Minds and brains of media multitaskers: Current findings and future directions

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Media and technology are ubiquitous elements of our daily lives, and their use can offer many benefits and rewards. At the same time, decisions about how individuals structure their use of media can be informed by consideration of whether, and if so how, the mind and brain are shaped by different use patterns. Here we review the growing body of research that investigates the cognitive and neural profiles of individuals who differ in the extent to which they simultaneously engage with multiple media streams, or "media multitasking." While the literature is still sparse, and is marked by both convergent and divergent findings, the balance of evidence suggests that heavier media multitaskers exhibit poorer performance in a number of cognitive domains, relative to lighter media multitaskers (although many studies find no performance differences between groups). When evidence points to a relationship between media multitasking level and cognition, it is often on tasks that require or are influenced by fluctuations in sustained goal-directed attention. Given the real-world significance of such findings, further research is needed to uncover the mechanistic underpinnings of observed differences, to determine the direction of causality, to understand whether remediation efforts are needed and effective, and to determine how measurement heterogeneity relates to variable outcomes. Such efforts will ultimately inform decisions about how to minimize the potential costs and maximize the many benefits of our ever-evolving media landscape.

attention | cognitive control | memory | interference | technology

In a world increasingly saturated with media and technology there is growing interest in whether media and technology use are impacting our brains and minds. American teenagers (13–18 y old) report engaging with media and technology for almost 9 h every day, not including time spent with media at school or for homework, and American "tweens" (8–12 y old) report close to 6 h every day (1). If one considers the amount of time youth spend juggling multiple media streams concurrently ("media multitasking"; 29% of total media time) (2), teens average over 11 h of daily media consumption and tweens average over 7 h. This phenomenon is not limited to American youth, as similar levels of media consumption are reported in other countries (3). Notably, media multitasking behavior is increasing in prevalence, almost doubling from 1999 to 2009 (from 16 to 29% of total media time) (2).

Given the extended temporal trajectory of human brain development, which spans into the 20s (4, 5), it is imperative to determine whether consistent multitasking with media and technology—a potential brain training of sorts—is exerting a significant and lasting impact on neurocognitive development. Even for fully developed brains it is possible that frequent engagement with simultaneous media streams affects cognition, behavior, and neural architecture. Alternatively, it may be that preexisting individual differences in underlying neurocognitive profiles result in different patterns of media use.

These questions, among others, prompted Ophir et al. (6) to conduct initial investigations of whether there are cognitive differences associated with varying levels of media multitasking behavior. They operationalized media multitasking using a novel media use questionnaire, which measured the concurrent use of 12 media streams (print media, TV, video on a computer, music, nonmusical audio, video or computer games, phone, IM/chat, text messaging, email, reading on the computer, other computer applications). Media multitasking was defined as the simultaneous use of two or more media streams, with a "media multitasking index" (MMI) quantifying the mean number of media an individual multitasks with during a typical media consumption hour. Note that the MMI does not index the number of hours multitasking with media, nor does it index media use while performing other activities (such as homework or classwork; what others refer to as "media-nonmedia multitasking"; e.g., ref. 7).

Since the initial study by Ophir et al. (6), interest in whether cognitive and neural profiles vary with media multitasking behavior has continued to grow. To our knowledge, 20 subsequently published empirical papers examined the relationship between task-based assays of cognition and media multitasking. The vast majority of these studies examined cognitive performance in young adults, with a few examining adolescents. In addition, two studies investigated media multitasking's association with differences in neural structure and function. Here we review what is currently known about whether and how cognitive and neural profiles vary with media multitasking behavior (for review of media-nonmedia multitasking findings and of the relationship between psychosocial variables and media multitasking see ref. 8). Our review reveals an emerging literature marked by points of convergence but also of divergence, with extant findings suggesting that, in some contexts, heavier media multitaskers are more likely to suffer lapses of attention (among other attention-related differences) relative to lighter media multitaskers. Building from the literature, which provokes more questions than it answers, we conclude by highlighting what we believe are the most pressing open issues for future investigation.

Current Findings

This review focuses on investigations of the cognitive and neural profiles of media multitasking populations, with the goal of understanding the neurocognitive mechanisms that vary with media multitasking behavior. We do not include studies exploring

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relationships with psychosocial or real-world variables, such as academic performance or sleep (reviewed in ref. 9). We restricted inclusion to studies that employed quantifiable indices of media multitasking behavior and that related these indices to task-based cognitive performance (i.e., we excluded studies that leveraged only self-report/survey measures of cognition) and/or to neural metrics (see Tables S1–S4 for included studies). We identified candidate studies in two ways: (*i*) We searched the databases of PubMed, Web of Science, and Google Scholar using the search term "media multitasking," and (*ii*) we performed a reverse citation search in Web of Science for the original paper that first introduced the MMI (6). We additionally followed up with authors to request supplemental statistical reporting that may not have been the focus of the published papers but were germane to discussions below.

In each section below we first review extant data from studies of young adults and then, where available, from studies of adolescents.

Cognitive Profiles Associated with Media Multitasking

Behavioral investigations have used a variety of tasks to assess whether working memory (WM), cognitive control (including interference management, sustained attention, task management, and inhibitory control), relational reasoning, and long-term memory (LTM) vary with media multitasking behavior. Relevant experiments examined whether cognitive performance differed as a function of everyday media multitasking (i.e., participants did not media multitask during the experimental tasks). It is important to note the marked heterogeneity of the studied populations, which included a wide mix of young adults from a number of countries, typically ranging in age between 18 and mid-30s, action video gamers and nongamers, and individuals recruited on college campuses or online via Amazon's Mechanical Turk; two studies selectively examined effects in adolescents. Many studies used an extreme-groups approach that compared individuals in the upper portion of the MMI distribution [heavy media multitaskers (HMMs), often those greater than 1 SD above the mean MMI score] to individuals in the lower portion of the distribution [light media multitaskers (LMMs), often less than 1 SD of the mean MMI]; most extreme-groups comparisons were based on small sample sizes (≤22 participants per group). A similar number of studies treated media multitasking as a continuous variable and tested for linear relationships with cognitive and neural outcome variables. The heterogeneity in demography, tasks, administration method (supervised in-laboratory tests vs. unsupervised online tests), power, and analytic approach, combined with the small number of studies contributing to the literature in each cognitive domain, have led to a complex and mixed pattern of significant effects and null results. While it is beyond the scope of this review to discuss each source of variance's potential contribution to discrepant findings, we consider sources of likely variance and how to remediate them in *Open Questions* below.

Despite the methodological heterogeneity, the weight of current evidence shows that, in some contexts, heavier media multitaskers underperform relative to lighter media multitaskers in a number of cognitive domains. While more investigation is needed, we advance a working hypothesis that an attentional lapse account may explain many (though not all) current findings. Specifically, relative to LMMs, HMMs may have greater difficulty staying on task due to attentional lapses and returning to task following a lapse from goal-relevant behavior; attentional lapses may negatively impact performance in other cognitive domains, such as memory. We posit that this greater probability of attentional lapsing may be due to a predisposition and/or conditioned bias toward exploratory behavior. Below, we evaluate this account in the context of the cognitive domains that have been investigated and the associated (albeit even more sparse) neural data.

WM.

To date, there have been at least 24 tests of whether WM abilities in adults vary with media multitasking level (Tables S1–S3); 13 tests used simple WM tasks and 11 used more complex WM tasks. Approximately half demonstrated that HMMs underperform LMMs on tests of WM, with the remainder reporting null effects; no study found adult HMMs to outperform adult LMMs. In adolescents, two of three tests revealed a significant negative relationship between media multitasking and WM.

Simple WM. Relatively simple tests of WM require the encoding and short-term maintenance of information, followed by reporting of the contents of WM (either through recall or in response to a retrieval probe). A frequently used simple visual WM paradigm is the change detection task, which entails the presentation of a number of visual targets to be encoded and maintained (target load can vary across trials), with targets appearing with or without distractors (distractor load also can vary across trials). The ability to hold the task-relevant visual information in mind over a brief delay is often indexed using the K metric (10) or d' (11, 12).

When assessing adult HMMs' and LMMs' ability to hold information in mind when no distractors were present, three of three tests revealed no significant main effect of group when examining performance across target load sizes of two, four, six, and eight items (ref. 6 and Exps. 1 and 2 in ref. 13). However, when considering only the low target load condition (two targets) all three tests revealed numerically lower performance in the HMMs, and this pattern was also observed in two other studies that included only two-target load trials (i.e., there were no high target load trials; rectangles and objects tasks in ref. 11). Building from this latter qualitative observation, separate tests assessed WM performance using a low target load and varying levels of distraction (from 0 to 10 distractors). Under these conditions, HMMs performed significantly worse than LMMs in 5 of 10 tests (rectangles and objects in ref. 11 and Exps. 1 and 2 in refs. 13 and 14), and there was a trend in an additional test (no-attention-training baseline condition in ref. 12, $P = 0.085$, personal communication). Each of these tests revealed a significant main effect of group, with overall lower performance in the HMMs; again, these tests examined WM with a target load size of two, a point to which we return below (for a summary of all reported effects see Table S1).

Complex WM. WM tasks can move beyond simply asking participants to hold information in mind to also requiring some form of manipulation and/or updating of the information being held in mind. Tests of complex WM in adults revealed either that heavier media multitasking is associated with lower performance or null effects (Table S2). In two studies, complex WM was probed using the AX variant of the Continuous Performance Task (AX-CPT), which requires the detection of context-dependent probes (an "A" followed by an "X" and not other letters). Cardoso-Leite et al. (14) reported worse performance in HMMs on the AX-CPT task with no distractors, whereas Ophir et al. (6) found no significant group difference. In complex span tests, when individuals were asked to hold two to five letters in mind while responding to interspersed math problems [the Operation Span Task (OSPAN)], participants who scored higher on the MMI performed more poorly (15), whereas when participants were required to judge the semantic accuracy of sentences and then recall, in order, the letters presented after each sentence (Automated Reading Span) no significant group difference was found (16). On n-back tasks of WM (2- and 3-back), Ophir et al. (6) observed a load (2- vs. 3-back) by group (HMM vs. LMM) interaction, with HMMs performing worse on the 3-back. When considering 2- and 3-back performance in nonvideogame players (for comparison with the literature), Cardoso-Leite et al. (14) also observed a main effect of group, with HMMs performing worse ($P = 0.03$, personal communication) and no interaction with load ($P = 0.5$, personal communication). Similarly, on both 2- and 3-back tasks, Ralph and Smilek (17) observed a negative relationship between media multitasking and performance (reduced WM sensitivity). By contrast, three other n-back tests revealed no effect of group and no interaction with load (ref. 18 and Exps. 1 and 2 in ref. 13). Finally, on a digit span task in which participants held a series of numbers in mind and then recalled them in the backward direction, there was no relationship between media multitasking status and performance (12).

WM in adolescents. The relationship between media multitasking behavior and cognitive performance in adolescents was examined in two studies (refs. 19 and 20 and Table S3; see also ref. 21 for data pooled across adolescents and young adults). In both studies the mean media multitasking scores for adolescent samples were markedly lower than the means for young adult samples. For instance, in Baumgartner et al. (19), a modified media multitasking measure (which could range from 1 to 4) was combined with a full-sample regression analysis as well as an extreme-groups approach; overall, the media multitasking scores fell toward the lower end of the scale (sample mean = 1.71). The relationship between scores on this modified measure and the MMI is unclear. In Cain et al. (20) the mean MMI score was 3.00 (median = 2.69), which is lower than that in Ophir et al.'s (6) Stanford undergraduate sample (4.38).

Cain et al. (20) used a "count span" task that required adolescent participants to count target shapes and hold the counts in mind across multiple arrays. They also probed performance on four n-back tasks of WM (0- through 3-back). On these complex WM tests higher MMI scores were associated with a lower count span and with worse performance on the n-back tasks (collapsed across load, as well as separately significant in the 0-back, 2-back, and 3-back tests). Baumgartner et al. (19) examined a digit span task, pooled across forward and backward span conditions, and observed a nonsignificant negative relationship between their media multitasking measure and performance (using a regression analysis) and a null effect of group (extreme-groups analysis).

WM summary. Extant data reveal either lower WM performance with heavier media multitasking or null effects, but no studies report significantly better WM with heavier media multitasking. For both complex and simple WM tasks findings are approximately evenly split among negative effects and null effects. Importantly, the effects in simple WM tasks are particularly evident when participants are to encode and maintain low target loads (i.e., when the task is relatively easy). This pattern suggests that media multitasking-related WM differences may emerge, in part, from differences in sustained attention and/or attentional control during task performance. It may be that heavier media multitaskers are more likely to suffer attentional lapses or to less effectively engage attentional control, and that this may be particularly the case when current task demands are low. We explore these possibilities further in the next two sections by reviewing studies of interference management and sustained attention.

Managing Interference. Extant data indicate that individual differences in performance on the change detection WM task partially stem from differences in distractor filtering (10) and in sustained attention (22, 23). In this section, we consider whether media multitasking-related differences in simple WM reflect, in part, differences in the ability to filter task-irrelevant information, by reviewing studies of interference management. We define "interference management tasks" as those that require the filtering of distracting information, either from the external environment (i.e., from perception) or the internal environment (i.e., from memory). We refer to these as filtering tasks and proactive interference tasks, respectively (Tables S4–S6).

Filtering: Interference from perception. Differences in filtering were assayed by investigating performance in the change detection task (discussed above) when varying levels of distraction were present. In the Ophir et al. (6) study, HMMs and LMMs encountered a randomly interspersed mixture of low (two), medium (four), and high (six) target load trials, with varying distractor loads (zero to eight distractors). When target load was low, HMMs' performance disproportionately declined as distractor load increased; by contrast, the effect of distractor load on performance did not vary across groups at medium and high target loads. In six subsequent experiments that used identical or related variants of the change detection task (11, 12, 14), with some reporting multiple tests, only one test revealed an interaction between group and distractor load (Exp. 1 in ref. 13). That interaction took the form of LMMs performing better on four-target load trials when zero and two distractors were present, but then falling down to HMMs' performance level when faced with four distractors; this pattern is more consistent with reduced simple WM performance in HMMs at lower loads, perhaps due to more prevalent attentional lapses, than with a diminished filtering account. Together, the results reveal limited evidence that HMMs show perceptual filtering deficits on this visuospatial change detection task.

Other investigations used the distractor variant of the AX-CPT task, wherein task-irrelevant distractor letters appeared between the cue and probe (i.e., between the A and the X, and between BX, AY, and BY). Across four AX-CPT studies there is more consistent evidence of reduced performance in heavier media multitaskers. Ophir et al. (6) observed that HMMs were disproportionately slower to respond to probes when distractor letters appeared between the cue and probe relative to when no distractors appeared (i.e., a significant group by distraction interaction). HMMs' greater sensitivity to the presence of distractors was particularly evident on AX and BX trials. On this same task, Cardoso-Leite et al. (14) observed lower performance in HMMs relative to LMMs, using an inverse efficiency score (IES) that considered both response time (RT) and accuracy; the group by distraction interaction was not significant. Finally, across two experiments that only included the distractor-present variant, Wiradhany and Nieuwenstein (13) observed that HMMs were slower than LMMs on BX and BY trials in Exp. 1, and on AX trials in Exp. 2.

In the absence of data from no-distractor trials in Wiradhany and Nieuwenstein (13) it is unclear whether HMMs' slower RTs on distractor-present AX-CPT reflect (*i*) reduced attentional control that results in greater sensitivity to perceptual distractors, which would converge with the findings of Ophir et al., or (*ii*) a more general group effect, which would suggest a broader attentional difference, such as diminished sustained attention, and would converge with the findings of Cardoso-Leite et al. (14).

The reduced attentional control account is consistent with findings from Moisala et al. (21), who examined filtering of distracting sentences in one modality while performing a semantic comprehension task on sentences in another modality. In that study, performance accuracy was negatively related to absolute time spent media multitasking (there also was a trend for a negative relationship with MMI scores), and there were trends for an interaction between distractor level (distraction/no distraction) and media multitasking (time spent scale, $P = 0.07$; MMI, $P = 0.10$; personal communication). In another study, reduced filtering was argued to boost HMMs' performance on a task where the to-be-ignored information was covertly diagnostic of target onset (24). Here, HMMs' reduced filtering of "distracting" auditory tones that were associated with visual target onset was argued to aid detection of the visual targets.

By contrast, a broader attentional difference account is consistent with findings from Gorman and Green (12), who examined flanker task performance (25) in HMMs and LMMs who had not undergone an attention training intervention. Here, HMMs performed worse than LMMs in judging the direction of a central arrow, regardless of whether it was flanked by congruently or incongruently pointed distractor arrows ($P < 0.002$; personal communication). However, Murphy et al. (26) observed no performance differences between HMMs and LMMs on low and high perceptual load variants of a letter flanker task.

Collectively, whereas the bulk of the data on the visuospatial change detection task indicate that media multitasking level is not related to distractor filtering performance (for a meta-analysis, see also ref. 13), extant data from other perceptual filtering paradigms provide some support for attentional differences between heavier vs. lighter media multitaskers, although significant differences are not always observed. At present, the literature does not adjudicate whether performance differences arise from a reduced ability to control attention (prioritizing task-relevant over task-irrelevant information), from a more generic sustained attention difference, or both.

Proactive interference: Interference from memory. Three studies examined whether HMMs are less able to manage interference that comes from memory; two of these studies (6, 27) showed significantly greater sensitivity to proactive interference in HMMs vs. LMMs. In the first study (6), the aforementioned group by complex WM load interaction (with HMMs showing disproportionately lower performance on the 3-back vs. 2-back task) was argued to be due to HMMs' increased proactive interference from nontargets in the 3-back task (i.e., HMMs false-alarmed more than LMMs to familiar nontargets). Critically, HMMs' greater susceptibility to interference was evidenced by increased false alarms as the task proceeded, presumably because the memory strength of the nontargets progressively accrued due to their repetition across the task. Note that in Ralph and Smilek (17), the negative relationship between media multitasking and n-back performance also was due to higher false alarms in heavier multitaskers; however, this study did not report whether false alarm rate increased over the course of the tasks. In the second study, Cain and Mitroff (27) observed greater proactive interference in heavier media multitaskers; here, a salient color popout primed HMMs more than LMMs to attend to salient popouts on the subsequent trial, changing performance. By contrast, a third test of proactive interference—using a recent probes task where participants were to reject foils that came from recent memory (from the previous one or two trials)—revealed no difference between HMMs and LMMs (16). Given the limited literature, future studies are needed to better understand when distracting mnemonic information differentially interferes with the performance of heavier media multitaskers and whether such effects reflect differences in attentional lapses, attentional control, or other mechanisms.

Interference management in adolescents. Data on the relationship between media multitasking and interference management in adolescents are even more limited. On a visuospatial WM task with two targets Cain et al. (20) reported a null relationship between MMI scores and the difference in performance when distractors were present vs. absent. The researchers argued that the null effect may have been due to ceiling effects. Baumgartner et al. (19) conducted a flanker task on an adolescent sample in The Netherlands; as noted above, a modified media multitasking measure was used and the distribution of scores appeared to fall toward the lower end of the scale. While this complicates comparisons to adult data, in this study the group (HMM vs. LMM) by interference (incongruent vs. congruent) interaction approached significance ($P = 0.08$), with HMMs being generally faster to respond to incongruent trials.

Interference management summary. Extant data reveal a mixed pattern of findings across investigations of perceptual and mnemonic filtering, with more negative effects than null effects, and a trend for one positive effect. As noted, null effects dominated in change detection tasks, whereas most other tasks in young adults revealed some evidence that HMMs underperform LMMs. It remains open as to whether these differences reflect reduced attentional control that results in greater interference and/or whether they stem from broader attentional differences, such as reduced sustained attention.

An interesting hint of the possible contributions of attentional lapses to diminished AX-CPT performance can be seen in the findings of Cardoso-Leite et al. (14), who observed worse performance in both LMMs and HMMs during no distractor vs. distractor trials, with HMMs showing a greater difference. This pattern raises the possibility that, without the challenge of and/or arousal elicited by having to filter distractors (28), participants were more likely to suffer lapses of attention (and thus performed worse than when distractors were absent), with HMMs being more susceptible. This pattern also may complement the above discussed findings on WM, wherein diminished WM performance was observed in HMMs particularly at lower target loads, and heavier media multitaskers showed higher rates of omissions (17), again suggesting an increased prevalence of attentional lapses in heavier media multitaskers.

Attention. Is there direct evidence for altered sustained attention in heavier media multitaskers (Table S7)? Ralph et al. (29) conducted two studies using a metronome response task, wherein participants were to estimate and respond to the predictable onset of auditory tones over the course of ~20 min. On this task, high vigilance or sustained attention is typically associated with less RT variability. In both studies, higher media multitasking was associated with higher RT variability, indicating a reduced ability to sustain attention throughout the course of the test. Ralph et al. (29) also tested goal-directed attention using the vigilance variant of the Sustained Attention to Response Task (SART). In this paradigm, participants were to continuously monitor for relatively infrequent targets (0.2 probability) while ignoring frequent (0.8 probability) nontargets. Higher media multitasking scores were associated with reduced performance, although the correlation was attenuated to trend level when controlling for age (29).

Two additional studies examined the relationship between media multitasking and attention. Minear et al. (16) used the Attention Network Test (ANT) to obtain individual measures of alerting, orienting, and task management and revealed no media multitasking-related differences. By contrast, a dual-location cuing variant of the Posner cuing paradigm used by Yap and Lim (30) revealed that higher multitaskers were numerically slower than lower multitaskers and were further slowed when probes appeared outside vs. inside the cued locations. The slower overall performance in the high MMI group potentially parallels the HMM vs. LMM group differences seen in other cognitive paradigms.

In sum, most studies to date report negative effects of media multitasking on measures of attention. While further investigations are needed to more fully understand whether and how attention abilities vary with media multitasking level, the findings of Ralph et al. (29), when considered in light of those discussed above for other domains, suggest that HMMs demonstrate diminished performance, relative to LMMs, when sustained goal-directed attention is required. Lending further support for this possibility, Gorman and Green (12) demonstrated that an attention training intervention that is thought to enhance focused attention resulted in greater performance gains in HMMs relative to LMMs.

Managing Task Goals. To the extent that media multitasking in everyday life serves as a form of cognitive training, one may expect a benefit of heavy media multitasking in situations where multiple tasks are to be managed. Viewed through this lens, "near transfer" of training via media multitasking may be evidenced as improved performance on laboratory-based tests of task switching or dual tasking.

Task switching. There have been 10 tests of the relationship between media multitasking and task-switching performance in adults (Table S8). Most studies used an unpredictable switch paradigm wherein participants could not determine in advance of trial onset whether or not a task switch would be required; two studies used a predictable switch paradigm. To date, the literature is marked by considerable divergence, with costs, benefits, and null relationships observed across studies.

In contrast to the positive transfer prediction, three unpredictable task-switching tests revealed that HMMs show larger "switch costs" relative to LMMs (ref. 6 and Exps. 1 and 2 in ref. 13). When cued before each trial to classify a number–letter pair based on the number (as odd or even) or letter (as vowel or consonant), these studies revealed that HMMs were disproportionately slower to make the classification if the prior trial required the alternate classification (a "switch" trial) rather than the same classification (a "stay" trial) (group difference in switch cost: $P < 0.05$ in ref. 6 and Exp. 1 in ref. 13; $P = 0.117$ in Exp. 2 in ref. 13).

However, other studies revealed different outcomes: (*i*) Two revealed findings consistent with the positive transfer prediction, in that HMMs showed smaller switch costs on the unpredictable switch letter/number paradigm (Exps. 1 and 2 in ref. 31), whereas (*ii*) five revealed null effects, three using an unpredictable switch paradigm (ref. 14 and Exp. 1 in refs. 16 and 32) and two using a predictable switch paradigm (ref. 12 and Exp. 3 in ref. 16). While Alzahabi et al. (32) did not reveal differential switch costs between HMMs and LMMs, the speed of task set reconfiguration increased as a function of MMI. Finally, while Gorman and Green (12) observed comparable switch costs in HMMs and LMMs, when subjects did not undergo attention training, overall performance on the task was worse in HMMs than in LMMs ($P = 0.014$, personal communication).

Dual tasking. Three studies investigated whether heavier media multitaskers are differentially able to perform two tasks simultaneously (i.e., within-trial task switching, rather than switching between two tasks on a trial-by-trial basis); all reported null effects of media multitasking on the ability to dual-task (Table S9). For instance, when participants performed the letter/number tasks simultaneously, rather than one task on each trial, HMMs exhibited similar dual-task costs to LMMs (31). Likewise, in the sentence comprehension task of Moisala et al. (21), HMMs were as able as LMMs to determine sentence congruency when simultaneously listening to auditory sentences and reading visually presented sentences. Finally, Ie et al. (33) assessed participants' ability to write an essay while also solving anagrams and found that when age and MMI were combined they predicted the dual-tasking score, but the effect was carried by the factor of age; MMI showed a null relationship with dual-tasking performance.

Task switching in adolescents. One study examined the relationship between media multitasking and task switching in adolescents using a predictable switch paradigm; a null effect was observed (19) (Table S10).

Task management summary. At present, it is challenging to discern a clear pattern from studies of task switching and dual tasking, as a few studies reveal positive "transfer" effects (i.e., a negative relationship between MMI and switch cost), a few reveal negative transfer effects, and even more report null results (sometimes with overall lower task performance in HMMs). This complex pattern may partly reflect the fact that there are multiple contributors to switch costs (32), from task-set reconfiguration processes to resolution of proactive interference at the task, conceptual, and response levels (34, 35). It is likely that particular experimental paradigms differentially load on one or a subset of the processes, and it is possible that these processes are each expressed differently in HMMs vs. LMMs. Alternatively, there may be no relationship between media multitasking and the ability to manage multiple tasks (for a meta-analysis see also ref. 13), with the across-study divergence stemming from unstable estimates due to the use of small sample sizes.

Inhibitory Control. Inhibitory control is thought to be a distinct form of cognitive control from attentional control/selection and sustained attention (36). Six studies examined whether the ability to withhold a prepotent or impulsive response differs across media multitasking levels (Table S11). Three studies utilized the impulsivity variant of the SART (also known as the Test of Variables of Attention), wherein participants were to respond to frequent (0.8 probability) targets and refrain from responding to the remaining infrequent nontargets (12, 29). Ralph et al. (29) conducted two studies, and while the first revealed that MMI and performance were uncorrelated, when they doubled the sample size in a replication study they observed a significant correlation between MMI and no-go errors, such that the higher the MMI score the more errors participants made. This latter relationship was no longer significant, however, once age and speed–accuracy tradeoffs were accounted for. In the third, Gorman and Green (12) found that, before attention training, HMMs performed more poorly than LMMs on an impulsivity variant of the SART, as indexed by IES ($P < 0.006$, personal communication).

Other studies examined how media multitasking relates to response inhibition or impulse regulation/delay of gratification. Ophir et al. (6) assessed response inhibition using the "stop-signal" task, and observed that HMMs did not differ from LMMs in their ability to withhold a prepared response. Similarly, Murphy et al. (26) observed no difference in go/no-go performance (under high and low cognitive loads) between HMMs and LMMs. By contrast, Schutten et al. (37) observed that heavier media multitaskers demonstrate steeper delay discounting slopes, suggesting a tendency toward more impulsive responding or difficulties delaying gratification. As is clear, the limited data available are mixed on whether heavier media multitasking is related to diminished inhibitory control and/or impulsive responding.

More consistency is observed on self-report batteries of impulsivity, where heavier media multitaskers consistently score as more impulsive relative to lighter media multitaskers, both for adults (refs. 11, 15, and 16, but see ref. 7) and for adolescents (19, 20).

Relational Reasoning. Three experiments assessed the relationship between media multitasking and nonverbal relational reasoning (Table S12), using the standard or advanced Raven's progressive matrices task (RPM) (Exps. 1 and 2 in refs. 16 and 32). In RPM, participants are to reason through the relationships among a set of items that form a pattern or rule and complete the pattern by filling in a missing cell. In all three studies, which used independent samples, heavier media multitaskers performed significantly worse [one effect was attenuated to marginal significance ($P = 0.056$) when accounting for self-reported motor impulsivity].

Long-Term Memory. Two studies investigated whether media multitasking is associated with differences in the ability to retrieve information from LTM, either from explicit memory (11) or implicit memory (18) (Table S13). In the explicit memory paradigm of ref. 11, common objects were encountered once in the change-detection task described above, constituting the encoding phase. On a subsequent old/new recognition memory test, HMMs were significantly worse at recognizing the objects that had appeared as targets in the change-detection task and were also marginally worse at recognizing distracting objects they had been instructed to ignore during encoding. HMMs' ability to remember either target or distractor objects was worse across all levels of distraction at encoding. Finally, the ability to hold targets in WM predicted LTM performance, suggesting that the factors driving HMMs' poorer WM performance are also exerting effects on LTM.

Implicit memory performance was investigated using a contextual cueing task, wherein participants identified a target in a complex visual array, with some arrays repeated across subsequent trials (18). While LMMs showed the predicted RT benefit on as arrays were repeated over time, HMMs did not show such a benefit.

LTM in adolescents. Implicit memory was assessed in adolescents in a weather prediction task, in which participants attempted to classify the probability of rain or sun given a set of one, two, or three card combinations that were probabilistically associated with each outcome (20) (Table S14). No relationship between performance and MMI was observed on this task.

LTM summary. While available data are quite limited, heavier media multitasking in adults was associated with poorer explicit and implicit LTM, but null effects were observed in adolescents.

Summary of Cognitive Findings. Overall, the literature demonstrates areas of both convergence and divergence. Converging findings reveal negative relationships between media multitasking and performance in some cognitive domains: WM and LTM, sustained attention, relational reasoning, and, to a lesser extent, interference management. In terms of divergence, it should be noted that the number of studies contributing to assessments in each domain is typically rather limited, and so it is difficult to determine whether there is a mechanistic account for when significant vs. null effects will be obtained (as opposed to the across-study variance's being due to measurement error; see *Open Questions* below). Notably, with the exception of task switching—where positive, negative, and null effects have all been reported—significant effects in all other domains have almost exclusively taken the form of underperformance with increasing media multitasking. While further investigation is needed, our working hypothesis is that attentional lapses may explain many of the current findings, with HMMs having more difficulty staying on task and returning to task when attention has lapsed from goal-relevant behavior (see *Mechanisms* below).

Neural Profiles Associated with Media Multitasking

Two studies investigated neural correlates of media multitasking, offering initial evidence for structural and functional differences (21, 38). Using structural and functional MRI, Loh and Kanai (38) observed a negative correlation between participants' MMI score and (*i*) gray matter volume in the anterior cingulate cortex (ACC) and (*ii*) resting-state "intrinsic connectivity" between the ACC and precuneus. Given that ACC is broadly responsive to cognitive control demands (39–41), these initial observations motivate further examination of whether there are individual differences in local and network-level neural architecture that covary with media multitasking behavior, and whether such differences relate to media multitasking differences in cognitive performance.

Using task-based fMRI, Moisala et al. (21) regressed the amount of time participants spent media multitasking with brain activity [blood-oxygen-level-dependent (BOLD) signal] while adolescents and young adults performed a sentence comprehension task under full attention, divided attention, or distracted attention. They found that, during sentence comprehension in the presence of distraction, heavier media multitasking was associated with greater activity in several prefrontal regions (lateral superior/middle frontal gyri and medial portion of superior frontal gyrus). Because activation in these prefrontal regions is known to vary with attentional demands, among other factors, these researchers interpreted this finding to mean that greater attentional effort was required to perform the distraction-laden variant of the task if a participant was a heavier media multitasker.

Open Questions and Future Directions

The foregoing findings comprise a rising tide of investigations revealing how cognitive and neural profiles may differ—or not—as a function of media multitasking behavior. The nascent state of the field raises many questions, pointing toward several key areas that require experimental evaluation.

Measurement Heterogeneity? Future research should focus on the methods of measurement in media multitasking studies, as measurement noise may partly account for the across-study variability currently evident in the literature. Here we discuss five potential sources of heterogeneity that may be leading to the mixed findings. First, the original media use questionnaire was created close to a decade ago (6), when the landscape of media was very different. An updated battery should reflect current media types, including social media, but may also consider querying newer media behaviors, such as content creation (e.g., blogging, video generation, and editing) and other generative behavior, such as coding. Second, the studies from a decade ago likely assayed very different populations from those enrolled in more recent studies, with today's HMMs likely having been exposed to ubiquitous media at an earlier age and for longer periods, and thus may exhibit developmental differences that prior HMMs did not have. Future batteries should assay the age of onset of multitasking with each media stream. Third, while the MMI measures the extent of media multitasking during a typical media consumption hour, an open question is whether this metric best captures the multitasking behavior that is most tightly related to individual differences in cognition and brain. An alternative, or complementary, measure that warrants further examination is the number of hours spent multitasking with media. Time spent media multitasking is likely to be correlated with the MMI, and recent data point to a relationship between this measure and neurocognitive function (18). Fourth, people likely media-multitask for very different reasons, leading to heterogeneous HMM populations that are currently being treated as a single population. Future batteries should query goals for engaging in media multitasking, and include assays of active vs. passive media consumption. Finally, the self-report method relies on individuals' accurately assessing and remembering their media use. This is particularly important, given studies showing that people both overestimate and underestimate their use of media (specifically, social media, with overestimation shown in ref. 42 and underestimation in refs. 43 and 44). While initial data suggest that test–retest reliability is high over short lags for the MMI (1-wk reliability $r = 0.93$; ref. 13) and moderate over very long lags for a modified MMI scale (1-y reliability $r = 0.52$, ref. 45), further data regarding the psychometric properties of these scales are needed (as are data establishing the relationships between the various scales of media multitasking that are emerging in the literature). In addition, validation of existing retrospective self-report measures can come through comparisons to real-time self-report measures (e.g., via experience sampling) and to objective measures (e.g., harnessing digital tracking technology to obtain more precise measures of real-world media use behavior).

Causality? Given how prevalent media multitasking behavior has become, a critical issue concerns the direction of causality—specifically, does heavier media multitasking cause cognitive and neural differences, or do individuals with such preexisting differences tend toward more media multitasking behavior? Is there an interaction, such that preexisting differences are exacerbated by excessive media multitasking, and vice versa (28)? Understanding the causal relationships will provide guidance on whether interventions are appropriate, and, if so, which may be most helpful.

If habitual heavy media multitasking is demonstrated to cause cognitive and neural changes, this raises additional questions regarding the timing, dosage, duration, and quality of media multitasking that induces changes, including the following. Are there sensitive periods during development during which the young brain is most vulnerable to the effects of media multitasking (for related data see ref. 28)? Does the type of media matter? Do the specific combinations of simultaneous media use matter? Are certain neurocognitive phenotypes more sensitive to the effects of media multitasking? Finally, are there positive impacts of media multitasking such that the individual is benefited by cognitive and neural changes? Gaining traction on these and related questions will require larger-scale samples that draw from individuals of all ages, media use histories, demographics, and neurocognitive profiles.

Remediation? Even before the direction of causality is determined, cognitive interventions may be helpful in remediating the observed differences associated with heavier media multitasking. Early support for this idea is provided by Gorman and Green (12), who demonstrated that HMMs benefited more than LMMs from an attention training intervention, mitigating HMMs' underperformance on multiple tasks that load on attentional processing (cf. ref. 33 for a study showing null effects of a mindfulness intervention). While suggestive, there are many open questions regarding the potential impacts of interventions, such as the following. How long-lasting are the effects of an intervention? Does the neurocognitive profile of the media multitasker matter for an intervention to be effective? Are there optimal training schedules? This suite of questions can help us understand which interventions are most effective, when should they be applied, as well as to whom, and for how long.

Mechanisms? Addressing causality and remediation will shed light on the causes of the underperformance in heavier media multitaskers, but concerted efforts should also be devoted to testing precise mechanistic hypotheses. The processing account proposed in Ophir et al. (6)—that HMMs' underperformance was due to deficits in filtering abilities—has garnered mixed support in subsequent investigations, with some paradigms providing further evidence for increased sensitivity to interference but many others revealing limited evidence of filtering failures [for a meta-analysis specifically focused on the cognitive domains explored in Ophir et al. (6) see ref. 13]. By contrast, the present broader review reveals stronger evidence for media multitasking effects on WM and LTM, sustained attention, relational reasoning, and, to a lesser extent, interference management. Additional studies of whether and, if so, when heavier media multitaskers demonstrate diminished memory and reasoning, along with reduced attentional control and/or increased attentional lapses are needed; ideally such studies would use high-powered designs, include independent sample replications, and incorporate additional tasks that can shed new light on the underlying processes.

Here we propose that the current task-based evidence points to the possibility that heavier media multitaskers experience more frequent or more disruptive lapses in attention (see also ref. 28), a finding that is complemented by (*i*) the observation that media multitasking was positively associated with omission errors (nonresponses) during 2-back and 3-back WM tasks (17) and (*ii*) positive relationships between media multitasking and self-reported everyday attentional failures (28, 46, 47) and prevalence of mind wandering (46). The attentional lapse hypothesis can be tested using behavioral and neural methods that specifically quantify attentional lapses [such as EEG-indexed oscillatory markers of attention (48) or multivariate classifications of goal states using BOLD fMRI data (49)]. A critical open question is whether media multitasking-related differences in behavioral and neural indices of attentional lapses account for the lower accuracy or slower responses sometimes observed in HMMs. Likewise, manipulations of sustained attention—via neural methods that can alter attentional states (such as transcranial magnetic stimulation or electrical brain stimulation) and behavioral methods that induce shifts in sustained attention (such as task-based conflict adaptation or vigilance manipulations)—can inform whether reduced performance in heavier media multitaskers, at least partially, reflects the disruptive consequences of lapses in attention.

What mechanisms could give rise to a greater tendency toward attentional lapses? One possibility is that heavier media multitaskers are more biased to "explore" alternative sources of information rather than "exploiting" the task-relevant or known information channel, an interpretation related to the hypothesis of diminished attentional control (see also ref. 28). Different balances between exploration and exploitation may result from particular neural profiles (50), and if the balance in HMMs is tipped in favor of exploratory behavior this may result in greater sensitivity to task-irrelevant internal and external sources of evidence that, while not facilitating current task performance, result in other forms of reinforcement. This perspective predicts that HMMs' poorer performance may be due to wider sampling during cognitive performance relative to LMMs, and preliminary support comes from Yap and Lim (30), who suggested that HMMs express a broader visuospatial attentional scope than LMMs. Going forward, this hypothesis may be directly tested using paradigms from the reinforcement learning literature that provide quantitative assays of exploratory and exploitative behavior.

An additional, and not mutually exclusive, mechanistic hypothesis is that the higher self-reported impulsivity in heavier media multitaskers reveals a lower threshold for the amount of evidence used in service of making decisions. Recent data demonstrate that heavier media multitaskers are more prone to reactive decision making and show steeper delay discounting slopes (37). Methods that quantify and track the accumulation of evidence during decision making may help reveal whether the relationship between impulsivity and lower performance in heavier media multitaskers reflects a critical underlying mechanism of action mediating cognitive performance.

Concluding Remarks

Media and technology are ubiquitous elements of our daily lives, and their use offers many benefits and rewards. Decisions about how adults and developing youth might structure their media use behavior can be informed by consideration of whether and, if so, how the mind and brain are shaped by different use patterns. Here we reviewed current findings on the cognitive and neural profiles of individuals who fall at different points along the spectrum of media multitasking behavior, finding that, in general, heavier media multitaskers often exhibit poorer performance in a number of cognitive domains. We stress, however, that such relationships are not always evident, with many studies reporting no performance differences between groups. When evidence points to a relationship between media multitasking level and cognition it is often on tasks that require, or are influenced by fluctuations in, sustained goal-directed attention. Given the real-world significance of such findings, we believe further research is needed to determine how measurement heterogeneity relates to variable outcomes, to uncover the mechanistic underpinnings of the observed differences, to determine the direction of causality, and to understand whether remediation efforts are needed and effective. Such efforts will ultimately inform decisions about how to minimize the potential costs and maximize the many benefits of our ever-evolving media landscape.

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