_{10} 3.348e+40). Post-hoc comparisons between conditions found that amplitude for the current primary task did not differ between distractor, switch, or ignore trials ($BF_{10} < 1.25$). Previous findings suggest that the amplitude of the P300 is reduced during dual-task paradigms, implying that P300 amplitude is a representation of processing capacity between concurrent tasks (Miyakoshi, Nomura, & Ohira, 2007; Isreal, Chesney, Wickens, & Donchin, 1980; Allison & Polich, 2007; Miller, Rietschel, McDonald, & Hatfield, 2011). Because we found no difference in amplitude across conditions, this may suggest that task demands remained consistent across all conditions. This is perhaps not surprising as the voluntary nature of the task allowed participants to optimize their cognitive resources.

Late component. We then examined a late component at 450-700ms. The best model included Channel ($BF_M = 49.03$), with no other model being supported (all $BF_{10} < 0.17$). When comparing across matched models, there was very strong evidence for the effect of channel ($\mathrm{BF}_{\mathrm{incl}}$ = 6.187e+23) with moderate evidence for a null effect of MMI ($\mathrm{BF}_{\mathrm{excl}}$ = 5.93). Given the model comparison results, it is not surprising that there was strong evidence for a null effect of condition ($\mathrm{BF}_{\mathrm{excl}}$ of 81.09) and strong evidence for a null effect of the interaction of channel and condition ($\mathrm{BF}_{\mathrm{excl}}$ = 30.05). In line with Figures 4.2 and 4.3, post hoc comparisons showed that amplitude was greatest over parietal sites at this time period, with robust differences between frontal and parietal sites (BF_{10} 3.365e+14). Post-hoc comparisons between conditions found that amplitude for the current primary task did not differ between distractor, switch, or ignore trials (BF_{01} < 9.03). Although the P600 is more typically related to synaptic language processing (Friederici, 1995) it may relate to the P3b (Coulson et al., 1998), and as such may have been elicited by the same processes during the task. However, because this is approximately the time frame in which a popup would appear during any trial, the component observed here may have been due to the appearance of a popup at this time (on relevant trials).

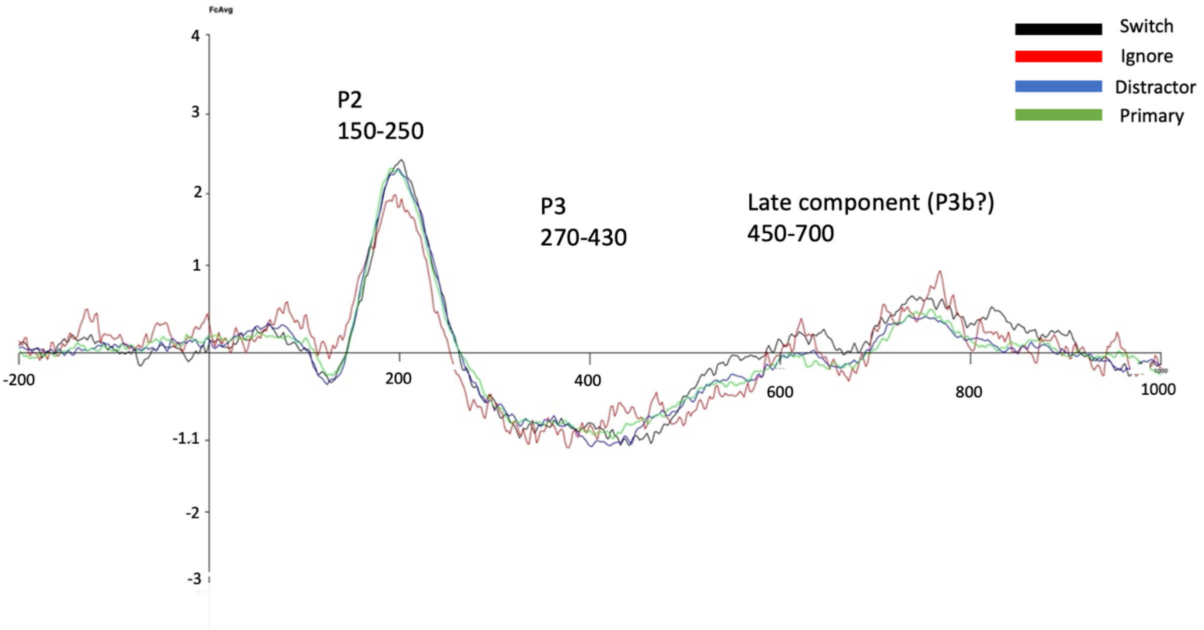


Figure 4.2 Average ERP Waveform Over Frontal Sites During Primary Task Processing

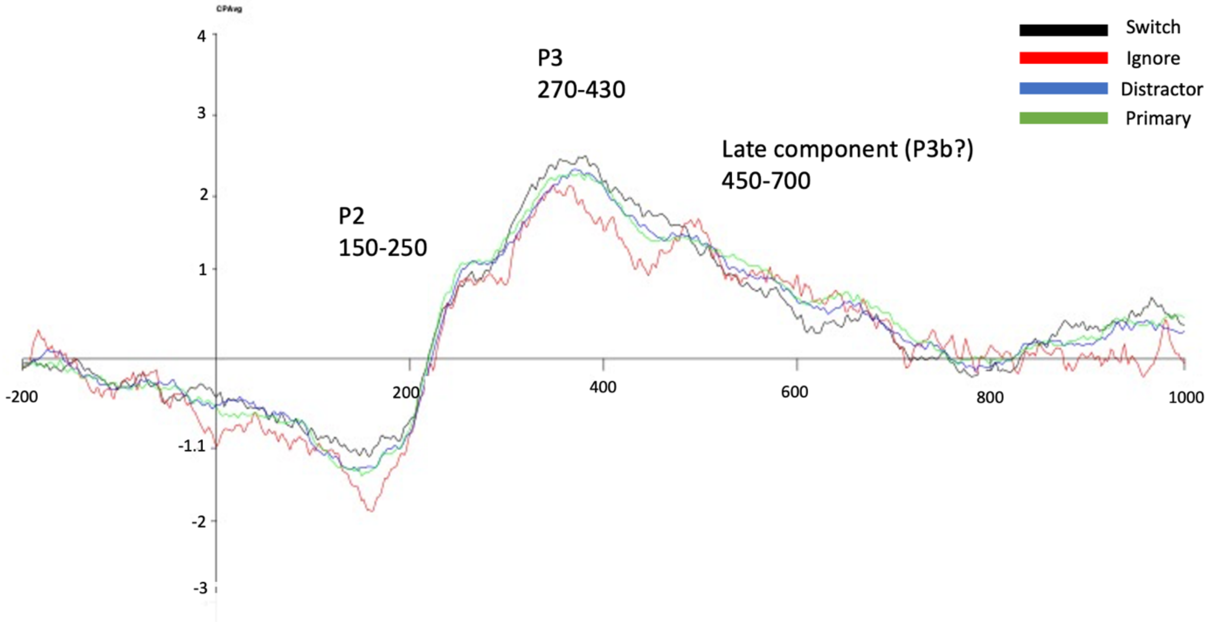
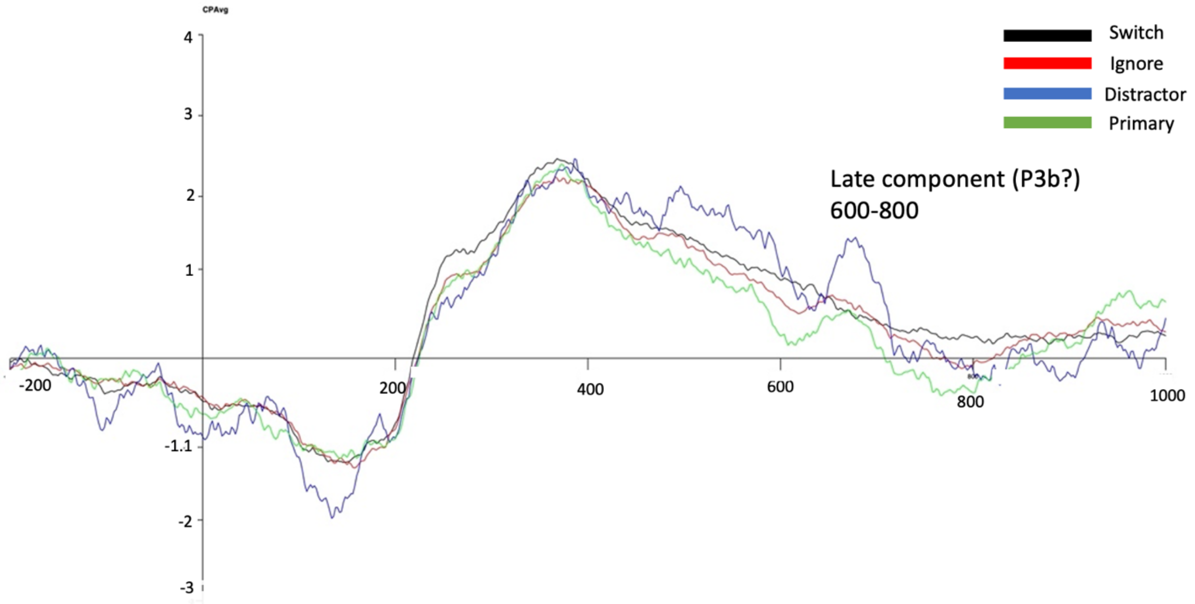


Figure 4.3 Average ERP Waveform over Central Sites During Primary Task Processing

Popup Stimulus Processing

To examine the differences in popup processing (distractor and switch popup), we created bins time-locked to the primary task stimulus onset that included the following distractor, switch, or ignore trial. We once again examined plots of the grand averaged ERPs to identify components of interest. We identified a positive late component at 600-800 ms along the averaged frontal (F1, Fz, F2, FC1, and FC2) and parietal midline sites (CP1, CPz, CP2, P1, Pz, P2). Based on the slower drift of the components, the mean amplitude was extracted for each participant from each site. The component was analyzed using a Bayesian repeated measures (RM) ANOVA with condition and channel cluster (parietal or frontal) as repeated factors, and MMI as a covariate.

Late component. When analyzing the late component at 600-800 ms post primary stimulus onset, the best model included channel, condition and the interaction between both ($BF_M = 12.48$), with no other model being supported (all $BF_{10} < 1.59$). When comparing across matched models, there was weak evidence for the effect of channel ($\text{BF}_{\text{excl}} = 1.24$), very strong evidence for a null effect of condition ($\text{BF}_{\text{excl}} = 56.39$), very strong evidence for an effect of the interaction of channel and condition ($\text{BF}_{\text{incl}} = 273.12$) with moderate evidence for a null effect of MMI ($\text{BF}_{\text{excl}} = 6.02$). In line with Figures 4.4 and 4.5, post hoc comparisons showed that there was no difference in amplitude between parietal and frontal sites at this time period, (BF_{10} 0.26). Post-hoc comparisons between conditions found that amplitude for the current primary task did not differ between distractor, switch, or ignore trials ($\text{BF}_{01} < 9.11$). An explanation for the observation of this component may be that this was related the appearance of a popup (on relevant trials) around this time.



Late component (P3b?)
600-800

Figure 4.4 Average ERP Waveform Over Central Sites During Popup Processing

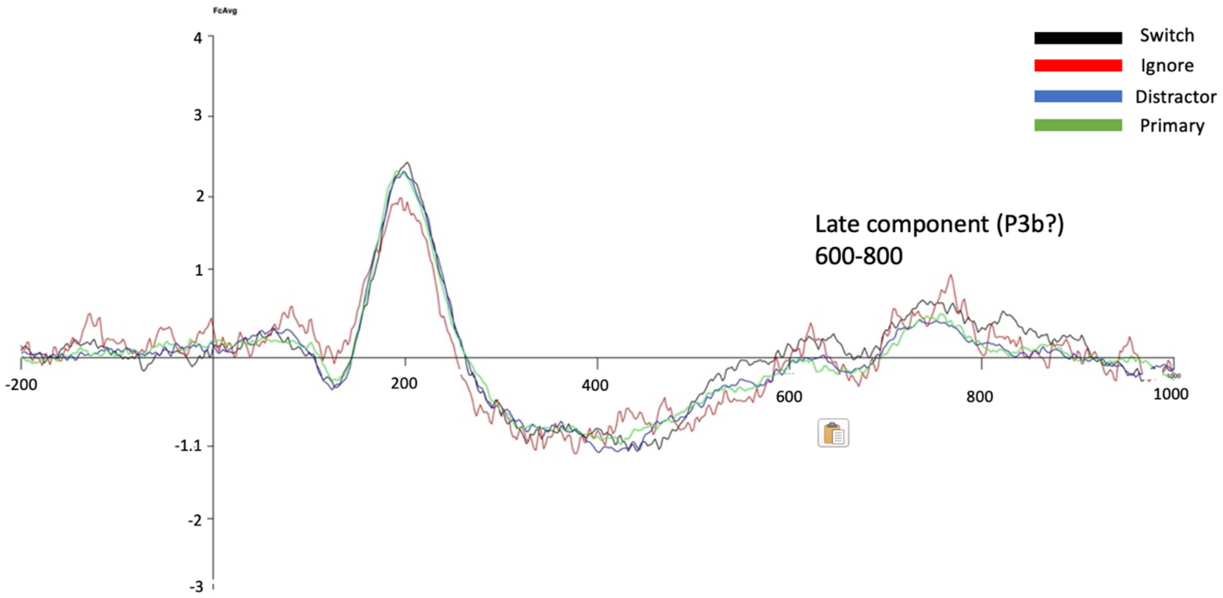


Figure 4.5 Average ERP Waveform Over Frontal Sites During Popup Processing

Discussion

In the present study, we attempted to more directly examine the link between media use frequency and distractor filtering with a revision of our novel task switching paradigm that featured stimuli specifically designed to distract individuals from the primary task. In line with previous research, we expected to see a more pronounced negative effect of media use on trials with a distractor stimulus present, indicative of heavy media multitaskers' inability to filter out distractors. We also expected to replicate our previous findings on the effects of media use frequency and task performance. Additionally, we examined for EEG markers of decision making, including the P300 ERP component. Briefly, we failed to replicate our original results by only finding anecdotal to moderate evidence of the lack of an effect of media use frequency on task performance, including on trials in which a distractor was present. We also found no difference in ERP component amplitude between primary task representation and popup processing, with or without MMI score as a covariate.

Behavioral Results Discussion

Interference cost, Distractor Cost, Primary$_{Distract}$, Primary$_{PostDistract,}$, and Popup$_{Ignore.}$

Although the study with our original iteration of the current paradigm resulted in weak evidence to support previous research that heavy media multitaskers are less able to efficiently filter out distractors (Lui & Wong, 2012; Murphy & Creux, 2021; Ophir et al., 2009), we have not replicated this finding in several revisions of our paradigm. We found no relationship between media use frequency and Popup$_{\text{ignore}}$ trials, or trials in which a popup occurred but the participant chose not to switch, or media use frequency and interference cost, or the difference in RT on trials in which the participant ignored a popup and the RT on trials in which no popup occurred. We interpreted this longer RT as the inability to filter irrelevant stimuli (the popup being ignored) on trials in which they did not intend to switch tasks. In the current study, we found very limited evidence to support our earlier predictions, suggesting that media multitasking is not related to distractor filtering.

To better assess the link between distractor filtering and media use frequency within our paradigm, we examined for a relationship between MMI score and Primary$_{\text{Distract}}$, or the average RT on primary task trials in which a distractor popup was present. We also examined for a relationship between average on primary task trials following a distractor popup (Primary$_{\text{PostDistract}}$) and media use frequency. Finally, we also examined the relationship between MMI score and Distraction Cost, or the average difference between RT on primary task trials in which no popup occurred and average RT on trials with a distractor popup. We reasoned that an effect of MMI score on Primary$_{\text{Distract}}$ would be seen as a longer RT on distractor trials due to the inability to filter out irrelevant stimuli (the popup being ignored). Similarly, we expected to see this slowing effect to linger immediately following a distractor popup trial, such that heavier media multitaskers would be slowed on primary task trials that followed a distractor trial. We also predicted that the difference in average RT on trials with no popups and average RT on distractor trials would be greater among heavy media multitaskers, again due to the inability to filter out irrelevant stimuli. However, we saw no evidence of any of these effects in the current study, suggesting that media multitasking incidence has no effect on the ability to ignore distractions.

Switch Rate, Popup$_{select}$, and Primary$_{repeat}$. Although greater impulsivity and worse inhibitory control has been linked to MMI scores (Gorman & Green, 2016; Sanbonmatsu et al., 2013; Murphy & Creux, 2021; Rogobete et al., 2021; Shin et al., 2019), our previous experiments have only found very weak links (as in our original experiment), or none at all. We again found a lack of evidence to substantiate a link between these two measures here.

In a similar vein, we previously hypothesized that Popup$_{select}$, or the average RT for an individual to choose to switch tasks in relevant trials, would be related to MMI scores. We expected that the link between frequent media use and impulsivity would result in frequent media multitaskers choosing to switch tasks more quickly and frequently. Instead, we have continued to find little evidence to support this suggestion in any of our follow up experiments, including the current one.

Research has suggested that media use frequency leads to a decreased ability to remain on task over time (Cain & Mitroff, 2011). In our original experiment, we found evidence to support this notion with our findings regarding Primary$_{repeat,}$ or primary task trials following a previous primary task trial, and MMI score. However, we have again found no further evidence to support this relationship in our subsequent studies. Taken together, this pattern of results seems to deny any effect of media use frequency on impulsivity, inhibitory control, or the ability to remain on task over time.

$Primary_{return}$, Return cost, Primary RT, and $Primary_{nopopup}$. Previous research has suggested that media frequency use is related to less efficient executive functioning (Becker, Alzahabi, & Hopwood, 2013; Cain & Mitroff, 2011; Murphy & Creux, 2021; Ophir et al., 2009; Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). However, both our previous and current findings regarding Return cost, or RT on primary trials with no popup present following a task switch, as well as $Primary_{return}$, or the average RT on all primary trials following a task switch, regardless of popup presence, suggest that no such relationship exists. Similarly, in spite of evidence from previous studies, we found no evidence for an effect of media use frequency on primary task trials with no popup present ($Primary_{nopopup}$). Taken together, these results contradict the previously found effects of media use incidence on executive function.

In the field of Human Factors Engineering, the goal activation model describes a distraction or interruption as a series of events (Altmann & Trafton, 2002). More specifically, an alert, such as the switch prompt in the current task, is the first component of a distraction, after which follows the proper interruption event (in our case, the secondary task trial), with the time between these two separate events being referred to as the interruption lag. They suggest that the resumption lag, or the time in between the interruption event and the following return to the previous task, is modulated by the length of the interruption lag, as well as any training the individual has with completing the tasks. Although our paradigm maps onto this theoretical framework quite nicely, our pattern of results goes against their established literature, even if we operationalize the degree of media use frequency as the training Altmann and Trafton refer to.

EEG Results Discussion

A larger P3 amplitude has been found to be related to smaller switch costs (Elchlepp, Lavric. Mizon, Monsel, 2012). This component has also been linked to the appearance of a rare stimulus in the place of more frequently presented stimuli (Polich, 2007). Due to the nature of our paradigm, we expected to see this deflection in distractor or switch trials.

Task representation. When looking for differences in task representation between different conditions, we found very few differences between $\text{Popup}_{\text{switch}}$ trials, $\text{Popup}_{\text{ignore}}$ trials, all primary trials, and distractor trials. However, the difference in P200 amplitude found between conditions may be attributed to task-set activation (Finke et al, 2011). The only difference not found here was between distractor and repeat trials, which may be due to similar processes of task-set activations being activated because in both trial types, the primary task remains as the target.

Task Set Reconfiguration. When examining the average ERPs between the different trial types, there was a distinct amount of overlap within the time series, leading to the lack of an effect of condition. This lack of difference may be due to the reconfiguration of the task set being completed prior to the beginning of the incoming primary task trial. The time between each subsequent task trial, regardless of task type, is often approximately 5 seconds, allowing more than enough time for a reconfiguration to take place before the following trial.

Further, due to the volitional aspect of the paradigm, allowing participants to be in control of what task type follows, this long amount of downtime between trials also contributes to their ability to reconfigure task sets (Imburgio & Orr, 2021). The long time period between primary tasks also makes it difficult to use traditional ERP averaging techniques to examine the inter-trial period. An alternative approach to decode the time course of this reconfiguration further might be multivariate pattern analysis (MVPA) may be needed. Recent research into this method has compared MVPA to traditional methods and suggests that MVPA can be used to infer cognitive stages (Berberyan et al., 2021).

While we also found no effect of condition (distractor, switch, or ignore trial) when examining the time-series immediately following a primary trial onset, it is crucial to note the large variability that more than likely contributed to the final pattern of results. Recently, multi-level modeling has been suggested as a method of ERP analysis that may elucidate how ERPs vary across trials over time (Volpert-Esmond, Page-Gould, Bartholow, 2021). Such a method may be helpful to further examine the neural mechanisms at play in the current study.

MMI Results. Finally, the lack of evidence for any effect of MMI on ERP amplitude further informs the overall inconsequential effect frequent media use frequency has on executive function. This pattern of effects is consistent with our behavioral results again showing no effect of media use incidence on any cognitive processes indexed by the task performance measures discussed.

Distractor Limitations

Although the distractor popup was implemented so that it would take the place of a “normal” popup prompt, there are several considerations that may be pertinent to address in later iterations of the paradigm. First, the distractor stimuli consisted of a small number of “meaningless” messages, such as “Great job!” Because the number of messages was small, repeated appearances of a message may have been able to capture the attention of an individual during a trial. As such, increasing the amount of possible distractor stimuli should fix this potential issue. Similarly, the messages all consisted of positive affirmations to the participant. It may be informative to diversify the valence of the distractor messages possible, including both negative and neutral messages. Additionally, a change in the color of the distractor messages may be another consideration for future iterations of the paradigm. This may increase or decrease the attentional capture of said messages, which may have a differential effect based on media use frequency. Finally, including the possibility of the distractor message occurring on the same trial as a task switch opportunity may provide for an even more direct way to assess distractor filtering in media multitaskers.

Other Considerations

Previous iterations of our paradigm succeeded in increasing the incentivization of task switches. However, a point that we did not address in this version of the task was the fact that an individual may not always be aware of what the result of attending to a new notification may be. In our current design, the number of points possible for completing a task switch successfully is presented while the option to switch is on screen. If we wish to bring this paradigm closer in line to a real-world multitasking environment, it may be pertinent to only inform participants of the exact point value gain for completing the task until after a switch has occurred. Additionally, introducing another modality, such as sound would help to further bring this paradigm in line with a typical real world multitasking environment, as the notifications seen in most said environments are accompanied by a sound clip. Ferris and Sarter (2008) have found evidence for a cross-modal link in attention that such a design would highlight.

MUQ Discussion

We used an identical version of the Media Use Questionnaire as our previous experiments. Although the differences between our version and the original Ophir and colleagues' version may contribute to our pattern of effects, our average MMI score was relatively in line with other studies that have used the original questionnaire. However, we must still acknowledge that tour changes limit the generalizability of our findings to studies using an unmodified version of the questionnaire. At the same time, several different iterations of the questionnaires have been developed within the media multitasking literature, with many resulting in different patterns of effects (Baumgartner et al., 2016; Lui et al., 2022; Pea, et al, 2012.). Kaye and colleagues (2020) point to the lack of standardization of a definition for media use frequency and the often-ambiguous distinctions between media use and "screen time" as a major reason for the mixed results seen in the literature, which result in a lack of generalizable findings.

Conclusion

Although our original study found some evidence of an effect of media use frequency on executive function, the relationships found were extremely weak, and were derived from a version of the paradigm that was lacking in several aspects that have been addressed in our following studies. The current pattern of results has remained consistent past our original study, further suggesting that the original findings were not robust. Taken together, our results add to the increasing number of studies with evidence to suggest the absence of an effect of media use frequency and executive function (Imren & Tekman, 2019; Parry & Le Roux, 2021). The lack of an effect found between ERP components and MMI further add to this conclusion.

CHAPTER V

GENERAL DISCUSSION

Overview of Findings

Previously, research into media multitasking has found mixed effects on media use frequency and executive function (Imren & Tekman, 2019; Parry & Le Roux, 2021), with a more prevailing notion that there is little to no interaction between both. However, an ecologically valid real-world multitasking paradigm still remains absent from the literature, with a majority of findings being driven by paradigms not originally intended to index multitasking. Lui and Wong (2021) noted the need for a more ecologically valid paradigm due to the discrepancy in findings between studies that used these classical, laboratory-based paradigms and paradigms that more closely aim to emulate real-world multitasking. Thus, the current work sought to establish said paradigm to assess real-world multitasking. We then used this paradigm to examine the effects of media use frequency on executive functioning. The paradigm was based on principles from the dual tasking and voluntary task switching literature to more closely approximate a real-world multitasking environment.

Chapter 2

In chapter 2, I outlined and tested the first iteration of said paradigm. It consisted of a primary and secondary task, with random (1 out of every 6 trials, on average) “popup” notifications that would prompt a participant with the choice to switch tasks. The primary task consisted of a math verification task, while the secondary task consisted of a word completion task. Participants earned points for a correct response to either task, and lost points for an incorrect or missed response. We used this paradigm to examine the effects of media multitasking (as indexed by a modified version of the Media Use Questionnaire defined by Ophir and colleagues (2009), attentional impulsivity (as indexed by Barratt's Impulsiveness Scale), and multitasking preference (as indexed by the Multitasking Preference Inventory) on several task performance measures.

Results were mostly inconclusive, with only weak negative effects of media use incidence on the ability for heavier media multitaskers' to return to a previous task set after engaging in a task switch and filter out distractors (in the form of an ignored opportunity to switch). Media use frequency was also associated with a weak overall slowing on primary task performance, both when no choice to switch is presented, as well as on repeat trials. This suggests an inability for heavy media multitaskers to remain focused on a task over time. Results regarding attentional impulsivity and multitasking preference were largely inconclusive as well. I identified several limitations of the initial iteration of this paradigm, including low incentives for switching tasks, harsh penalties for incorrect responses to the secondary task, and a low amount of task switch opportunities.

Chapter 3

Thus, in chapter 3, I sought to improve upon my original design and correct these limitations. I designed two different iterations of the task. In task iteration 1, I retained the same point values and deductions for both the primary and secondary tasks. However, I increased the chances for a popup prompt to appear from ⅙ to ¼, this change was also made in task iteration 2, albeit with a further change to the performance incentivization. In this version of the task, all point penalties were moved, and instead of a static reward for successful completion of the secondary task, the points possible ranged from 10-25 and were randomized on every trial. The number of points possible for any given trial were shown on screen during the trial.

Overall, this solved the problem of an extremely low switch rate, giving us more switch trial data to analyze. Along with the changes made to the paradigm, we also examined for an effect of tDCS on task performance. Additionally, we also collected EEG data to examine neural markers of preparatory control and decision making. Specifically, we examined ERP components, such as the P300 throughout different task conditions, such as trials in which a participant ignored a popup or switched tasks. Behavioral results from both task iterations provided little to no evidence of any effect of media use frequency on task performance. Similarly, we also saw no effect of tDCS condition. We found a number of possible ERP components in both iterations of the task. However, we found very little in the way of differences in task representation between switch and ignore (only difference found was in task iteration 1) trials. We also found no effect of media use frequency on any ERP component.

Chapter 4

In chapter 4, I focused on the effects of media multitasking on distractor filtering. To do this, I developed a further iteration of the task paradigm that included the appearance of a distractor popup that would appear randomly throughout the task at a rate of 1 out of 3 primary task trials. Popup frequency was increased once again to match this. The paradigm was otherwise unchanged from the previous chapters' task iteration 2. We again collected EEG data to examine for the same decision making and preparatory control markers. Along with the specific analyses related to distractor popup trials, I aimed to replicate the results from chapter 3. This proved to be the results of our behavioral analyses, with no effects of media multitasking on task performance found, including no difference in the ability to filter out distractors. We again found a number of possible ERP components, such as a P200 and P300, but only evidence of an effect of condition in P200 amplitude, with differences in all conditions, save for distractor and repeat trials. MMI was also not found to predict any ERP components at all.

Overall, our pattern of results throughout all three studies suggests that media use frequency has almost no effect on task performance, and as an extension, on executive function. While this is at odds with some previous work in the literature, it is not unheard of, with several meta-analyses arriving to the same conclusion (Parry & Le Roux, 2021). We found similar results in terms of EEG markers of decision making, with no differences attributed to media use frequency, or even, for the most part, between different task conditions.

Interpretations From a Different Field

Thus far, we focused on the task switching literature's interpretation of our findings. It may be prudent to consider other fields that also focus on similar mechanisms and interactions, such as the field of Human Factors Engineering. In Altmann and Trafton's (2002) goal-activation model, they suggest that a distraction or interruption is more than a single event. More specifically, they posit that an alert is the first component of a distraction, after which follows the proper interruption event. The time between these two separate events is then referred to as the interruption lag. Altmann and Trafton also suggest that the length of the interruption lag and the training of the individual completing the tasks can affect the resumption lag, or the time in between the interruption event and the resuming of the previous task. Viewed through the lens of our paradigm, the "alert" can be referred to as the switch popup prompt. The individual then determines their own interruption lag (up to a maximum of 5 seconds), after which the interruption event (the secondary task) then immediately follows. The training of the individual that Altmann and Trafton refer to can then be operationalized as the degree of media use frequency.

In an investigation of the resumption lag, Altmann and Trafton found that the average resumption lag was much longer than the average time between primary task trials (Altmann & Trafton, 2004). In our design, we operationalized this as return cost, or the average difference between RT on primary task trials following a switch and primary task trials during which no popup occurred. However, we found no significant effect as a result of media use incidence.

Latorella (1996), using the real-world context of a flight deck, found that distractions mid-task were detrimental to task performance, leading to more errors and an increase in task performance time. Given this finding, it is especially surprising that the distractor popups in our paradigm had no effect on performance differences, but this may be explained by the distractor popups not being as salient or disruptive as in the above study. In a similar vein, Hameed and colleagues (2009) demonstrated the effectiveness of informative cues within the field of interruption management, finding that informative switch cues led to high efficacy throughout the task. In our paradigm, the informative cue can be compared to the switch prompt including the number of points possible for successfully completing the task. However, our pattern of results suggests that even these informative cues did not result in a difference in performance as predicted by media use frequency. This may be due to the fact that the secondary task trial would always include a different word, with no way to efficiently prepare for the upcoming trial.

Future Directions

The current work established the first few steps in the development of a new multitasking paradigm. As such, there are still several modifications that can be done to further bring it in line with a real-world multitasking environment. Regardless of which of any modifications are made, we must also acknowledge that because our previous studies have been underpowered, a much larger sample size is needed for any subsequent investigations.

Sound Cues

The inclusion of sound throughout the tasks is a critical component missing from the current iterations of the paradigm. Audio cues are a prevalent aspect in any real-world multitasking environment, as more often than not, the tasks we are performing include sound in one way or another, and the notifications that appear on screen will also be accompanied by their own sound cue. More specifically, a future design should include a version of the task in which each stimulus has its own audio cue associated with it and compare it to a separate version of the task in which the distractor and switch prompts have an identical cue. Ferris and Sarter (2008) have found evidence for a cross-modal link in attention that such a design would highlight, and may more closely mirror previously researched multitasking contexts, such as a flightdeck. Further, this design would also lend itself to a closer examination of mechanisms of spatial attention via ERPs, as has already been investigated (Eimer, van Velzen, and Driver, 2002). In a similar vein, the introduction of different (or identical) color text for distractor and switch popups would also help approximate a real-world multitasking environment, as the notifications and tasks we usually see on screen may also vary in color.

EEG Methodology

Further, because of the possible reconfiguration of task sets due to the longer and more variable time period between every component within the paradigm makes traditional methods of ERP averaging less effective to examine inter-trial periods. A future study should involve multivariate pattern analysis (MVPA) to decode the time course of said inter-trial periods. Multi-level modeling in conjunction with ERP analysis may also help with examining the variation of ERP component variation throughout a testing session. (Volpert-Esmond, Page-Gould, Bartholow, 2021).

Frequency Bands

We have only begun to scratch the surface in terms of EEG correlates of task switching that can be investigated using this multitasking paradigm. Further investigation is warranted regarding the ERP components already discussed in the previous projects, but future studies should also consider frequency band oscillations. Alpha band power has been shown to decrease during cognitively demanding tasks, along with an increase in theta band power (Slobounov et al., 2000; Fairclough et al, 2005.). However, Puma and colleagues (2018) have found that lower frequency bands in general are related to higher performance when examining cognitive workload in a multitasking environment. Therefore, I would expect to see a decrease in alpha band power, along with an increase in theta band power during trials in which a popup prompt is present as compared to trials in which only the primary task is available. Although the MMI has thus far not been useful to predict task performance, if media multitasking negatively affects cognition, then MMI should show a predictive relationship with alpha band power.

Changes to Distractor Popups

Aside from the above, a further iteration of the task should also increase the number of possible distractor messages possible. The current low number of messages may contribute to a decrease in attentional capture once a message has been repeated several times. Further, distractor messages should be more varied in terms of their valence. Currently, the only messages possible have a positive tone for the participant. It may be pertinent to include messages with a more negative association, as well as neutral, completely irrelevant stimuli. These changes would help bring this more in line with a real-world multitasking environment, as the distractors we encounter will usually be varied, and certainly not all positive in tone.

It may also be pertinent to modify the task so that a distractor stimulus can appear during the same trial as a switch popup to allow for a more direct assessment of the effect a said stimulus has on the task at hand. Distractors may occur at any time in a real-world situation, including when the opportunity to switch tasks presents itself, so our paradigm should account for that possibility as well. Additionally, in such a scenario, it is not always possible to know what the benefits to switching tasks may be. Therefore, it may be prudent to no longer show the number of points possible for successfully completing a task switch along with the prompt to switch. The possible reward would then instead be shown after or during the secondary task instead.

Multitasking Training

In line with Altmann and Trafton's goal activation theory (2002), an experiment design that features a training phase with the task would test the notion that training an individual would result in a decrease in the resumption lag after an interruption. More broadly, research also suggests that training increases multitasking performance (Dux et al., 2009), but an examination on the effect media use frequency has on training effects is warranted.

Mixing and Switch Costs

I also suggest an experiment design that would seek to compare mixing and switch costs using our paradigm, as well as measures of media use frequency. A mixed task design would combine more than one possible task set within a trial. For example, participants in a study by Strobach and colleagues (2012) completed two distinct tasks in different modalities within the same block of trials, while also completing single-task based blocks. A mixing cost was then calculated as the difference in performance between single-task blocks and mixed block, while a switch cost was calculated as the difference between task repetitions and task switch trials.

Modifying the current paradigm to include both block types, with the mixed block including tasks that index different modalities would allow for an examination of mixing costs, switch costs, and media use frequency.

Eye-tracking

Finally, I suggest the integration of my multitasking paradigm with a study of eye-tracking. Research into task switching has found that changes in reward prospect result in higher cognitive flexibility, with pupillometry being used as a means to investigate the underlying processes at play (Fröber, Pittino, and Dresibach, 2020). Due to the random rewards for completing the secondary task, we should, in theory, be able to capture these changes in pupil diameter to then examine for an effect of media multitasking. Furthermore, with both a distractor and switch popup at play, it may be interesting to examine eye gaze as a function of media use frequency. For example, would higher media multitaskers be more prone to direct their eyes towards the area that is associated with a switch popup?

Measuring Media Use

Despite the vast number of changes and adaptations that can be made to the paradigm, it would still be unable to index the effects of media multitasking on real-world multitasking if the method of measuring the former is not reliable, or even valid. The media multitasking index designed by Ophir and colleagues is a product of its time and must continue to be updated with the ever-changing media use landscape. Some work in this regard has already occurred (Baumgartner et al., 2018; Lui et al., 2022), even within the current work, but the field lacks a well-defined, validated method of indexing media use frequency. Instead, researchers use their own variations of the measure, leading to a lack of generalizability to the rest of the body of literature. In a recent study, Lui and colleagues (2022) used different measurements of multitasking, including the Media Use Questionnaire, and an app usage tracker via their mobile devices. They did this due to the self-report nature of the Media Use Questionnaire, as it is true that individuals may not be aware of how much time they spend multitasking on any given day. Further, other, abridged versions, of the Media Use Questionnaire, including one specific to adolescents, have been developed, with their own patterns of results. As such, it is clear that more work is necessary to develop a holistic index or measure of the extent to which an individual media multitasks, and until one is established, some of the work in the field may not be fully indexing what is intended.

In conclusion, while results were mostly inconclusive in terms of media use frequency's involvement in executive functioning, this dissertation has laid the groundwork for future work in developing a more ecologically valid assessment of real-world multitasking. As technology continues to only increase in its pervasiveness in our culture, the effects of the prolonged usage of these media devices will remain a topic of interest for years to come.

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APPENDIX A

CHAPTER II TABLES

Table A.1. Descriptive statistics for the MUQ (Media Use Questionnaire), MPI (Multitasking Preference Inventory), BIS-11 (Barratt's Impulsiveness Scale), and the three second order factors within the BIS.

	MMI Score	MPI Score	Total BIS	Attentional	Motor	Nonplanning
Mean	2.95	38.54	62.59	17.76	21.1	23.73
Median	2.82	37	61	17	20	23.5
SD	1.28	10.93	9.72	3.86	4.29	4.17

Table A.2 Means, standard deviations, and correlations with confidence intervals for all surveys and behavioral measures

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12
1. MMI Score	2.95	1.28												
2. MPI Score	38.54	10.93	-.10 [-.30, .11]											
3. BIS Attentional	17.76	3.86	.09 [-.12, .29]	.29** [.09, .47]										
4. Switch Rate	0.31	0.30	-.08 [-.28, .13]	.40** [.21, .56]	.13 [-.08, .32]									
5. Popup$_{Selec}$t	1.31	0.35	-.12 [-.35, .12]	-.12 [-.35, .12]	-.15 [-.38, .09]	-.21 [-.43, .03]								
6. Return Cost	0.34	0.41	.18 [-.07, .41]	-.18 [-.41, .07]	-.08 [-.32, .17]	-.38** [-.57, -.15]	.31* [.08, .52]							
7. Interference Cost	0.01	0.22	.08 [-.14, .28]	.10 [-.11, .31]	-.03 [-.24, .18]	-.11 [-.31, .10]	.01 [-.23, .26]	-.01 [-.26, .23]						
8. Primary$_{Repeat}$	2.30	0.41	.22* [.02, .41]	.19 [-.01, .39]	.08 [-.13, .28]	.07 [-.14, .27]	.15 [-.09, .38]	.36** [.13, .56]	-.04 [-.25, .17]					
9. Primary RT	2.32	0.41	.24* [.03, .42]	.20 [-.01, .39]	.10 [-.11, .30]	.09 [-.12, .29]	.14 [-.10, .37]	.38** [.16, .57]	-.04 [-.25, .17]	1.00** [1.00, 1.00]				
10. Secondary RT	2.62	0.50	.09 [-.15, .33]	-.07 [-.31, .18]	.01 [-.24, .25]	-.03 [-.27, .22]	-.11 [-.35, .14]	.38** [.15, .58]	.13 [-.12, .37]	.29* [.05, .50]	.30* [.06, .51]			
11. Primary$_{Nopopup}$	2.31	0.42	.24* [.03, .42]	.19 [-.02, .38]	.10 [-.11, .30]	.09 [-.12, .29]	.14 [-.10, .37]	.39** [.16, .58]	-.08 [-.29, .13]	1.00** [.99, 1.00]	1.00** [1.00, 1.00]	.29* [.05, .50]		
12. Popup$_{Ignore}$	2.33	0.46	.26* [.05, .44]	.23* [.02, .42]	.08 [-.13, .28]	.05 [-.16, .25]	.13 [-.11, .36]	.34** [.11, .54]	.40** [.21, .56]	.90** [.84, .93]	.90** [.85, .93]	.33** [.09, .53]	.88** [.82, .92]	
13. Primary$_{Return}$	2.69	0.71	.25*	.01	-.02	-.23	.21	.82**	-.07	.83**	.84**	.45**	.84**	.73**

	[.00, .46]	[-.24, .25]	[-.27, .22]	[-.45, .02]	[-.03, .43]	[.73, .89]	[-.31, .18]	[.73, .89]	[.75, .90]	[.23, .63]	[.75, .90]	[.59, .83]

Table A.3 Descriptive statistics for main behavioral measures analyzed

	Switch Rate(%)	Return Cost	Interference Cost	$\text{Popup}_{\text{select}}$
Mean	0.31	0.34s	0.1s	1.31s
SD	0.30	0.41s	0.22s	0.35s

Table A.4 Regression results using switch rate as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	0.36**	[0.20, 0.52]							
MMI Score	-0.02	[-0.07, 0.03]	-0.08	[-0.29, 0.14]	.01	[.00, .07]	-.08		
								R^2 = .006 95% CI[.00,.07]	
(Intercept)	0.24	[-0.19, 0.66]							
MMI Score	-0.02	[-0.07, 0.03]	-0.09	[-0.30, 0.13]	.01	[-.03, .04]	-.08		
Total BIS	0.00	[-0.00, 0.01]	0.07	[-0.15, 0.28]	.00	[-.02, .03]	.05		
								R^2 = .010 95% CI[.00,.07]	ΔR^2 = .004 95% CI[-.02, .03]
(Intercept)	-0.02	[-0.43, 0.39]							
MMI Score	-0.01	[-0.05, 0.04]	-0.02	[-0.23, 0.18]	.00	[-.01, .01]	-.08		
Total BIS	-0.00	[-0.01, 0.00]	-0.05	[-0.26, 0.16]	.00	[-.02, .02]	.05		
MPI Score	0.01**	[0.01, 0.02]	0.41	[0.21, 0.62]	.16	[.02, .29]	.40**		
								R^2 = .166** 95% CI[.03,.28]	ΔR^2 = .155** 95% CI[.02, .29]

Table A.5 Regression results using return cost as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	0.15	[-0.11, 0.42]							
MMI Score	0.06	[-0.02, 0.15]	0.18	[-0.07, 0.43]	.03	[.00, .15]	.18		
								R^2 = .033	
								95% CI[.00,.15]	
(Intercept)	0.36	[-0.33, 1.05]							
MMI Score	0.07	[-0.02, 0.16]	0.20	[-0.06, 0.46]	.04	[-.05, .13]	.18		
Total BIS	-0.00	[-0.01, 0.01]	-0.08	[-0.34, 0.18]	.01	[-.03, .04]	-.03		
								R^2 = .039	ΔR^2 = .006
								95% CI[.00,.15]	95% CI[-.03, .04]
(Intercept)	0.49	[-0.23, 1.22]							
MMI Score	0.06	[-0.03, 0.15]	0.18	[-0.08, 0.44]	.03	[-.05, .11]	.18		
Total BIS	-0.00	[-0.01, 0.01]	-0.04	[-0.30, 0.23]	.00	[-.02, .02]	-.03		
MPI Score	-0.01	[-0.02, 0.00]	-0.16	[-0.42, 0.10]	.02	[-.05, .09]	-.18		
								R^2 = .062	ΔR^2 = .023
								95% CI[.00,.17]	95% CI[-.05, .09]

Table A.6 Regression results using interference cost as the criterion

Predictor	b	b 95% CI [LL, UL]	$beta$	$beta$ 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	r	Fit	Difference
(Intercept)	-0.03	[-0.14, 0.09]							
MMI Score	0.01	[-0.02, 0.05]	0.08	[-0.14, 0.29]	.01	[.00, .07]	.08		
								R^2 = .006 95% CI[.00,.07]	
(Intercept)	-0.02	[-0.32, 0.29]							
MMI Score	0.01	[-0.02, 0.05]	0.08	[-0.14, 0.29]	.01	[-.03, .04]	.08		
Total BIS	-0.00	[-0.01, 0.00]	-0.01	[-0.23, 0.21]	.00	[-.00, .00]	.01		
								R^2 = .006 95% CI[.00,.05]	ΔR^2 = .000 95% CI[-.00, .00]
(Intercept)	-0.07	[-0.39, 0.25]							
MMI Score	0.02	[-0.02, 0.05]	0.10	[-0.12, 0.32]	.01	[-.03, .05]	.08		
Total BIS	-0.00	[-0.01, 0.00]	-0.04	[-0.27, 0.18]	.00	[-.02, .02]	.01		
MPI Score	0.00	[-0.00, 0.01]	0.12	[-0.10, 0.35]	.01	[-.03, .06]	.10		
								R^2 = .020 95% CI[.00,.08]	ΔR^2 = .014 95% CI[-.03, .06]

Table A.7 Regression results using popup$_{select}$ as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	1.42**	[1.20, 1.64]							
MMI Score	-0.04	[-0.11, 0.03]	-0.12	[-0.37, 0.12]	.02	[.00, .12]	-.12		
								R^2 = .015 95% CI[.00,.12]	
(Intercept)	1.63**	[1.18, 2.07]							
MMI Score	-0.03	[-0.10, 0.04]	-0.10	[-0.35, 0.14]	.01	[-.04, .06]	-.12		
Attentional	-0.01	[-0.04, 0.01]	-0.13	[-0.38, 0.11]	.02	[-.04, .08]	-.15		
								R^2 = .033 95% CI[.00,.13]	ΔR^2 = .018 95% CI[-.04, .08]
(Intercept)	1.71**	[1.22, 2.21]							
MMI Score	-0.03	[-0.11, 0.04]	-0.12	[-0.37, 0.13]	.01	[-.04, .07]	-.12		
Attentional	-0.01	[-0.03, 0.02]	-0.10	[-0.36, 0.16]	.01	[-.04, .05]	-.15		
MPI Score	-0.00	[-0.01, 0.01]	-0.10	[-0.36, 0.16]	.01	[-.04, .05]	-.12		
								R^2 = .042 95% CI[.00,.13]	ΔR^2 = .009 95% CI[-.04, .05]

Table A.8 Descriptive statistics for the exploratory behavioral measures analyzed.

	$\text{Primary}_{\text{return}}$	$\text{Popup}_{\text{ignore}}$	$\text{Primary}_{\text{nopopup}}$	Primary RT	Secondary RT	$\text{Primary}_{\text{repeat}}$
Mean	2.69s	2.33s	2.31s	2.32s	2.62s	2.7s
SD	0.71s	0.46s	0.42s	0.71s	0.5s	0.41s

Table A.9 Regression results using primary$_{\text{return}}$ as the criterion

Predictor	b	b 95% CI [LL, UL]	$beta$	$beta$ 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	r	Fit	Difference
(Intercept)	2.27**	[1.82, 2.72]							
MMI Score	0.15*	[0.00, 0.29]	0.25	[0.00, 0.49]	.06	[.00, .20]	.25*		
								R^2 = .061*	
								95% CI[.00,.20]	
(Intercept)	2.45**	[1.29, 3.62]							
MMI Score	0.15*	[0.00, 0.30]	0.26	[0.00, 0.51]	.06	[-.05, .18]	.25*		
Total BIS	-0.00	[-0.02, 0.02]	-0.04	[-0.30, 0.21]	.00	[-.02, .02]	.03		
								R^2 = .062	ΔR^2 = .002
								95% CI[.00,.18]	95% CI[-.02, .02]
(Intercept)	2.40**	[1.16, 3.64]							
MMI Score	0.16*	[0.00, 0.31]	0.26	[0.00, 0.52]	.06	[-.05, .18]	.25*		
Total BIS	-0.00	[-0.02, 0.02]	-0.05	[-0.32, 0.21]	.00	[-.02, .03]	.03		
MPI Score	0.00	[-0.01, 0.02]	0.04	[-0.22, 0.29]	.00	[-.02, .02]	.01		
								R^2 = .064	ΔR^2 = .001
								95% CI[.00,.17]	95% CI[-.02, .02]

Table A.10 Regression results using $\text{Popup}_{\text{Ignore}}$ as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	2.06**	[1.83, 2.29]							
MMI Score	0.09*	[0.02, 0.16]	0.26	[0.05, 0.46]	.07	[.00, .18]	.26*		
								R^2 = .065* 95% CI[.00,.18]	
(Intercept)	1.89**	[1.27, 2.51]							
MMI Score	0.09*	[0.01, 0.16]	0.24	[0.03, 0.45]	.06	[-.04, .15]	.26*		
TotalcBIS	0.00	[-0.01, 0.01]	0.06	[-0.15, 0.27]	.00	[-.02, .03]	.11		
								R^2 = .069* 95% CI[.00,.18]	ΔR^2 = .004 95% CI[-.02, .03]
(Intercept)	1.66**	[1.02, 2.29]							
MMI Score	0.10**	[0.03, 0.17]	0.28	[0.08, 0.49]	.08	[-.03, .18]	.26*		
Total BIS	-0.00	[-0.01, 0.01]	-0.01	[-0.23, 0.20]	.00	[-.01, .01]	.11		
MPI Score	0.01*	[0.00, 0.02]	0.26	[0.05, 0.47]	.06	[-.03, .16]	.23*		
								R^2 = .131** 95% CI[.01,.24]	ΔR^2 = .062* 95% CI[-.03, .16]

Table A.11 Regression results using $\text{Primary}_{\text{Nopopup}}$ as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	2.08**	[1.87, 2.30]							
MMI Score	0.08*	[0.01, 0.14]	0.24	[0.03, 0.44]	.06	[.00, .17]	.24*		
								R^2 = .057*	
								95% CI[.00,.17]	
(Intercept)	1.90**	[1.33, 2.47]							
MMI Score	0.07*	[0.00, 0.14]	0.22	[0.01, 0.43]	.05	[-.04, .13]	.24*		
Total BIS	0.00	[-0.01, 0.01]	0.07	[-0.14, 0.28]	.01	[-.02, .03]	.12		
								R^2 = .062	ΔR^2 = .005
								95% CI[.00,.17]	95% CI[-.02, .03]
(Intercept)	1.72**	[1.13, 2.30]							
MMI Score	0.08*	[0.02, 0.15]	0.26	[0.05, 0.47]	.06	[-.03, .16]	.24*		
Total BIS	0.00	[-0.01, 0.01]	0.01	[-0.20, 0.23]	.00	[-.00, .01]	.12		
MPI Score	0.01*	[0.00, 0.02]	0.21	[0.00, 0.43]	.04	[-.04, .12]	.19		
								R^2 = .104*	ΔR^2 = .042*
								95% CI[.00,.21]	95% CI[-.04, .12]

Table A.12 Regression results using Primary RT as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	2.09**	[1.88, 2.31]							
MMI Score	0.08*	[0.01, 0.14]	0.24	[0.03, 0.44]	.06	[.00, .17]	.24*		
								R^2 = .055*	
								95% CI[.00,.17]	
(Intercept)	1.90**	[1.34, 2.47]							
MMI Score	0.07*	[0.00, 0.14]	0.22	[0.01, 0.43]	.05	[-.04, .13]	.24*		
Total BIS	0.00	[-0.01, 0.01]	0.08	[-0.14, 0.29]	.01	[-.02, .03]	.12		
								R^2 = .061	ΔR^2 = .005
								95% CI[.00,.16]	95% CI[-.02, .03]
(Intercept)	2.11**	[1.20, 3.01]							
MMI Score	0.07*	[0.01, 0.14]	0.23	[0.02, 0.44]	.05	[-.04, .14]	.24*		
Total BIS	0.00	[-0.01, 0.01]	0.09	[-0.13, 0.31]	.01	[-.03, .04]	.12		
MPI Score	-0.01	[-0.03, 0.01]	-0.06	[-0.28, 0.16]	.00	[-.02, .03]	.01		
								R^2 = .064	ΔR^2 = .003
								95% CI[.00,.16]	95% CI[-.02, .03]

Table A.13 Regression results using secondary RT as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	2.51**	[2.19, 2.83]							
MMI Score	0.04	[-0.06, 0.14]	0.09	[-0.16, 0.35]	.01	[.00, .10]	.09		
								R^2 = .009 95% CI[.00,.10]	
(Intercept)	3.07**	[2.24, 3.90]							
MMI Score	0.06	[-0.05, 0.16]	0.14	[-0.12, 0.40]	.02	[-.05, .08]	.09		
Total BIS	-0.01	[-0.02, 0.00]	-0.19	[-0.45, 0.07]	.03	[-.05, .12]	-.16		
								R^2 = .043 95% CI[.00,.15]	ΔR^2 = .034 95% CI[-.05, .12]
(Intercept)	3.08**	[2.20, 3.96]							
MMI Score	0.06	[-0.05, 0.16]	0.14	[-0.12, 0.40]	.02	[-.05, .08]	.09		
Total BIS	-0.01	[-0.02, 0.00]	-0.19	[-0.46, 0.08]	.03	[-.05, .11]	-.16		
MPI Score	-0.00	[-0.01, 0.01]	-0.01	[-0.27, 0.26]	.00	[-.00, .00]	-.07		
								R^2 = .043 95% CI[.00,.14]	ΔR^2 = .000 95% CI[-.00, .00]

Table A.14 Regression results using $\text{primary}_{\text{repeat}}$ as the criterion

Predictor	*b*	*b* 95% CI [LL, UL]	*beta*	*beta* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	*r*	Fit	Difference
(Intercept)	2.08**	[1.87, 2.30]							
MMI Score	0.07*	[0.01, 0.14]	0.22	[0.02, 0.43]	.05	[.00, .16]	.22*		
								R^2 = .051*	
								95% CI[.00,.16]	
(Intercept)	1.95**	[1.38, 2.51]							
MMI Score	0.07*	[0.00, 0.14]	0.21	[0.00, 0.43]	.04	[-.04, .13]	.22*		
Total BIS	0.00	[-0.01, 0.01]	0.06	[-0.16, 0.27]	.00	[-.02, .02]	.10		
								R^2 = .054	ΔR^2 = .003
								95% CI[.00,.15]	95% CI[-.02, .02]
(Intercept)	1.76**	[1.18, 2.35]							
MMI Score	0.08*	[0.01, 0.15]	0.25	[0.04, 0.46]	.06	[-.03, .15]	.22*		
Total BIS	-0.00	[-0.01, 0.01]	-0.01	[-0.22, 0.21]	.00	[-.00, .00]	.10		
MPI Score	0.01*	[0.00, 0.02]	0.22	[0.01, 0.43]	.04	[-.04, .12]	.19		
								R^2 = .098*	ΔR^2 = .044*
								95% CI[.00,.20]	95% CI[-.04, .12]