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Research article

Active vs passive media multitasking and memory for lecture materials

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A R T I C L E I N F O

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A B S T R A C T

Access to digital technology in the 21st century has led to the emergence of media multitasking (MMT), which involves attempting to engage with multiple streams of media at the same time. This behaviour, which is frequently considered to be a form of inattention, has become increasingly prevalent in educational settings, such as undergraduate lectures. The aim of the present study was to examine *volitional* media-multitasking (MMT) during an asynchronous online lecture by giving participants the opportunity to engage with a secondary, non-required media stream (i.e., the game of snake). Participants (n = 222) were randomly assigned to either an Active condition, in which they could *play* the snake game using the arrow keys; or a Passive condition, in which they could watch the snake game, but could *not* play it. In both conditions, participants could toggle the snake game on and off, using a keypress. MMT was indexed behaviourally by measuring the percentage of time participants had the secondary stream toggled on (i.e., snake time percentage), a method pioneered by Ralph et al. (2020), and subjectively by asking participants to what extent they engaged with other media while the lecture was playing. Following the lecture, participants completed a multiple-choice quiz and self-reported their level of MMT. Our behavioural measure (i.e., snake time percentage) indicated that participants spent significantly more time MMT in the Active condition than the Passive condition. However, there were no significant differences in self-reported MMT or quiz performance across conditions. Furthermore, correlations between both measures of MMT and quiz performance were non-significant. Thus, the present study found no performance decrement as a result of, or in association with, increased volitional MMT.

1. Active vs. Passive media multitasking and memory for lecture materials

As many undergraduate lecturers can readily attest, students sometimes engage in learning unrelated tasks on their laptops or

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cellphones even as they are sitting in a lecture and supposed to be attending to the lecture material [1–6]. By strolling down the aisles of the lecture hall, one can witness students answering emails, watching YouTube, online shopping, or playing video games. These behaviors are referred to as media multitasking (MMT), as they involve the attempted consumption of multiple streams of media—the lecture and the unrelated computer-based task(s)—at the same time. What is particularly noteworthy about these examples of MMT, is that they are not required or imposed by the assigned primary task (e.g., learning in class), but rather are engaged in voluntarily, of the person's own accord. Recently this form of MMT has been named 'volitional MMT' [7]. Another notable feature of the above examples is that students' MMT can sometimes involve passive engagement (e.g., watching soccer) and other times active engagement (e.g., playing a videogame) with the secondary medium. Inspired by the foregoing examples, here we examine the prevalence and impact of active vs. passive volitional MMT on learning from undergraduate lecture videos.

Experimental studies of MMT and education have consistently indicated that media multitasking is associated with poorer memory performance [8–16]. However, critically, much of the experimental research on MMT has focused on *required* MMT, rather than the type of volitional multitasking that typically occurs in classrooms and lecture halls or while viewing online lectures. For example, Waite et al. [16] found that students who were assigned to a texting condition during a classroom presentation performed significantly worse on a knowledge test of factual information, and tended to take lower quality notes than those assigned to a non-texting condition. Unsurprisingly, those in the texting condition performed more poorly on items that were presented while they were texting, compared to the rest of the items. Similarly, Downs et al. [11] required participants to respond to questions on Facebook (delivered at 2-min intervals) and found they performed more poorly on a quiz than those asked to take notes or to simply watch the lecture. Further, it seems that required MMT has a negative impact on learning across many different contexts. For instance, Blaisman et al. [8], examined different distractors that students might experience during an online lecture (e.g., folding laundry, watching videos, playing a videogame, etc.), reporting that students performed significantly worse compared to a baseline lecture regardless of the type of distraction. Thus, the main finding from these studies is that required MMT leads to poorer learning and retention of lecture content.

Consistent with the foregoing experimental findings, numerous correlational and observational studies have found a negative relation between MMT and educational performance [1, 5, 6, 17–25; see 25 for a review]. Several studies have surveyed college students and found that MMT during class predicted lower GPA [3,17,19,26]. One study collected reports of MMT during lectures throughout the term using thought probes and found that more MMT was associated with poorer performance on end of lecture quizzes as well as term tests [6]. In a laboratory setting, Brooks [18] assessed participants' MMT during a 15-min video lecture using self-reports and behavioural indices (i.e., clicking data) and found a negative relation between the amount of MMT and their memory for the video lecture. One weakness of these studies, however, is that they do not account for individual differences that may be present among those who choose to engage in differing amounts of media multitasking while attending a lecture. For example, it is possible that those who media multitask more during lectures also engage in more MMT while studying, or study inefficiently [17,24,26]. There could also be differences in more general cognitive traits, such as in sustained attention abilities [27,28] or general motivation levels.

Some experimental studies have examined MMT in a way that might be best described as semi-volitional—where students are still assigned to conditions and required to engage in some form of multitasking, but have some level of control over their behaviour. An example would be giving participants the freedom to choose *when* they respond[1] to a text message [29–31] or complete their required tasks [14,15]. Another example would be intervention studies that restrict the use of laptops and other technology during some lectures or conditions, but allow for volitional behaviour in the naturalistic/control condition (i.e., in the conditions that allow normal technology use [32–34]). Some of these studies report results that are consistent with the foregoing literature, finding that MMT negatively impacts performance [14,15,30] or that restricting technology use improves performance [32,33]. One interesting study was conducted by Bowman et al. who required students to respond to instant messages (IMs) while reading a passage [29]. Critically, students could take as long as they needed to respond to IMs and read the passage. As such, while they took longer to complete the reading than control participants who were not messaging, they did not show any performance decrement on a reading comprehension test. Similarly, Rosen et al. [31] combined researcher-sent and personal text messages (i.e., extraneous messages participants received on their personal phones) and examined the total number of messages students received over the course of a 30-min lecture. They found that those who sent and received more texts performed worse on a memory test for lecture material. Critically, students were able to *choose* when to read and respond to the texts they received and it was observed that the longer the delay between receiving and responding to a text, the better their performance was, though the authors did not test this effect formally [31]. In sum, while some studies have found negative effects of MMT in volitional or semi-volitional circumstances, or have found a benefit to the removal of technology from lectures, other studies suggest that the negative effects of MMT may not be present when MMT is voluntary.

These results bring to mind an interesting possibility; namely, that students engaging in MMT during a lecture may wait until a more opportune moment in the lecture, thus counteracting the potential negative impact on learning from the unrelated media engagement. That is, situations in which students are able to MMT volitionally (or semi-volitionally) may provide them with the flexibility to multitask *strategically* [7] a behaviour that experiments requiring MMT are less able to assess. Strategic MMT could allow students to alleviate boredom or increase arousal in targeted moments when the lecture content is familiar, thus mitigating the negative impact on task performance, while addressing other needs (e.g., reducing boredom) [7]. Put differently, students may engage

[1] Notably, the various studies on MMT are not all consistent in reporting whether the timing of students' MMT was monitored, whether their response timing was enforced or open, or whether students were *aware* of whether they had unlimited time. While many studies specify these details, others do not—likely because the degree of volition over MMT was not the specific research question. Still, this is just one example of a variable that can be changed by the instructions or the participant's awareness of what level of control they have, and serves to illustrate why examining volitional MMT specifically is an important consideration.

in MMT when they can 'get away with it' and stop MMT in moments when the instructor is presenting new information (e.g., where MMT is more likely to have a negative impact on their learning[2]).

Recently, Ralph et al. [7; Experiment 2] introduced a useful paradigm for systematically studying volitional MMT experimentally. Participants were presented with the opportunity to watch a secondary media stream (i.e., a video on illusions) while completing the n-back task. The video was presented above the stimuli for the n-back on the same screen. Critically, the secondary video was optional, and participants had the ability to toggle the video on and off "at their leisure" while completing the task. Further, the participants were made aware of this via task instructions, where they were informed there was no test on the content of the video—that it was simply for them to watch, if they wished, while completing the task. Thus, the degree of multitasking participants chose to engage in could be measured by calculating the total number of n-back trials participants had the video toggled on.

Using this paradigm, the authors were able to assess how participants' voluntary MMT behaviour was impacted by factors such as task difficulty, which they assessed by randomly assigning participants to either a high demand or low demand n-back task (i.e., 2-back or 0-back). Participants in the high cognitive demand condition (i.e., the 2-back task), engaged in significantly less MMT than those in the low demand (i.e., the 0-back task) condition, as evidenced by having fewer n-back trials with the video toggled on. This result is consistent with the idea that participants MMT strategically [35] by engaging in less MMT when doing so has a negative impact on performance (i.e., when task demands are high). Interestingly, exploratory analyses from the study also suggested that increased MMT was linked to greater reductions in boredom, as boredom ratings were found to be lower when participants had the opportunity to media multitask. The authors point out this could indicate that participants use MMT to address emotions concerns, such as alleviating boredom, even if it means incurring performance costs.

The foregoing raises the possibility that MMT and its consequences might vary as a function of various situational factors. Of particular interest to the present study is the degree to which participants can *actively* engage with the secondary media source. Intuition suggests that secondary media affording active engagement, such as playing a video game, might increase the likelihood of MMT compared to media offering only a passive engagement opportunity (such as watching a video). The possibility of active engagement with a distracting video game, for instance, should have entertainment value, increase one's sense of agency (i.e., over the distracting medium), provide the positive reward associated with successful engagement, and increase investment in the outcome of the game. In contrast, passive viewing of a distracting video, or someone else playing a video game, has only entertainment value.

While many studies have explored MMT in the educational context, few have specifically examined voluntary, non-required multitasking whereby the frequency, timing, and duration of multitasking are controlled by the participant, as is typically the case in naturalistic learning contexts. The present study adapted the volitional MMT methodology developed by Ralph et al. [7] to an educational setting, by giving participants the option to simultaneously engage with a secondary stream of the video game called 'snake' at the same time as viewing the lecture video (see Fig. 1). While viewing the lecture, participants could toggle the secondary stream (i.e., snake) on or off by pressing the 't' key. MMT was measured in two ways,[3] which included: 1) indexing the percentage of time participants viewed the lecture with the snake game toggled on; and 2) collecting participant's self-reports about the amount of time they spent media multitasking (including with their other devices, such as a smartphone) while viewing the video lecture at the end of the experiment (see Fig. 2).

This general methodology allowed us to explore several research objectives. First, to explore whether the time participants spent media multi-tasking would be influenced by the extent to which participants could interact with the secondary stream (i.e., snake) (Research Question 1 (RQ1)). Thus, the study included two conditions, one in which participants could actively play the snake game using the arrow keys while viewing the lecture (the Active condition), and one in which participants were only able to passively watch a prerecorded version of the game being played by someone else (the Passive condition). One possibility is that playing the game allows participants to invest in the progress of the game in a way that simply watching the game (with the ability to turn it on and off) does not. As such, this could make MMT more enticing in the Active condition than the Passive condition, leading participants to MMT more in the Active condition than the Passive condition. However, an alternative possibility is that those in the Passive condition might believe their engagement with the snake game is of a sufficiently low intensity to not interfere with their ability to attend to the lecture—which could lead to them leaving the snake game on for longer than those in the Active condition, resulting in more MMT in the Passive condition.

A second aim was to assess whether the opportunity to MMT actively versus passively differentially impacts memory for lecture content (RQ2). To this end, after viewing the lecture video in the Active and the Passive conditions, participants were required to complete a memory test that evaluated their retention of the lecture content. We expected a tight link between the degree of MMT and lecture retention such that any differences in engagement groups (Active vs. Passive) would be reflected in group differences in memory performance. Based on the research described above, our expectation was that the group with higher level of MMT (should a difference emerge) would show poorer memory performance.

A final aim was to explore the general relations between the degree of MMT during lecture viewing and memory for lecture material (RQ3), which was addressed by examining the correlations between indices of MMT (i.e., snake time percentage & subjective reports) and performance on the memory test for lecture content. Again, the expectation was that increased levels of MMT on each measure would be associated with a decrease in performance on the memory test.

[2] Though individual differences in meta-awareness might mean that some students are better at choosing strategic moments to engage in MMT than others, such that those who are less meta-aware more frequently MMT when it will harm their learning.

[3] Blur/focus data to track any multitasking using other browser windows was also collected, a coding error prevented proper tracking of this behaviour in the active condition.

Fig. 1. *A screenshot of the practice phase of the experiment from the Active condition.*
Note. The snake game/video is presented at the bottom right. The snake grows in length by one square for each target (i.e., red square) that it touches. The instructions for toggling the snake game/video on and off were constantly present at the bottom of the screen.

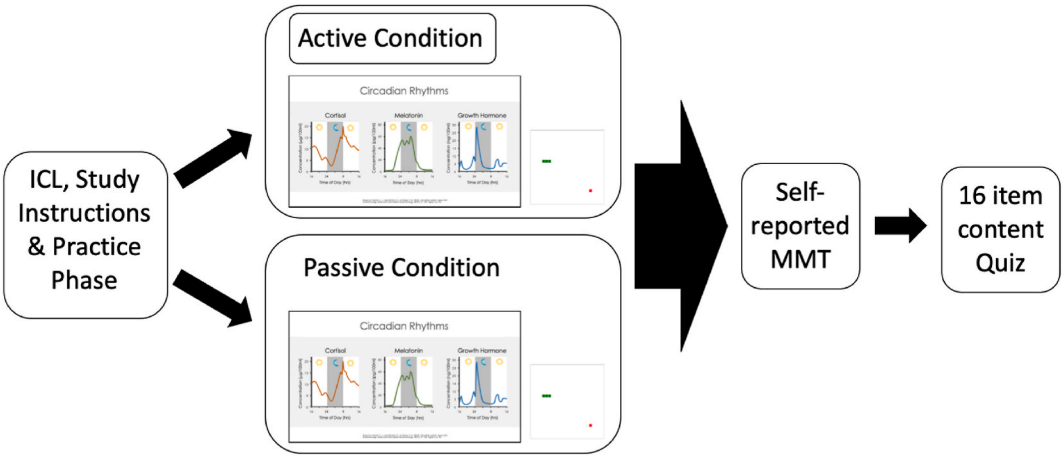

Fig. 2. Experimental Procedure.
Note. This figure demonstrates the experimental procedure used in the study.

The rest of the manuscript is organized as follows; first is the Method, including descriptions of the participants, materials, and procedures, followed by the Results, General Discussion and Conclusion. Further, all data and the R code used to conduct the analysis, as well as the study materials (e.g., lecture video, lecture transcript, lecture slides, study instructions, and quiz questions) have been made publicly available at the Open Science Foundation (OSF) and can be accessed at: https://osf.io/eb38k/

2. Method

This section describes the methodology and materials, including the participants, media, measures of MMT, memory test and procedure.

2.1. Ethics and consent

This study was reviewed and approved by the McMaster Research Ethics Board on January 27th, 2022 with the approval number: 5685. All participants provided written informed consent to participate in the study.

2.2. Participants

Two hundred and fifty-one undergraduate students at McMaster University (Ontario, Canada) participated in the study in exchange for partial course credit.[4] Data collection took place between March 10th and April 15th'2023.[5] Twenty-four participants (14 in the active condition vs 10 in the passive condition) were removed for performing equal to or below chance on the quiz. The final sample included 227 participants (179 women, 44 men, 2 non-binary, and 2 prefer not to answer), with 129 in the Active condition and 98 in the Passive condition.

2.3. Media

2.3.1. Lecture video

The lecture video was 22-min in length and focused on the topic of circadian rhythms. It was designed for a second-year undergraduate course on physiological psychology and included PowerPoint slides with basic animations and a voiceover from the instructor. The slides included diagrams of physiological systems and processes as well as sparse text (i.e., labels and descriptive statements).

2.3.2. The snake game

While the lecture video was playing, participants were given the opportunity to engage in either Active or Passive media multitasking a secondary media stream that featured the snake game. The game included a small red square (i.e., the target), and a green rectangle made of three consecutive squares (i.e., the "snake") that would increase in length by one square with each target caught (i.e., by touching the red square with the front, or 'head', of the snake; see Fig. 1). Engagement with the game differed between the Active and Passive conditions. In the Active condition, participants could play the game by using the arrow keys to control the snake, while those in the Passive condition watched a recording of snake being played by another player.

2.4. Measures

2.4.1. MMT

Media multi-tasking during video watching was assessed in two ways. The first way involved the percentage of time that the snake game was in view. While the lecture video was playing, participants were able to press the "t" key to toggle the snake game on (i.e., to put it in full view, to the right of the lecture; see Fig. 1) or to toggle the game off (to remove it from view). Toggling instructions were on-screen at all times, so participants could not forget the instructions. The software was designed to record events during every second of the lecture. One of these events was whether the snake game was on (in view) or off (out of view). Thus, for each participant, a percentage of media multitasking was calculated by summing the total number of seconds the snake game was toggled on and dividing by the total number of seconds the lecture video was playing (i.e., 1309 s/trials). For participants in the active condition, their gameplay data was also recorded. The raw data for each participant is available on OSF, as is an example of the lecture (https://osf.io/eb38k/).

The second measure of MMT was subjective in nature. At the end of the experiment (i.e., following the conclusions of the quiz), participants to self-reported on their level of media multitasking, during the experiment. Specifically, participants were asked to rate "How frequently have you used a digital device (e.g., phone, laptop, tablet, TV) for something unrelated to the lecture?" on a slider (0 – Almost never, 100 – Almost always).

2.4.2. Memory test

Memory for lecture content was assessed using a 16-item multiple choice quiz. Each question had four answer options (see Appendix).[6] The memory test included questions about content sampled roughly evenly in time across the video lecture. The full quiz can be found in the Appendix. The questions were presented on the study webpage following the lecture.

2.5. Procedure

After obtaining informed consent, participants were randomly assigned to either the Active or Passive version of the experiment. Following a brief practice session, during which participants learned how to toggle snake on or off while viewing a different video (the beginning of Andy Puddicombe's TEDTalk "All it takes is 10 mindful minutes"), participants were presented with a lecture on the topic of circadian rhythms. The instructions for how to toggle the snake game on and off were constantly present at the bottom of the screen, during the practice session, and during the lecture. Aside from whether the snake game was Active (i.e., participants could move the snake using the arrow keys) or Passive (i.e., participants could only watch the snake as it moved), the conditions were identical. The lecture was delivered in a plain straightforward fashion (a transcript, clip, etc. is available on OSF: https://osf.io/eb38k/). Following the lecture, participants were presented with a multiple-choice test or the lecture content.

[4] The raw data also includes three pilot participants who were removed at this stage.

[5] Six pilot participants collected February 17th/18th were not included as the initial data format was not suitable for analyses. These data are also included on OSF in a separate folder.

[6] One question mistakenly included a fifth option. See Appendix.

3. Results

The results for the present study are presented in three sections corresponding to the three main objectives outlined above. First, we assess whether participants differed between Active and Passive conditions in terms of their MMT behaviour as indexed by the percentage of time participants played snake and by their subjective reports of MMT. Second, we assessed the impact of Active and Passive MMT conditions on memory test performance. Finally, we investigated the relations between our measures of multitasking and memory test performance. All data and R code used to conduct the analysis, as well as the study materials (e.g., lecture video, lecture transcript, lecture slides, study instructions, and quiz questions) have been made publicly available at the Open Science Foundation (OSF) and can be accessed at: https://osf.io/eb38k/

3.1. Media multitasking behaviour

To assess whether the opportunity to engage in Active vs. Passive MMT impacted participant MMT behaviour, we began by examining the percentage of time in the lecture participants spent with snake toggled on (i.e., snake time). As can be seen in Fig. 3A, the data for snake time percentage was not normally distributed in either condition.

As such, we took a non-parametric approach and conducted bootstrapping with 10000 resamples because the bootstrapping procedure does not make any assumptions about the distributions of the data. Specifically, we constructed a simple regression model using lm() [36] to predict snake time percentage using condition (Active vs. Passive), and conducted bootstrapping using the reg.boot. table function from apaTables [37]. As can be seen in Table 1, a significant b-weight indicated an approximately 12% (95% CI 2.94, 20.49) difference between the groups, such that those in the Active condition (M = 63.15, SD = 30.03) spent significantly greater percentage of the lecture with the snake game toggled on than those in the Passive condition (M = 51.42, SD = 34.72). Using Cohen's guidelines [38], the semi-partial correlation squared[7] of 0.03 [95% CI 0.00, 0.10] indicated that this was a small effect. In addition, Cohen's *d* effect size with bootstrapped 95% confidence intervals was calculated using the rstatix package[8] [39]. These results also indicated an effect of condition that ranged from small to moderate Cohen's d = 0.36 [95% CI 0.08, 0.63].

Further, participants self-reported their multitasking at the end of the experiment (i.e., after completing the quiz). While the distributions for self-reported MMT were largely normal (see Fig. 3B), there was evidence of rightward skew. Diagnostic plots of the model also suggested a divergence from normality. So, once again, the apa.reg.boot.table function was used to conduct a bootstrapping procedure with 10000 samples. There was no significant effect of condition on self-reported multitasking, as indicated by a non-significant b-weight [95% CI -6.55, 8.59] and non-significant semi-partial correlation estimated as 0.00 [95% CI 0.00, 0.02] meaning the model did not account for any significant variation in self-reported MMT (see Table 2), and that there was no significant difference between those in the Active condition (M = 64.24, SD = 28.20) and the Passive condition (M = 63.26, SD = 29.56). For consistency, the rstatix package was again used to generate bootstrapped confidence intervals of effect size[9] Cohen's d = 0.03 [95% CI -0.24, 0.29], which is interpreted as a negligible effect.

3.1.1. Memory for lecture content

To examine whether the opportunity to engage in either Active or Passive MMT (and the difference in MMT behaviour these conditions elicited) impacted participants' memory for lecture content, we examined the effect of condition on participants' quiz scores. The Cronbach's alpha for the quiz was 0.72, indicating acceptable/good reliability for the test. The data for quiz scores was relatively normal (see Fig. 4), so a Welch's *t*-test was applied using the t.test function [36]. The results indicated that there was no significant difference between the Active (M = 59.11, SD = 16.79) and Passive (M = 60.59, SD = 17.30) conditions t(199) = -0.65, p = 0.52, Cohen's d = -0.09 [95% CI -0.35, 0.17]. Thus, there was no evidence for a difference in memory performance between the groups, despite the significant difference in terms of media multitasking behaviour (as assessed by snake time percentage).

3.2. Correlations between memory and MMT measures

Finally, we explored the relations between the MMT measures and memory performance using conducting correlational analyses within each group[10]. Given the non-parametric nature of the snake time variable, Spearman's *rho* was used to assess the associations using a ranking-based measure. The results of these correlations are presented in Table 3, which shows the correlations for the Active condition above the diagonal and those for the Passive condition below the diagonal. The relation between self-reported MMT and performance was nominally negative in both conditions. While this correlation was initially significant in the Active condition, this was no longer the case after applying a Bonferroni correction for multiple comparisons. No other correlations were significant.

4. General Discussion

The present study examined active and passive volitional MMT in an educational context, using a novel paradigm, based on the

[7] This is equivalent to the R^2 with only one predictor in the regression.
[8] 95% CIs of effect size generated via bootstrapping (n = 10000) with the bca method.
[9] 95% CIs of effect size generated via bootstrapping (n = 10000) with the bca method.
[10] As the groups were significantly different in snake time percentage, it was inappropriate to collapse them.

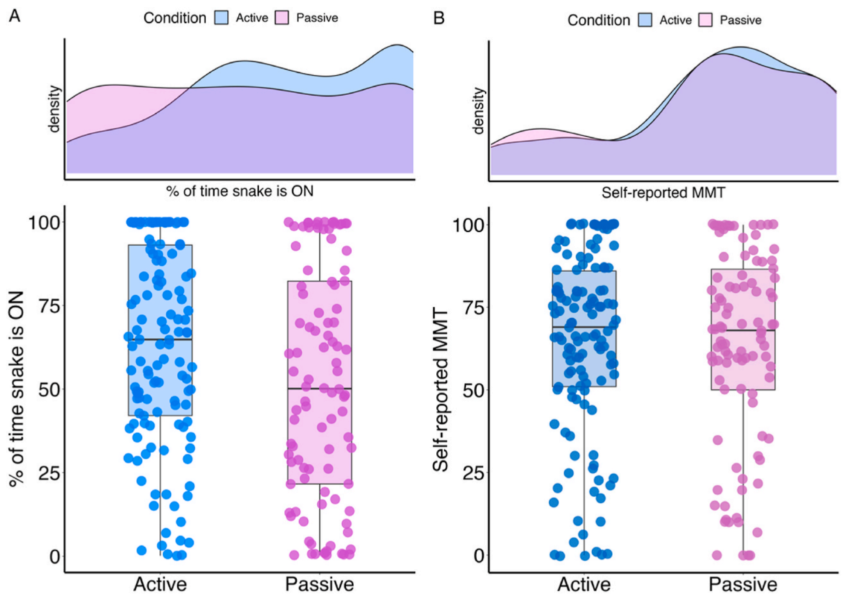

Fig. 3. The effect of condition on behavioural and self-reported media multitasking.
Note. Fig. 3A depicts the effect of condition on snake time percentage. Panel B depicts the effect on self-reported MMT. Each panel shows the distribution using a density plot (above) and a boxplot with jittered points (below).

Table 1
Bootstrapped regression results using snake time percentage as the criterion.

Predictor	*b*	*b* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	Fit
(Intercept)	51.42**	[44.53, 58.30]			
Condition Active	11.72**	[2.94, 20.49]	0.03	[0.00, 0.10]	
					$R^2 = 0.032$** 95% CI [0.00, 0.10]

Note. A significant *b*-weight indicates the semi-partial correlation is also significant. *b* represents unstandardized regression weights. sr^2 represents the semi-partial correlation squared. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. * indicates $p < 0.05$. **indicates $p < .01$.

Table 2
Bootstrapped regression results using self-reported MMT as the criterion.

Predictor	*b*	*b* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	Fit
(Intercept)	63.26**	[57.41, 68.93]			
Condition Active	0.99	[-6.55, 8.59]	0.00	[0.00, 0.02]	
					$R^2 = 0.000$ 95% CI [0.00, 0.02]

Note. A significant *b*-weight indicates the semi-partial correlation is also significant. *b* represents unstandardized regression weights. sr^2 represents the semi-partial correlation squared. *LL* and *UL* indicate the lower and upper limits of a confidence interval, respectively. * indicates $p < 0.05$. **indicates $p < .01$.

work of Ralph et al. [7]. While viewing a lecture video, participants were simultaneously able to either actively play a game of snake, or passively view a recording of the game being played by someone else. The results showed that compared to the Passive condition, participants in the Active condition spent more time with the snake game on screen while the lecture was playing, suggesting that the opportunity to *actively* engage with secondary media leads to significantly more MMT than the opportunity for passive engagement with the media. Yet, there was no difference in participants' subjective reports of MMT between the Active and Passive conditions, indicating that participants' subjective reports did not match these behavioural differences between groups. Furthermore, there was no evidence of a difference between the Active and Passive conditions in terms of quiz performance, nor were there any significant correlations between MMT and memory for the lecture content.

Why is it that despite the difference in the amount of volitional MMT across Active and Passive conditions, there did not appear to

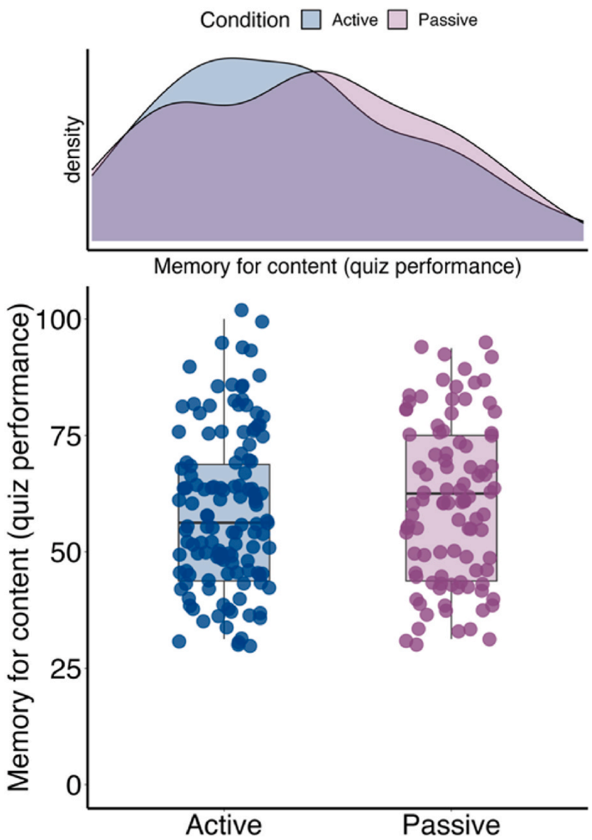

Fig. 4. The effect of condition on memory for lecture content.

Table 3
Quiz performance and MMT.

	1	2	3
1 Quiz performance	–	-0.11	-0.16
2 MMT (Snake %)	-0.14	–	0.02
3.Self-reported MMT	-0.19	0.07	-

Note. The Passive condition is presented below the diagonal and the Active condition is presented above the diagonal. No significant relations were found.

be any negative impact of increased MMT on memory performance? This is an interesting question, particularly when considered in the context of prior work which examined non-volitional MMT. Several studies in this vein [8–16] have found performance decrements when participants are *required* to engage in MMT while learning. Given these findings, one possible explanation of our findings is that when multitasking is *volitional* (as is the case in many real-world scenarios), individuals may be able to multitask strategically, thus limiting the performance decrements they experience. That is, students might be aware when lecture content is familiar or unimportant (i.e., unlikely to be tested) and selectively engage in MMT during those periods while remaining attentive to the lecture during the rest of the time. This conclusion is consistent with the work of Ralph et al. [7], who found that participants strategically modulate their levels of media multitasking in response to task difficulty. Future studies examining this possibility further could directly ask students about the various strategies they implement while engaging in MMT during learning sessions.

Of course, there remains the alternative possibility that volitional multitasking does impact learning, but that the measure used to assess participant memory in the present study was not sensitive enough to capture this impact. That is, the assessment of memory—a multiple choice quiz—relied largely on recognition memory. While recognition memory might be immune to volitional MMT, higher-order memory processes, such as generative or elaborative processing that led to richer representation, may be impaired by volitional MMT. For example, Hembrooke & Gay [33], found evidence that students who were required to close their laptops during a lecture performed better than those who used their laptops normally, but this effect was only present on recall, not recognition, questions [see also 32]. Still, it should be noted that prior research in which participants were *required* to MMT and learning was assessed with multiple choice quizzes showed performance decrements [9–16], suggesting that it might be the volitional nature of the MMT rather than the type of memory test that best explains the lack of a relation between MMT and learning in the present study. Perhaps future studies could address these alternative explanations by directly manipulating whether MMT is volitional or required, while also manipulating whether the memory test depends on recognition or more elaborative processing. Furthermore, another possibility is that the impact of MMT may differ in longer lectures, or different groups of learners, which cannot be assessed by the present data. For example, elementary students may not be as adept at identifying moments for strategic MMT, leading them to miss critical information. While assessing this possibility was not a goal of the present study, it highlights another interesting direction for future research.

One strength of the present study is that we measured MMT using both a behavioural metric (i.e., snake time percentage) and subjective reports. Interestingly, there were no significant correlations between these MMT measures, suggesting that they captured different aspects of MMT. Using multiple measures is useful because each measure has its specific strengths and weaknesses. For instance, the time with the snake game visible has the benefit that it allows for continuous behavioural monitoring of media multitasking wherein participants are assumed to be multitasking whenever the snake game is toggled on. However, potential limitations are that 1) snake time does not necessarily index participants internal attention or engagement, since they could attend to the lecture even when snake is toggled on, and 2) it does not capture other kinds of MMT behaviour that are known to occur, especially in online contexts [40,41]. For example, a possible limitation is that the effect of MMT could be underestimated, because the snake game might be less enticing than the typical MMT that students engage in during online lectures (e.g., using instagram, tiktok, or online shopping). On the other hand, subjective reports have the advantage that they can capture all forms of media multitasking participant may have engaged in, whether on the computer, or on other devices. However, these reports are disadvantaged by participants' various biases and by individual differences in memory limitations and self-awareness. Future research could focus on clarifying the specific strengths and weakness of these measures, or investigate alternative types of multi-tasking using a similar volitional paradigm (perhaps allowing students to toggle a social media stream on and off). Such investigations might also shed light on our finding that the behavioural metric revealed significant differences in MMT between Active and Passive conditions, while the self-report assessments did not.

5. Conclusions

In conclusion, the present study provides useful insights into how the type of engagement (Active vs. Passive) afforded by learning-unrelated media influences volitional MMT in an educational context. Our findings suggest that learning-unrelated media that afford active interaction are more likely to lead to MMT than media that only allow passive engagement. Strikingly, though, the amount of MMT did not impact learning as indexed by recognition of lecture content. This raises the intriguing possibility that when students are not required to MMT, but are allowed to engage in MMT voluntarily, they do so strategically, restricting the MMT to moments when missing lecture material is unlikely to be detrimental to test performance. We believe that the current study highlights the utility of the volitional MMT paradigm pioneered by Ralph et al. [7] and provides a useful jumping off point for future research on volitional MMT.

Ethics and consent

This study was reviewed and approved by the McMaster Research Ethics Board on January 27th, 2022 with the approval number: 5685. All participants provided written informed consent to participate in the study. The authors have no competing/financial interests to declare.

Data availability statement

All data and R code used to conduct the analysis, as well as the study materials (e.g., lecture video, lecture transcript, lecture slides, study instructions, and quiz questions) have been made publicly available at the Open Science Foundation (OSF) and can be accessed at: (https://osf.io/eb38k/).

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CRediT authorship contribution statement

Jeremy Marty-Dugas: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **J. McHardy Robert:** Writing – review & editing, Software, Project administration, Methodology, Investigation. **Brandon Ralph:** Writing – review & editing. **Joe Kim:** Writing – review & editing, Funding acquisition. **Daniel Smilek:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Quiz on Lecture Content

1. Circadian rhythms occur over a period of time that is ___ long

a) 12 h
b) 18 h
c) 24 h
d) 36 h
e) 48 h

2. Which of the following hormones is NOT impacted by the circadian rhythm?

a) Cortisol
b) Growth Hormone
c) Adrenaline
d) Melatonin

3. Which best describes cortisol levels when sleeping?

a) Low just after falling asleep, spike before wake
b) Low just after falling asleep, stay low throughout the night
c) Spike just after falling asleep, decrease before wake
d) Spike just after falling asleep, stay high throughout the night

4. Which of the following hormones is characterized by a sharp peak right when falling asleep?

a) Cortisol
b) Melatonin
c) Growth Hormone
d) Serotonin

5. Researchers found that the average ratings for when students felt "at their best" had peaks in the morning and the afternoon. What was the main issue with this finding?

a) It doesn't take into account differences between "morning" people and "evening people"
b) The researchers had a small sample size
c) Students have different periods of "feeling their best" than the average person
d) It doesn't take into account people who "feel their best" at extreme times of day

6. Late chronotypes perform more poorly than early chronotypes on what type of tasks performed in the morning?

a) Psychomotor Vigilance
b) Executive Function
c) Physical Strength
d) All of the above

7. Which of the following best describes the relationship between chronotypes and age over the lifespan?

a) People start as early chronotypes in childhood, shift to late chronotypes in teens/early twenties, and then continue to be late chronotypes
b) People start as early chronotypes in childhood, shift to late chronotypes in teens/early twenties, and then slowly become early chronotypes
c) Chronotypes are stable and do not change with age
d) Chronotypes fluctuate constantly based on the individual's sleep behaviours

8. Which of the following is NOT a benefit to having later high school start times?

a) Lower rates of absence
b) Increased academic performance
c) Increased mood
d) Start times are better aligned to teens chronotypes

9. What is the main exogenous cue for biological rhythms?

a) Temperature
b) Melatonin
c) Sunlight
d) Cortisol

10. How many days does it take for sleep wake periods to completely reverse when a person has a free running circadian rhythm?

a) 5 days
b) 8 days
c) 10 days
d) 15 days

11. Zeitgebers are best defined as ____

a) External factors that influence circadian rhythm
b) Internal factors that influence circadian rhythm
c) Reset cues to help keep circadian rhythm on track
d) Factors that move circadian rhythm off track

12. What is the most important zeitgeber for those who are completely blind?

a) Light
b) Melatonin
c) Blind people frequently experience free running circadian rhythms
d) Blind people often have to deal with insomnia and daytime sleepiness

13. Circadian rhythms are particularly sensitive to what area of light on the visible spectrum?

a) Blue: 445–485 nm
b) Green: 400–565 nm
c) Yellow: 565–590 nm
d) Red: 625–740 nm

14. Complete the following sentence: "Blue light from light emitting diodes … "

a) only has an impact after 5 h of exposure.
b) leads to suppression of melatonin production in older adults.
c) could be phototoxic to the eye and lead to retinal damage.
d) only interferes with free-running circadian rhythms.

15. Which of the following is NOT a symptom of jet lag

a) Difficulty falling asleep at night
b) Sleepiness during the day
c) Irritability
d) Disrupted eating patterns

16. Assuming you live in the central timezone, "phase advance" is associated most closely with

a) Toronto bedtimes
b) Eastward travel
c) Vancouver bedtimes

d) Westward travel

References

[1] C.B. Fried, In-class laptop use and its effects on student learning, Comput. Educ. 50 (3) (2008) 906–914.
[2] W.C. Jacobsen, R. Forste, The wired generation: academic and social outcomes of electronic media use among university students, Cyberpsychol., Behav. Soc. Netw. 14 (5) (2011) 275–280.
[3] R. Junco, In-class multitasking and academic performance, Comput. Hum. Behav. 28 (6) (2012) 2236–2243.
[4] E.D. Ragan, S.R. Jennings, J.D. Massey, P.E. Doolittle, Unregulated use of laptops over time in large lecture classes, Comput. Educ. 78 (2014) 78–86.
[5] J.M. Kraushaar, D.C. Novak, Examining the affects of student multitasking with laptops during the lecture, J. Inf. Syst. Educ. 21 (2) (2010) 241–252.
[6] J.D. Wammes, B.C. Ralph, C. Mills, N. Bosch, T.L. Duncan, D. Smilek, Disengagement during lectures: media multitasking and mind wandering in university classrooms, Comput. Educ. 132 (2019) 76–89.
[7] B.C. Ralph, P. Seli, K.E. Wilson, D. Smilek, Volitional media multitasking: awareness of performance costs and modulation of media multitasking as a function of task demand, Psychol. Res. 84 (2020) 404–423.
[8] R.N. Blaisman, D. Larabee, D. Fabry, Distracted students: a comparison of multiple types of distractions on learning in online lectures, Scholarsh. Teach. Learn. Psychol. 4 (4) (2018) 222.
[9] M.A. Conard, R.F. Marsh, Interest level improves learning but does not moderate the effects of interruptions: an experiment using simultaneous multitasking, Learn. Indiv Differ 30 (2014) 112–117.
[10] S. Dietz, C. Henrich, Texting as a distraction to learning in college students, Comput. Hum. Behav. 36 (2014) 163–167.
[11] E. Downs, A. Tran, R. McMenemy, N. Abegaze, Exam performance and attitudes toward multitasking in six, multimedia–multitasking classroom environments, Comput. Educ. 86 (2015) 250–259.
[12] A.C. Gingerich, T.T. Lineweaver, OMG! Texting in class= u fail:(empirical evidence that text messaging during class disrupts comprehension, Teach. Psychol. 41 (1) (2014) 44–51.
[13] J.H. Kuznekoff, S. Titsworth, The impact of mobile phone usage on student learning, Commun. Educ. 62 (3) (2013) 233–252.
[14] E.F. Risko, D. Buchanan, S. Medimorec, A. Kingstone, Everyday attention: mind wandering and computer use during lectures, Comput. Educ. 68 (2013) 275–283.
[15] F. Sana, T. Weston, N.J. Cepeda, Laptop multitasking hinders classroom learning for both users and nearby peers, Comput. Educ. 62 (2013) 24–31.
[16] B.M. Waite, R. Lindberg, B. Ernst, L.L. Bowman, L.E. Levine, Off-task multitasking, note-taking and lower-and higher-order classroom learning, Comput. Educ. 120 (2018) 98–111.
[17] S. Bellur, K.L. Nowak, K.S. Hull, Make it our time: in class multitaskers have lower academic performance, Comput. Hum. Behav. 53 (2015) 63–70.
[18] S. Brooks, Does personal social media usage affect efficiency and well-being? Comput. Hum. Behav. 46 (2015) 26–37.
[19] R. Junco, Student class standing, Facebook use, and academic performance, J. Appl. Dev. Psychol. 36 (2015) 18–29.
[20] W.W. Lau, Effects of social media usage and social media multitasking on the academic performance of university students, Comput. Hum. Behav. 68 (2017) 286–291.
[21] A. Lepp, J.E. Barkley, A.C. Karpinski, The relationship between cell phone use, academic performance, anxiety, and satisfaction with life in college students, Comput. Hum. Behav. 31 (2014) 343–350.
[22] M.C. Patterson, A naturalistic investigation of media multitasking while studying and the effects on exam performance, Teach. Psychol. 44 (1) (2017) 51–57.
[23] S.M. Ravizza, D.Z. Hambrick, K.M. Fenn, Non-academic internet use in the classroom is negatively related to classroom learning regardless of intellectual ability, Comput. Educ. 78 (2014) 109–114.
[24] H. Winskel, T.H. Kim, L. Kardash, I. Belic, Smartphone use and study behavior: a Korean and Australian comparison, Heliyon 5 (7) (2019) e02158.
[25] K.E. May, A.D. Elder, Efficient, helpful, or distracting? A literature review of media multitasking in relation to academic performance, Int. J. Educ. Technol. Higher Educ. 15 (1) (2018) 1–17.
[26] R. Junco, S.R. Cotten, A decade of distraction? How multitasking affects student outcomes, Multitasking Affect. Student Outcome. (2011). (Accessed 13 September 2011).
[27] B.C. Ralph, D.R. Thomson, J.A. Cheyne, D. Smilek, Media multitasking and failures of attention in everyday life, Psychol. Res. 78 (2014) 661–669.
[28] K.K. Loh, R. Kanai, Higher media multi-tasking activity is associated with smaller gray-matter density in the anterior cingulate cortex, PLoS One 9 (9) (2014) e106698.
[29] L.L. Bowman, L.E. Levine, B.M. Waite, M. Gendron, Can students really multitask? An experimental study of instant messaging while reading, Comput. Educ. 54 (4) (2010) 927–931.
[30] Y. Ellis, B. Daniels, A. Jauregui, The effect of multitasking on the grade performance of business students, Res. Higher Educ. J. 8 (1) (2010) 1–10.
[31] L.D. Rosen, A.F. Lim, L.M. Carrier, N.A. Cheever, An empirical examination of the educational impact of text message-induced task switching in the classroom: educational implications and strategies to enhance learning, Psicol. Educ. Rev. Psicól. Educ. 17 (2) (2011) 163–177.
[32] A.L. Glass, M. Kang, Dividing attention in the classroom reduces exam performance, Educ. Psychol. 39 (3) (2019) 395–408.
[33] H. Hembrooke, G. Gay, The laptop and the lecture: the effects of multitasking in learning environments, J. Comput. High Educ. 15 (2003) 46–64.
[34] J.S. Mendoza, B.C. Pody, S. Lee, M. Kim, I.M. McDonough, The effect of cellphones on attention and learning: The influences of time, distraction, and nomophobia, Comput. Hum. Behav. 86 (2018) 52–60.
[35] B.C. Ralph, D. Smilek, Individual differences in media multitasking and performance on the n-back, Atten. Percept. Psychophys. 79 (2017) 582–592.
[36] R Core Team, R: A language and environment for statistical computing, R Found. Stat. Comput. 78 (2023) 78–86. Vienna, Austria, https://www.R-project.org/. overtimeinlargelectureclasses. Computers & Education.
[37] D. Stanley, apaTables: create American Psychological Association (APA) style tables, R package version 2.0.8 (2021). https://CRAN.R-project.org/package=apaTables.
[38] J. Cohen, Statistical Power Analysis for the Behavioral Sciences, second ed., Erlbaum, Hillsdale, 1988.
[39] A. Kassambara, Rstatix: pipe-friendly framework for basic statistical tests, R package version 0.7.2 (2023). https://CRAN.R-project.org/package=rstatix.
[40] A.C. Drody, E.J. Pereira, D. Smilek, A desire for distraction: uncovering the rates of media multitasking during online research studies, Sci. Rep. 13 (1) (2023) 781.
[41] A. Lepp, J.E. Barkley, A.C. Karpinski, S. Singh, College students' multitasking behavior in online versus face-to-face courses, Sage Open 9 (1) (2019) 2158244018824505.