

Cognitive control in media multitaskers

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Chronic media multitasking is quickly becoming ubiquitous, although processing multiple incoming streams of information is considered a challenge for human cognition. A series of experiments addressed whether there are systematic differences in information processing styles between chronically heavy and light media multitaskers. A trait media multitasking index was developed to identify groups of heavy and light media multitaskers. These two groups were then compared along established cognitive control dimensions. Results showed that heavy media multitaskers are more susceptible to interference from irrelevant environmental stimuli and from irrelevant representations in memory. This led to the surprising result that heavy media multitaskers performed worse on a test of task-switching ability, likely due to reduced ability to filter out interference from the irrelevant task set. These results demonstrate that media multitasking, a rapidly growing societal trend, is associated with a distinct approach to fundamental information processing.

attention | cognition | executive function | multitasking | working memory

In an ever-more saturated media environment, media multitasking—a person's consumption of more than one item or stream of content at the same time—is becoming an increasingly prevalent phenomenon, especially among the young (1). Researchers have examined the immediate effects of multitasking, and of media multitasking in particular, on memory, learning, and cognitive functioning (2–4). However, it is unknown whether and how chronic heavy multitaskers process information differently than individuals who do not frequently multitask (viewing multitasking as a trait, not simply a state). This issue seems especially pertinent in light of evidence that human cognition is ill-suited both for attending to multiple input streams (5, 6) and for simultaneously performing multiple tasks (7–9). Is breadth-biased media consumption behavior mirrored by breadth-bias in cognitive control? That is, are chronic multitaskers more attentive to irrelevant stimuli in the external environment and irrelevant representations in memory?

The present research addressed this question via a series of cognitive control studies comparing chronic heavy media multitaskers to those who infrequently multitask. The goal was to examine whether there is a relationship between chronic media multitasking and cognitive control abilities. One possibility is that chronic media multitaskers exhibit advantages in cognitive control, which would motivate future work to establish whether heavy multitasking confers or reflects these advantages. Alternatively, if heavy media multitasking behavior is associated with deficits in cognitive control, such a finding would offer important prescriptive guidance irrespective of the direction of causality. If chronic media multitasking is the cause, then a change in multitasking behavior might be warranted. Conversely, if chronic media multitasking behavior is more frequently engaged in by individuals least able to cope with multiple input streams, then behavior change may confer particular benefits to these individuals as they would have to deal with fewer distractors.

Results

Media Multitasking Index. To identify people who are heavy vs. light media multitaskers, we developed a questionnaire-based

media multitasking index to determine the mean number of media a person simultaneously consumes when consuming media and selected those individuals who were heavy media multitaskers (HMMs were one standard deviation or more above the mean) or light media multitaskers (LMMs were one standard deviation or more below the mean) on this index. We then examined these groups' abilities on cognitive control dimensions that could indicate a breadth-bias in cognitive control at different control loci: the allocation of attention to environmental stimuli and their entry into working memory, the holding and manipulation of stimulus and task set representations in working memory, and the control of responses to stimuli and tasks.

Filtering Environmental Distractions: Filter and AX-CPT Tasks. In a test of filtering ability (10)—an ability that can point to a breadth orientation in allowing stimuli into working memory—participants viewed two consecutive exposures of an array of rectangles and had to indicate whether or not a target (red) rectangle had changed orientation from the first exposure to the second, while ignoring distractor (blue) rectangles (Fig. 1A). We measured performance for arrays with two targets and 0, 2, 4, or 6 distractors. Repeated-measures ANOVA revealed a group*distractor level interaction (Fig. 1B), $F(1, 39) = 4.61, P < 0.04$: HMMs' performance was linearly negatively affected by distractors, $F(1, 18) = 9.09, P < 0.01$, whereas LMMs were unaffected by distractors, demonstrating that LMMs have the ability to successfully filter out irrelevant stimuli, $F(1, 21) = 0.18, P > 0.68$.

Further evidence for HMMs' tendency to allow irrelevant stimuli into working memory emerged on the AX-CPT variant (11, 12) of the Continuous Performance Task (13). This task examined whether HMMs and LMMs differ in their representation and maintenance of context. Participants viewed cue-probe pairs of letters, and were to respond "yes" when they saw the target cue-probe pair, "AX", that is, an "A" (cue) followed by an "X" (probe). All other combinations—"A" then not-"X" ("AY"), not-"A" then "X" ("BX"), and not-"A" then not-"X" ("BY") were to be responded to with a "no" button press. In addition to the standard version of the AX-CPT, we administered a second version using distractor letters, identified by a different color, that intervened between cue and probe (14). In this version, participants were to ignore letters marked as distractors and to perform the task as if they did not exist.

Performance analyses revealed no significant differences between HMM and LMM performance in the standard AX-CPT in either accuracy (d'), $t(28) = 0.51, P > 0.61$, or response times, $t(28) = -0.16, P > 0.88$. However, in the AX-CPT with distractors, HMMs were 77 ms slower to respond to the probes, $t(28) = -3.33, P < 0.002$ (Fig. 2), even though there was again no difference in accuracy, $t(28) = 0.01, P > 0.99$. The response time difference was driven by responses to those trials where an

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susceptible to interference from items that seemed familiar, and that this problem increased as working memory load increased (from the two- to the three-back task). This problem also became more acute for HMMs as the task progressed, because proactive interference from irrelevant letters accumulated across the experiment. Specifically, a general linear model of the likelihood of a false alarm in the three-back task revealed: (a) no main effect of HMM/LMM status nor of time, but (b) a significant HMM/LMM status*time interaction, such that the number of false alarms increased over time more rapidly for HMMs, $B = 0.081$, $P < 0.001$. These data demonstrate that HMMs are not only less capable of filtering out irrelevant stimuli from their environment, but also are less capable of filtering out irrelevant representations in memory.

Task Switching. To compare the two groups' task-set switching abilities, we used a task-cued stimulus-classification procedure (17): participants were presented a number and a letter, and performed either a letter (vowel or consonant) or a number (even or odd) classification task depending on a cue presented before the stimulus. Switch cost was calculated as the difference in mean response time between trials preceded by a trial of the other type (switch trials) vs. trials preceded by a trial of the same type (nonswitch trials). HMMs' switch cost was 167 ms greater than that of LMMs, $t(28) = -2.62$, $P < 0.01$; specifically, HMMs were 426 ms slower to respond to switch trials, $t(28) = -2.66$, $P < 0.01$, and 259 ms slower to respond to nonswitch trials, $t(28) = -2.27$, $P < 0.03$. The difference in switch cost was not simply a result of a general difference in performance on response-time decision tasks: as reported earlier, LMMs and HMMs did not exhibit differences in response times on the AX-CPT task when no distractors were present. In addition, switch cost was still significant when calculated in proportion to each participant's nonswitch trial mean response time, $t(28) = -2.04$, $P < 0.05$. Because switch costs have been attributed to competition from activation of the irrelevant task-set (18–20), these results suggest that HMMs are less capable of filtering out the irrelevant task-set representation in memory on a given trial. This conclusion is reinforced by HMMs' slowing on nonswitch trials: such slowing in performance of mixed-task blocks has been termed the "mixing cost" and is attributed to interference from the currently irrelevant task (21).

Collectively, the data suggest that HMMs are less likely to filter irrelevant representations arising from either external or internal sources. To ensure that this different cognitive control profile was not driven by general cognitive differences between members of the HMM and LMM groups, we compared HMMs and LMMs from an independent sample of participants on a number of broader measures. This analysis revealed no significant differences between the groups in SAT scores, need for cognition (22), performance on a creativity task (23), or ratings on the Big Five Trait Taxonomy—extraversion, agreeableness, conscientiousness, neuroticism, and openness (24)—all $t(30) < 1.24$, $P > 0.22$; the Media Multitasking Index (MMI) also did not differ with gender, $t(31) = 0.19$, $P > 0.85$.

Furthermore, although individual differences on measures of cognitive control may be driven by individual differences in working memory capacity, evidence from the filter task suggests that LMMs and HMMs do not differ in this regard. Specifically, we examined LMM and HMM performance on the filter task for arrays with 2, 4, 6, or 8 targets and no distractors (target-only arrays); this is a direct measure of memory capacity (10). A repeated-measures ANOVA clearly showed no main effect for HMM/LMM status ($F < 1$), nor an interaction between HMM/LMM status and the number of targets ($F < 1$). In addition, the groups clearly did not differ with respect to any particular number of targets [all $t(39) < 1.04$, all $P > 0.30$]. Thus, we can rule out differences in working memory capacity between

HMMs and LMMs as the cause of differences in cognitive control.

Finally, the analyses presented here focus on the approximately one-third of the population who would be conventionally called "heavy" or "light" media multitaskers, that is, people who were one or more standard deviations away from the mean. This dichotomization should not lead to biases in the results, because the distribution of multitasking is approximately normal, there are no outliers, and we are not using the center of the distribution.

There was insufficient variance within conditions on the cognitive control tasks to examine within-condition effects with one exception (which reinforces our conclusion): among HMMs performing the filter task, a regression of performance on MMI scores and number of distractors yielded a significant and negative MMI*number of distractors interaction, $B = -0.04$, $t(17) = 2.22$, $P < 0.04$, demonstrating that even among heavy multitaskers, more intensive multitaskers are more susceptible to distractors.

Discussion

The present research suggests that individuals who frequently use multiple media approach fundamental information-processing activities differently than do those who consume multiple media streams much less frequently: their breadth-biased media consumption behavior is indeed mirrored by breadth-biased cognitive control. HMMs have greater difficulty filtering out irrelevant stimuli from their environment (as seen in the filter task and AX-CPT with distractors), they are less likely to ignore irrelevant representations in memory (two- and three-back tasks), and they are less effective in suppressing the activation of irrelevant task sets (task-switching). This last result is particularly striking given the central role attributed to task-switching in multitasking (25).

These results suggest that heavy media multitaskers are distracted by the multiple streams of media they are consuming, or, alternatively, that those who infrequently multitask are more effective at volitionally allocating their attention in the face of distractions. This may be a difference in orientation rather than a deficit; that is, although the data reveal negative effects in HMMs on performance of tasks that require cognitive control, it remains possible that future tests of higher-order cognition will uncover benefits, other than cognitive control, of heavy media multitasking, or will uncover skills specifically exhibited by HMMs not involving cognitive control.

The present data suggest that LMMs have a greater tendency for top-down attentional control, and thus they may find it easier to attentionally focus on a single task in the face of distractions. By contrast, HMMs are more likely to respond to stimuli outside the realm of their immediate task, and thus may have a greater tendency for bottom-up attentional control and a bias toward exploratory, rather than exploitative, information processing (26, 27). If so, they may be sacrificing performance on the primary task to let in other sources of information.

With the diffusion of larger computing screens supporting multiple windows and browsers, chat, and SMS, and portable media coupled with social and work expectations of immediate responsiveness, media multitasking is quickly becoming ubiquitous. These changes are placing new demands on cognitive processing, and especially on attention allocation. If the growth of multitasking across individuals leads to or encourages the emergence of a qualitatively different, breadth-biased profile of cognitive control, then the norm of multiple input streams will have significant consequences for learning, persuasion, and other media effects. If, however, these differences in cognitive control abilities and strategies stem from stable individual differences, many individuals will be increasingly unable to cope with the changing media environment. The determination of cause and effect and the implications of these differing strategies

for other types of information processing are critical issues for understanding cognition in the 21st century.

Materials and Methods

This research was conducted in five parts: a media use questionnaire and index, three sets of cognitive experiments (Parts I, II, and III), and a final set of questionnaires administered online. All aspects of the study involved informed consent of the participants and were approved by the Stanford Human Subject Review Board.

Media Use Questionnaire and MMI. *Participants.* Two-hundred sixty-two university students participated in the questionnaire for course credit. The questionnaire was administered online, and took approximately 20 min to complete.

Questionnaire design. The questionnaire addressed 12 different media forms: print media, television, computer-based video (such as YouTube or online television episodes), music, nonmusic audio, video or computer games, telephone and mobile phone voice calls, instant messaging, SMS (text messaging), email, web surfing, and other computer-based applications (such as word processing). For each medium, respondents reported the total number of hours per week they spend using the medium. In addition, they filled out a media-multitasking matrix, indicating whether, while using this primary medium, they concurrently used each of the other media "Most of the time," "Some of the time," "A little of the time," or "Never." As text messaging could not accurately be described by hours of use, this medium was discarded from the analysis as a primary medium, although it still appeared as an option in the matrix (meaning respondents could still report text messaging while being engaged in other media).

Index creation. To create the MMI, we assigned numeric values to each of the matrix responses as follows: "Most of the time" (= 1), "Some of the time" (= 0.67), "A little of the time" (= 0.33), and "Never" (= 0). For each primary medium, we summed the responses. This resulted in a measure of the mean number of other media used while using each primary medium. To account for the different amounts of time spent with each medium, the MMI was created by computing a sum across primary media use weighted by the percentage of time spent with each primary medium. Thus, the index is an indication of the level of media multitasking the participant is engaged in during a typical media-consumption hour. In summary, the formula is as follows:

$$\text{MMI} = \sum_{i=1}^{11} \frac{m_i \times h_i}{h_{\text{total}}}$$

where m_i is the number of media typically used while using primary medium i , h_i is the number of hours per week reportedly spent using primary medium i , and h_{total} is the total number of hours per week spent with all primary media.

Index results. The MMI produced a relatively normal distribution, with a mean of 4.38 and standard deviation of 1.52. This suggests that there is not a bimodal distribution of "heavy multitaskers" and "nonmultitaskers." Nonetheless, we can identify individuals who very frequently use multiple media and those who tend to limit their use of multiple media. Media multitasking was correlated with total hours of media use, $r(260) = 0.46$, $P < 0.001$. However, this is not an artifact of our measurement approach, because we control for the total number of hours of media use in our computation of the media multitasking index.

Part I: Filtering and Response Inhibition. *Participants.* Based on the questionnaire, those students with an MMI less than one standard deviation below the mean (LMMs) or an MMI greater than one standard deviation above the mean (HMMs) were invited to participate. The invitation yielded 22 LMMs and 19 HMMs who gave informed consent and participated in the study for course credit.

Procedure. Participants completed four tasks assessing different facets of cognitive control: the Stroop Task, a task-switching procedure, a filtering task, and a stop-signal task (data from the Stroop Task and this implementation of the task-switching procedure are not included in this report). The tasks were performed using a PST Serial Response Box and a Dell Poweredge computer running EPrime 2.0 software, with stimuli presented on a Dell Trinitron 17" CRT display. All participants performed these tasks in the same order, taking approximately 50 min to complete the entire study.

Filtering task. Attention allocation and stimulus filtering refer to the ability to willfully allocate attention to some stimuli in the environment, thus allowing those stimuli to enter working memory, while preventing other, irrelevant stimuli from entering working memory. In the filtering task, participants were

told they would view a number of different arrays of red and blue rectangles. They were instructed to pay attention *only* to the red rectangles, and to *ignore* the blue rectangles.

In each trial of the task, participants were presented with an array of red and blue rectangles of differing orientations for 100 ms (Fig. 1A). After an interval of 900 ms, a second array was presented, this time for 2,000 ms, and participants were asked to indicate whether *one* of the red rectangles had changed orientation (orientation changes consisted of rotation by 45° either clockwise or counterclockwise, and no more than one red rectangle ever changed orientation). Participants indicated that a change had taken place by pressing a button marked "yes," and that no change had taken place by pressing a button marked "no." Trials were separated by an interval of 200 ms.

To measure the participants' filtering effectiveness, different numbers of blue rectangles (distractors) were included in the arrays: 0, 2, 4, or 6. In addition, the number of red rectangles (targets) also varied between 2, 4, 6, and 8. The rectangles were evenly and randomly distributed within the display area, and no two rectangles overlapped or were within one rotation of overlapping. Target-distractor combinations were restricted so that the size of the array never exceeded eight rectangles in total. For example, if there were four target rectangles, there would only be zero, two, or four distractor rectangles. Thus, there were 10 possible combinations.

After completing a practice session, participants performed a single block of 200 trials, with an equal number of trials of each of the target-distractor combinations, and an equal number of change and no-change trials within each type of array. Trial order was randomized.

Presumably, if a person filters distractors effectively, an increase in the number of distractors should have no effect on performance. Conversely, if a person does not filter effectively, performance should decline as the number of distractors rises. To test filtering ability, the effect of added distractors on performance in the filtering task was examined in all trials with two targets. We focused on the two-target arrays as these contained the widest range of target-distractor combinations. In addition, two targets should be well within the memory capacity of most participants, allowing for high initial performance (in trials with target-only arrays) and thus more easily discernible distractor effects. The comparison thus examines four possible arrays of rectangles: two targets, with 0, 2, 4, or 6 distractors. We computed the performance measure in terms of memory capacity (10, 28): $K = S(H-F)$, where K is the memory capacity, S is the size of the array, and H and F are the hit (a correct indication that a rectangle had rotated) and false alarm (an incorrect indication that a rectangle had rotated) rates, respectively. Because participants were explicitly told to ignore distractors, S , the size of the relevant array, was set to the number of targets, that is, two.

Stop-signal task. Response inhibition was measured using a stop-signal task. In this task, participants were first presented 24 words (balanced for familiarity), one at a time, in random order, and instructed to categorize them as either animal or nonanimal as quickly as possible by pressing one of two buttons. Each word appeared twice, for a total of 48 trials, constituting an initial timing block. The participants were then presented the same words and asked to make the same categorization—but to withhold their response if a tone (the stop-signal) was heard before they entered their response.

After a practice session, the participants performed three blocks of 96 trials each. The stop-signal was present on 25% of trials, with trials presented in random order. When present, the stop-signal was presented 225 ms before the mean response time as calculated based on the participant's performance in the initial timing block.

Part II: Two- and Three-Back Tasks. *Participants.* Thirty Stanford students took part in this second study for course credit. Participants were recruited based on their MMI, calculated from their responses to the Media Use Questionnaire, in the same manner used for Part I. This time, 15 LMMs and 15 HMMs responded to the invitation, and took part in the study after having given their informed consent.

Procedure. These studies used the same tools and setting used in the first study. The N-Back tasks were administered after a Stroop Task (excluded from this report). The entire study took approximately 40 min to complete.

Two- and three-back tasks. To examine individual differences in the ability to monitor and update multiple representations in working memory, we used the two- and three-back tasks. In these tasks, participants were presented a series of individual letters in the middle of the screen. Each letter was presented for 500 ms, followed by a white screen for 3,000 ms. Upon presentation of a letter, participants were to indicate whether or not the present letter was a "target," meaning that it matched the letter presented two (for the two-back task) or three (for the three-back task) trials ago. They pressed one button for "target" and another for "nontarget."

Participants completed a practice session and then three blocks of the

two-back task, with each block consisting of 30 trials, including 10 target and 20 nontarget trials. After completing the two-back task, participants performed a training session and three blocks of the three-back task. Performance was calculated using d' .

Part III: Task-Switching and AX-CPT. Participants. Thirty-two Stanford students took part in this second study for course credit. Participants were recruited based on their MMI, calculated from their responses to the Media Use Questionnaire, in the same manner used for Part I. Again, 15 LMMs and 15 HMMs took part in the study after having given their informed consent.

Procedure. These studies used the same tools and setting used in the first two studies. The task-switching procedure was administered first, followed by the AX-CPT and finally the AX-CPT with distractors. The entire study took approximately 60 min to complete.

Task switching. To measure the cost of switching between task sets, we used a number-letter task. In this task, participants switched back and forth between classifying numbers and classifying letters, according to a cue presented at the outset of each trial. Participants were presented with one of two cues ("NUMBER" or "LETTER") for 200 ms, followed by a stimulus that consisted of a digit-letter pair (such as "2b" or "b2"). Participants classified the stimuli using two buttons, depending on the task indicated by the cue. If shown the NUMBER cue, participants were to press the left button for an odd number and the right button for an even number. If, conversely, participants were shown the LETTER cue, they were to press the left button if the letter in the stimulus was a vowel and the right button if it was a consonant.

The set of letters consisted of the vowels a, e, i, and u, and the consonants p, k, n, and s. The set of even numbers consisted of 2, 4, 6, and 8, whereas the odd numbers were 3, 5, 7, and 9. The relative positions of the number and letter were counterbalanced across trials. The interval between cue offset and stimulus onset was set to 226 ms, and the intertrial interval was set to 950 ms.

Participants performed practice sessions for number categorization, letter categorization, and switching. Participants then performed the recorded session, consisting of four blocks. Each block consisted of 80 trials, with an equal frequency of 1, 2, 3, and 4 same-trial sequences, yielding 40% switch trials and 60% nonswitch trials. The cost of switching between task sets was computed by comparing mean response times in trials preceded by the same type of trial (a nonswitch trial—the second of two consecutive "NUMBER" or "LETTER" trials) with mean response times in trials preceded by a different trial type (a switch trial—a "NUMBER" trial preceded by a "LETTER" trial, or vice versa).

AX-CPT. To both measure HMMs and LMMs ability to maintain contextual information and to conceptually replicate our results from the filter task, we used the AX-CPT both without and with distractors. In the AX-CPT, participants viewed a sequence of letters presented for 300 ms each in red on a black screen. The letters formed cue-probe pairs, such that 4,900 ms elapsed between presentation of cue and probe, and 1,000 ms between successive trials.

Participants were to maintain the cue in memory, which could be either the letter "A" or some other letter (other than "X," the target probe, and "K" and "Y," for their similarity to "X"), until they saw the probe, which could be "X" or some other letter (not including "A," "K," or "Y"). If they saw the cue "A" followed by the probe "X," they were to press a button marked "YES." For all other cue-probe combinations, they were to press a button marked "NO." Participants were also instructed to respond "NO" to all cue letters.

The AX-CPT with distractors has one difference from the previous task: between every cue and probe, presented in red, participants saw three additional, distractor letters (which could be any letter but "A," "X," "K," or "Y") presented in white. Distractors were also presented for 300 ms, with a 1,000-ms interval between the cue and the first distractor, between each of the distractors, and between the last distractor and the probe (thus maintaining the 4,900-ms interval between cue and probe from the original AX-CPT). Participants were instructed to respond with a "NO" button press to the distractors, but to otherwise completely disregard them, such that a red "A" cue followed by a red "X" probe, no matter what white distractor letters were in between, called for a "YES" response, and all other cue-probe pairs called for a "NO" response.

MMI and Gender, SAT Scores, Need for Cognition, Creativity, Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness. To examine the relationship of media multitasking and the above traits and measures, we conducted a final online questionnaire. Here, a new group of 110 participants filled out the MMI questionnaire as well as their SAT scores, gender, the Need for Cognition index questionnaire, the Big Five Trait Taxonomy (including measures of extraversion, agreeableness, conscientiousness, neuroticism, and openness), and a creativity task derived from the Torrance Tests of Creative Thinking (TTCT). The data from participants with an MMI one standard deviation or more above and below the mean (16 HMMs and 17 LMMs) were compared. All creativity task responses were coded by a single coder blind to the participants' MMI scores; to verify the reliability of the coding, a second coder coded a subset consisting of the responses of 10 participants. Correlations of scores from the two coders were high: $r(100) = 0.97, P < 0.001$ for scores of fluency, $r(100) = 0.93, P < 0.001$ for scores of uniqueness of ideas, and $r(100) = 0.96, P < 0.001$ for scores of flexibility.

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