Divided Attention=Diminished Uptake?
Multitasking with Computing Devices at Presentations

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ABSTRACT

For colloquium style presentations where audience attention is voluntary, computing devices present an interesting conundrum. Audience members may benefit from simultaneously using a device to take notes or perform other tasks while still attempting to pay attention to the lecture, but the device may also distract its owner, other audience members, or the speaker. We report on two studies of the use of computing devices by people attending colloquium style presentations. We first conducted a survey exploring perceptions of speakers and attendees about the disruptiveness of laptop and smartphone usage during presentations. Then we explored and validated some of the findings in an observational study. We used video to study shifts of attention between devices and presentations, matching them to conceptual blind spots identified by short quizzes given to attendees. We find significant losses of recall associated with increased attention to devices and motivation for attending the presentation, and individual differences in recall of presented information and levels of concern about missing information.

Author Keywords

Attention, multitasking, presentation, laptops

ACM Classification Keywords

H5.m. Information Interfaces and Presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

The use of mobile computing devices such as laptops and smartphones by people attending lectures, meetings and presentations is a feature of our modern-day landscape [14]. The form factor and portability of these devices allow them to be brought into any setting, where they can enhance a presentation as an auxiliary source of information or for note taking. However, probably more often than not, the devices are used for unrelated tasks such as checking email, resulting in shifts of attention away from the presentation.

This diversion of attention may have important consequences. For face-to-face meetings and classroom lectures where attention is mandatory, the use of devices is viewed with caution [9, 13]. However, for colloquium style presentations where attendance and undivided attention is voluntary, usage of devices to multitask presents an interesting conundrum for everyone present. First, device usage is ambiguous –it may be to take notes or look up references, or it may be to perform unrelated activities. The nature of the use is not evident to onlookers. Second, attendees have no obligation to pay full attention to the presentation; a device provides an opportunity to divide attention between the presentation and other tasks. On the other hand, there may be a social cost for not paying attention, and the activity may negatively affect the speaker and other audience members. With increasing mobile device use and wireless access, such multitasking behavior is likely to be a reliable feature of presentations, meetings and lectures.

As a step toward an understanding that may contribute to more effective attention allocation for those who need to multitask while attending presentations, we investigated patterns of audience attention during colloquium-style presentations. In contrast to classroom style lectures, colloquium speakers are not responsible for ensuring the learning of the material. Attendees have varying motivations for attending and may consequently demonstrate corresponding levels of attentional distribution. We attempt to understand and characterize how and why devices are used, the distribution of attention to devices versus speaker, and the influence of the device usage on recall of material presented. We explore whether use of devices leads to "attentional blind spots," that would indicate challenges in the ability to process two streams of information simultaneously [15].

We first investigate perceptions of and preferences for the use of computing devices during presentations via surveys of speakers and attendees. The data identifies perceived costs and benefits from the perspectives of users and those who may be indirectly affected, such as speakers and other audience members. We identify ways that device users try to blend device usage into the environment so as to reduce distractions.

In a second phase of research, we used findings from the survey to frame an in situ study of the distribution of attention between device and presentation. We identified attentional switches between device and speaker by coding videos of audience interaction. We explored the nature and extent of conceptual blind spots that might be induced by device usage by giving attendees voluntary pop quizzes following presentations. We then correlated the recall of content with both the microstructure and higher-level pattern of attendee attention to a device and the speaker. We report several findings on reduced recall with states of increased attention to computing devices, notably that laptop users on average score significantly lower than non-device users on concepts presented in the talk.

The key contributions of the studies include results on i) the perceived costs and benefits of device usage during presentations by speakers and device users, ii) the distribution of the attention by attendees to devices versus the speaker, and iii) the relationship of the distribution of attention on the ability to recall presentation content at the end of presentations. The findings characterize the nature and potential costs of multitasking with devices during presentations and inform solutions to help users better manage their attention.

RELATED WORK
In this section we review prior work on divided attention and on device usage during lectures and meetings.

Divided Attention and Task Performance
Understanding effects of divided attention on task performance has long been a focus in cognitive science. Early work in this area has investigated relationships between attention and mental capacity to understand how humans perform concurrent activities. Kahneman [10] introduced the notion of a 'capacity model' suggesting that there is a general limit on humans' ability to perform tasks, but the limited capacity can be flexibly allocated across multiple activities. Other experiments have shown that these limitations may impact performance when attention is divided across multiple tasks [12, 18]. People can effectively execute multiple tasks when the processing load is low and/or different processing resources are used, but for higher loads performance on one task is often compromised for performance on another [19]. Related work has provided evidence of attention sharing and flexible allocation of attention across tasks through attention operating characteristics (AOC) [11, 16].

Our work focuses on a specific domain—the dual task scenario of paying attention to a speaker while performing tasks on a computing device. Our goal is to characterize cognitive resource sharing, and information processing limitations when users divide attention across assimilation of the audio-visual lecture content, and device interactions. We leverage existing theory to explain our findings.

Effects of dividing attention across device and lecture
Many recent studies have investigated the costs [1, 8, 14] and benefits [3, 7] of using laptops in *lecture* settings, where attendees (students) are expected to devote their full attention to the lectures and activities related to the lecture. Campbell and Pargas [3] discuss usage of laptops in classroom settings as a 'beneficial and integral' part of the learning experience and present challenges educators face in adopting lesson plans to integrate the device into the day's lecture. Hembrooke and Gay [8] highlight the disruptive effects on learning that usage of laptops can cause, showing decreased performance for those who used laptops in a classroom. The primary cited reason was distractions caused by having access to many applications, diverting attention from the class lecture. Barkhaus [1] found that students performed on average 1.6 different activities during a lecture, which included surfing the web, email or work on other assignments. He also found that laptops usage in the classroom is often polarized: the devices are used either as a supplement to the lecture, or for multitasking on unrelated tasks.

In the settings of face-to-face meetings, Newman [14] investigated sources of disruption and showed that laptop users often drifted off to activities less relevant to the meeting, had difficulty reengaging in the conversation, and after rejoining the conversation would occasionally embark on topics that were no longer relevant.

Our research complements prior work as we focus on the use of computing devices during presentations *where attendee attendance and attention is voluntary*, and speakers are not responsible for ensuring that the audience assimilates the content. *Unlike* classroom lectures, where attendees are required to pay full attention to the lecture, in colloquium style presentations, attendees are often less obligated to focus on the lecture, and have more flexibility in attending to tasks on a device as long as is their behavior is not socially disruptive. We hypothesize that this subtle difference in attention may incur unique patterns of device use and different perceptions of social cost, as well as variances in attainment of presented content.

RESEARCH OVERVIEW
Our goal is to understand how speakers and attendees are affected when audience members interact with devices during colloquium-style lectures, where audience interest and attention are voluntary and vary widely. We posed the following questions:

1. How do speakers perceive cost and benefits of audience members using devices during lectures?
2. How do attendees perceive the costs and benefits?
3. How does attention shift between the presentation and a device, and what is the impact on information intake?

To address these questions, following a brief pilot study, we conducted a broad survey, then videotaped and analyzed three presentations in detail. We focused on the use of laptops and smartphones, which afford different capabilities and visibility.

	Got all useful info	Missed some
Had laptop	19 (41%)	27 (59%)
No laptop	72 (57%)	54 (43%)

Table 1. Self reports of information acquisition in pilot study

PILOT STUDY

To get a general sense of how device users perceived multitasking to affect their intake of information from a presentation, we conducted a pilot study. Following five internal presentations by outside speakers, we distributed a brief questionnaire to audience members who knew nothing of our motives. One question was "Which of these best describes your experience today?" followed by the choices "I picked up all of the lecture information that would be useful to me," "I picked up most of the lecture information that would be useful to me," and "I missed significant information." The final question, the only one mentioning technology, asked simply "Which of these items did you have with you in the lecture?" followed by the choices Tablet, Laptop, Phone, Pen and paper.

172 audience members completed the questionnaire, of whom 46 brought laptops. We observed that most used them, whereas only a few people with phones did. We ran a logs odd ratio (LOR) [2] on the effects of having a laptop on the self reports of information acquisition (see table 1) and the resulting LOR of 0.64 (odds ratio 1.9, S.E.=0.35) yielded a significant effect of having a laptop on whether users report that they missed useful information (z=1.83, p=0.034, one-tailed.) Given that not all laptop possessors used them, the effect is likely to be stronger than shown. The fact that laptop possessors *believe* that they are missing information, yet use them anyway, motivates the following in-depth studies of perceived costs and benefits as well as effects on actual information acquisition.

STUDY 1: UNDERSTANDING PERCEIVED COSTS AND BENEFITS OF MULTITASKING DURING LECTURES

To assess attitudes toward the use of devices, we surveyed speakers and audience members, who might be indirectly affected even when they do not use a device themselves. Do perceptions of costs and benefits differ across groups? Can we derive insights into how to allay any concerns?

Speakers were surveyed to determine perceptions of the potential benefits of device use and the potential risks of distracting the users or others in the room. How open are speakers to the integration of devices during presentations, as is happening in places with laptops in classrooms [3]?

The audience surveys probed why people use devices during presentations, and how they perceive and balance benefits and costs. Understanding the importance to audience members of such device use could affect modifications in policies, technologies to support better multitasking, or changes in presentation styles.

Participants
The speaker survey was administered to external speakers—university professors, industry researchers and

Topic	Speaker	Audience
Prevalence and patterns of device usage during lectures	What proportion of your audience uses a device at some point during your lecture?	For what percentage of lectures you attend do you use a device?
		Why do you/don't you use a device?
		In what situations do you use a device?
Costs, benefits and social implications	How does device usage benefit users?	
	How distracting is device usage to the user?	
	How disrespectful is it to the speaker?	
	How much do you accept device use as a norm?	
	Opinion on whether multitasking should be minimized in lectures	
Strategies to manage user attention	Do you consider usage of device as an indicator of user attention?	How do you divide attention between device and lecture?
	Do you tailor lectures in advance/in real time to accommodate device usage?	What do you do to show you are paying attention?
	Have you ever asked audience to turn off device or commented on device usage?	How do you think things should change regarding device usage during lectures?
		How would you feel about wireless being cutoff at lectures?

Table 2. Sample survey questions.

evangelists—and internal members of our research organization who also frequently delivered colloquium lectures to academic and industry audiences. The audience survey was sent to employees in our institution who subscribed to a mailing list for lecture announcements. All participants received a small gratuity.

Methodology
External speakers were contacted through their hosts and given a paper survey to fill out before or after their talk if they consented. The same survey was put online for employees with experience presenting in colloquium settings. The audience survey was administered online.

Survey Questions
Survey questions broadly addressed the prevalence and patterns of device usage during lectures, perceived social impact, benefits and distraction costs, and strategies to manage attention. Table 1 presents some of the questions.

Survey Results
We collected 62 responses to the speaker survey (11 external, 51 internal) and 112 responses to the audience survey. Results are presented in parallel when possible to enable comparison across speaker and audience responses.
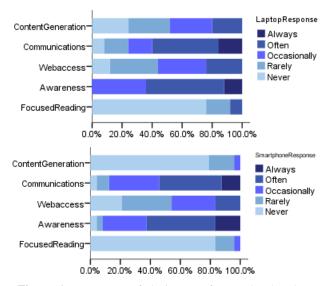
Figure 1. Frequency of device use for unrelated tasks as composed from responses (top image: laptops; bottom image: smartphones). The *x*-axis indicates % of users.

Figure 2. Frequency of how often users switch to devices under certain circumstances. *x*-axis indicates % of users.
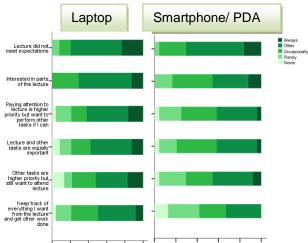
Perceived prevalence of device usage

Only 16% of the speakers reported that they never or rarely noticed audience members using a device. About 75% estimated that over 10% of audience members used devices, with some estimating it to be over 50%.

40% of audience respondents reported using laptops and 33% using smartphones for at least one in four lectures they attend. The 60% who do not frequently use these devices reported being distracted (67% for laptops, 42% for smartphones), but tolerated others using devices. 56% reported that they were only distracted by laptops when it was too conspicuous and 35% reported not being affected at all. For smartphones, 42% reported being affected only when noticeable and 51% reported not at all.

Patterns of device usage by audience members

Only 24% of laptop users and 8% of smartphone users reported using devices solely for lecture-related tasks such as taking notes, looking up references, or communicating about the lecture. Others reported engaging in unrelated content generation (writing, editing text, code, diagrams etc.), communication, web access, awareness (glancing to see status or incoming information) and focused reading. Figure 1 shows the reported frequencies of engagement in unrelated tasks. Over 80% report occasionally, often or always using laptops and smartphones for awareness and communication tasks, and about 50% for web browsing. About 80% of device users reported never using them for focused reading, and over 75% reported never using a smartphone for content generation tasks.

When do audience members turn to their device for tasks unrelated to the lecture? About 75% report often switching to a device when the lecture does not meet expectations. 5% reported always switching in this situation. The need, desire, and choice to multitask were also supported by other rationales (see Figure 2).

Benefits, Costs and Social Implications

Responses to our questions on perceived costs and benefits were on a Likert scale of 1 to 7, 1 being strongly disagree and 7 being strongly agree. We compared responses across speakers and audiences, and across laptops and smartphones. Table 3 summarizes the results.

There was wide agreement that a laptop can enhance presented content, although audience members were more positive than speakers (M_{aud}=5.48, $M_{speaker}$=4.65, p<0.023). Speakers did not believe that smartphones could enhance the experience, with audience members showing high variance on this issue. Both groups agreed that laptops can help listeners multitask, but only audience members felt that smartphones can.

Speakers felt strongly that both laptops and smartphones distract users. Audiences were more neutral on this, and close to 50% of device users agreed that even though they miss some information while interacting with devices, the benefits of multitasking make it worthwhile (see Figure 3).
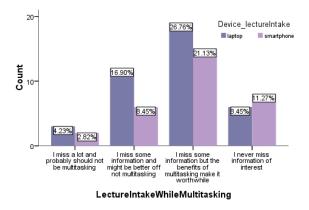

Figure 3. Perceptions of balancing between presentation intake and multitasking on device. The *y* axis indicates number of respondents agreeing with the statement on the *x* axis.

		Speaker	Audience	p
Enhances lecture experience for user	Laptop	**4.65*** (1.57)	**5.48**** (1.87)	0.023 (0.55)
	Phone/ PDA	**3.21**** (1.77)	3.34 (2.09)	0.755
	P	0.00 (0.46)	0.038 (0.39)	
Enables Users to multitask	Laptop	4.5 (1.54)	**5.00*** (2.09)	0.187
	Phone/ PDA	3.97 (1.57)	**5.00*** (1.55)	0.006 (0.09)
	p	0.02 (0.15)	0.17	
Distracts user	Laptop	**5.76**** (1.1)	3.76 (1.89)	0.001 (0.32)
	Phone/ PDA	**5.62**** (1.24)	3.84 (1.52)	0.001 (0.28)
	p	0.27	0.025 (045)	
Disrespectful to speaker		3.84 (1.65)	**5.48**** (1.55)	0.001 (0.21)
Feature of the world that we are in		**5.13 **** (1.39)	**4.9**** (1.72)	0.39
Should minimize multitasking at lectures		**4.44** (1.73)	**4.19** (1.87)	0.437

indicates that the p-value <0.01
**indicates that the p-value <0.001*

Table 3. Mean ratings of benefits, costs and social perception of device usage during lectures (1=strongly disagree, 7=strongly agree, 4=neutral). Standard deviations and significant p-values are shown in parentheses. Values significantly different than the neutral value of 4 are in bold.

In terms of social implications, audiences reported feeling that device usage could be disrespectful to speakers (M=5.48), but the speakers themselves did not strongly agree (M=3.84, where 4 is neutral). Audience members may know that they are not fully attentive and therefore feel somewhat disrespectful: 62% of respondents who rated disrespect high (6+ on the 7-point scale) also reported performing many unrelated laptop tasks, and 71% reported performing many unrelated smartphone tasks.

Speakers cannot be sure what a device is used for, which may deter them from attributing disrespect. One wrote:

"it's hard to tell whether the device is used in a positive way (e.g., taking notes) or a negative way (e.g., distracted by IM)"

"I find that in general such use is for email/im and not for enhancing the lecture experience, therefore high use equates to low interest and attention. A note taking participant is looking up at you frequently or while typing - an inattentive user is looking down and reading"

In addition, speakers are willing to accommodate such multitasking because they know that the ability to use a laptop could induce people to attend when they have other tasks requiring attention.

"There are many reasons to use a laptop that might be tied to the talk (taking notes or looking up a paper the talk reminded you about). Additionally, there are many demands on everyone's time. Presumably if they are at my talk, they found it important enough to want to hear what I have to say while trying to balance that with other demands on their time."

This sentiment was echoed by audience members, who widely opined that banning devices from lectures would be detrimental: "I don't think things should be changed because I think the benefits of the work (and non-work which can be beneficial too) people do during lectures outweigh the loss of information resulting from less attention." Most reacted negatively to the idea of turning off wireless access during presentations.

However, some dissented, maintaining that paying attention should be the top priority of people in the room:

 "I think people should be discouraged from coming to lectures if folks can't pay attention to what the speaker has to say. There is nothing worse than having someone doing other work and not paying attention to what is happening in the room. However, I wouldn't want to ban laptops as taking notes via laptop is important."

Others suggested that device users could be positioned where they would minimize distracting the speaker or other audience members. However, as we noted, most speakers and non-device-users accept that multitasking is a feature of our world and accept it when use is discrete.

We also asked whether audience members would feel more comfortable using devices if more people around them used them. The majority reported that the behaviors of others did not impact them, but some reported feeling it would make their own device usage more socially acceptable:

"…as that would be an indication of the cultural norms for that setting' and 'the more using their laptop, the more the perceived acceptance of using a laptop during a lecture.'

Some expressed concern about image: Seeing others use devices reduces guilt about what they considered to be less acceptable behavior: "just because I won't be as obvious" and "because there is a safety in numbers and for myself, I feel device usage is slightly bad behavior." With some dissent, the overall tone reflected the survey finding that collectively, device use during lectures could create a poor perception the audience (M=5.1).

Strategies for managing attention
74% of laptop users and 71% of smartphone users reported that they mostly pay attention to a presentation and occasionally switch to the device when other tasks demand attention. This was captured in the following comment:

"While my use of devices at lecture tends to be limited, I occasionally need to: - look at the slides directly on my laptop (maybe i am a slide ahead or behind or it is hard to see the screen from my seat) - keep an eye for high priority email that may come my way. - take a couple of notes (as opposed to typing every word the speaker says) - look up some related

information online There may be rare occasion where someone may show up at a talk and find out it is quite different then what they expected. While in general it would be best to leave at that point, there may be occasion where it would create too much disruption and using your device discretely is a better way to go."

Device users also reported a desire to demonstrate to speakers that they were paying attention. Frequent eye contact, asking questions, and putting away a device were commonly cited ways to show interest and respect.

67% of speakers stated that they considered device use a negative indicator of interest in their lecture, but only 23% reported acting on it in real time and 12% reported tailoring lectures in advance to take audience multitasking into account. One commented:

"When I seem to be losing the audience for any reason, I modify my delivery. Lots of heads down over laptops with users appearing to be reading rather than mostly looking up while writing means that they have drifted off into email or web pages and I need to pull them back in."

Reservations about modifying lectures to inhibit or incorporate device usage appeared to be based in the ambiguity of such use (e.g., taking notes, multitasking out of necessity, multitasking out of lack of interest), as well as the fact that only a fraction of audiences use a device. Most speakers felt that it was up to audience members to decide how to attend. This may reflect the colloquium setting, as well as the fact that speakers also attend presentations and may themselves multitask on occasion.

Summary of findings

Overall, survey results suggested that speakers accept device use as part of the present day culture where people want to multitask and be productive. The speakers surveyed did not appear to feel that device users are disrespectful, but expressed some concern about the potential for distraction.

Responses also suggested that attendees are well aware of the potential for distraction, but for many the lure of increased productivity is too great to abandon device use. The fact that audience members reported being less inclined to attend presentations should devices be banned or wireless turned off is a testament to the importance placed on the ability to multitask.

The findings may be skewed by a sample population for whom advanced devices are generally available and often an essential tool. However, in understanding device use and its impact, it is prudent to study and consider implications in this setting, which may become more typical.

The surveys also suggest that audience members may act to mitigate multitasking and reduce disruption. We developed an activity coding schema to explore this.

STUDY 2: UNDERSTANDING MULTITASKING IN LECTURES AND EFFECTS ON USER ATTENTION

Based on the findings from the surveys, we conducted an observational study to get a better understanding of how people divide their attention across a device and a

Figure 4. Viewer for coding audience actions during lectures. The top right stream is from the fish-eye camera and the bottom two are from two high-definition cameras providing coverage for all audience members in the room.

presentation, and how this impacts their ability to garner information presented during the lecture.

Methodology

We examined three guest lectures from the well-publicized research lecture series at our institution. Two were general interest topics with which most employees could resonate: using mobile phones to monitor traffic, and comparing and contrasting science, engineering, computing and software development. The other presentation was a specialized investigation of topics in decision theory.

For each lecture, we videotaped the audience with two high definition ceiling-mounted video cameras in the front corners of room at a 35-40 degree angle facing the audience. A third view was provided by an Axis 212 PTZ fish-eye camera mounted from the ceiling. The goal was to have all audience members in one of the three camera views; however, for one lecture a technical breakdown resulted in losing video of about half of the audience. A custom viewer provided synchronized views of the video streams captured through the three cameras in addition to a speaker stream. Figure 4 provides a consolidated view of the video streams from a sample presentation.

At the end of each presentation, we distributed a questionnaire to attendees. It included questions designed to measure of how well people assimilated the lecture material, similar to those used by Barkhuus [1]. The questions were generated by the experimenters during the presentation and chosen to be relatively specific to the lecture, rather than generally knowledge. They covered content presented on slides, remarks made by speakers, topics referred to multiple times, and conceptual questions. Ten questions probed a sample of concepts presented through most of the presentation. We also inquired into motivation for attending, how they felt they had distributed their attention between a device being used (if any) and the presentation, and whether they were satisfied with the information they had picked up from the presentation. This

allowed us to link their loci of attention and underlying motivation to their performance on the questions.

The questionnaire was distributed to all audience members, but participation was voluntary. 65 of 98 people responded. 29 reported carrying a laptop, a smart phone or both. Audience members were not informed of the questionnaire before the end of the presentation.

Analysis of user interaction with devices

The videos were analyzed and coded to understand how audience members switched attention between devices and the presentation. Of course, looking down at a device does not necessarily mean that a person is unable to audit and follow the presentation. We wanted to collect evidence as to how often this does and does not occur.

For analyzing the videos, we developed a coding schema based on the surveys in Study 1 and initial observations of the video. We were interested in: i) time looking at a speaker with the device closed, ii) time looking at a device with the device open, iii) time looking down and/or interacting with a device, iv) number of times a device was opened, and v) number of times a device was closed. We could not code every device user in the audience due to limited visibility or limited use of device, but we captured a representative sample of people who actively interacted with their devices during the presentations.

On the timeline of the presentation video we identified when each topic pertaining to a challenge question was presented. This allowed us to explore relationships between the focus of attention (presentation or device) when a topic was discussed and the performance on the corresponding question. We also noted when events occurred during the presentation that might have interrupted the delivery flow, notably audience questions or laughter. This allowed us to explore whether unexpected shifts in presentation flow triggered corresponding shifts in attention for device users, as suggested in some psychology literature [6, 17].

Results

Attendance across the two general interest presentations numbered 44 and 43, respectively. 15 people attended the specialized presentation. We approximated the number of devices by consolidating views from the video and self-reports on the questionnaire, arriving at 9, 17, and 6 in the respective lectures. 31% of attendees reported having either a laptop or a phone with them. However, the number of devices was likely higher: not everyone responded to the survey, some brought devices but never used them, and smaller devices may have been occluded in the video feeds. Device users were distributed throughout the room, not clustered towards the end rows as reported in [2].

Overall effects of device usage and motivation on information intake

We used the number of correct answers on the challenge questions as a metric for how well users took in presentation information. We conducted a two-way ANOVA on the number of correct answers with *devices* (none, laptop, phone, laptop and phone, pen and paper) and *motivation for attending lecture* ('very interested in topic', 'thought there would be something useful', 'respect for speaker', 'increase audience size', 'other') as the factors.

On average, respondents answered 6.2 (S.D. 2.3) of the 10 challenge questions correctly. There was a significant effect of having a device on the number of correct answers ($F(4, 50)=5.71$, $p<0.001$, partial $\eta^2=0.31$). Post hoc Bonferroni tests showed that people with laptops only (N=18) had significantly fewer correct answers (M=4.35, S.D. 0.436) than people who reported no devices (N=27, M=7.26, S.D. 0.583, $p<0.002$) or who had phones only (N=9, M=7.39, S.D. 0.776, $p<0.013$). We observed phones to be used less frequently and with less duration than laptops. Users with only a phone may intend to focus on the presentation as much as non-device users. People who reported having phones only, pen-and-paper only (N=9, M=6.39, S.D. 0.669) and both laptops and phones (N=2, M=5.98, S.D. 1.42) did not do significantly worse than people who reported bringing nothing, though they trended lower.

There was no main effect of motivation, but there was a significant interaction between device used and motivation on the number of correct answers on the challenge questions ($p<0.001$). Post hoc Bonferroni tests showed that users who reported being 'very interested in the topic' or that they 'thought there would be something useful' showed no significant differences in performance on the challenge questions based on device use. This indicates that highly interested users were able to more effectively divide attention across the device and the presentation.

The interaction effects came from those who reported that they attended the presentation 'out of respect for the speaker'. For this group, laptop users scored significantly less (M=4.2, S.D.=0.81) than non-device users (M= 7.93, S.D.=0.48, $p<0.002$). No differences were found across other classes of device use, suggesting that lower motivation and device type influence information uptake.

To compare self-perception of information uptake to performance on the challenge questions, we ran a partial correlation between self reports (*I missed significant information, I picked up most of the useful information, I picked up all the lecture information that would be useful to me*) and correct answers. No significant correlations were found, suggesting that users may not correctly judge how much they miss from presentations due to distractions.

Patterns of attentional focus of device users

Finally, we analyzed attentional focus for device users during presentations by considering people who answered the survey and were visible in a video stream. We could fully view 11 attendees over the three lectures who used devices, in each case a laptop. We analyzed how they directed attention to the device and the presentation.
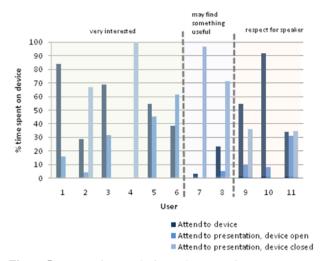
Figure 5. Percent time on device and presentation. Users are grouped by reported motivation for attending the presentation.

Figure 6. Frequency of episodes where user is attending to the laptop and average time on each episode for each user (User 4 has no data as he did not use his laptop after the talk started.). Data is grouped by motivation for attending lecture.

Figure 5 shows the proportion of time spent interacting with the laptop and attending to the presentation. People are grouped by their reported motive for attending. The behavior patterns are similar. Most of them kept their laptop open for most of the presentation and switched attention between it and the speaker. The average number of *glances-back-and-forth* was 49.3/hour (S.D. 43). Average frequency of episodes where someone focused entirely on the device was 24.3/hour (S.D. 21.7), and the average duration across all episodes was 1m, 10s. As shown in Figure 6, individual frequencies (Min=4, Max=62) and lengths of episodes (Min=22s, Max=5m 43s) varied. The number of users is too low for statistical testing, but the patterns suggest that those who report attending out of respect and because they thought there might be something useful have lower switching frequencies and spend longer stretches looking at their laptops. In contrast, those who reported being very interested in the presentation have shorter episodes of laptop viewing and higher frequencies of looking at the speaker. Their device use occurs in short but frequent time slices, interleaved with apparent attention to the presentation. This is consistent with the Study 1 finding that such actions were undertaken frequently to reduce social
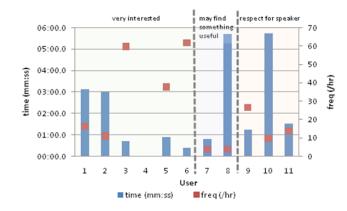
costs of using devices during a presentation.

Figure 7 shows the distribution of attention for six laptop users at a single presentation. Note the frequent shift of attention between the device and the speaker. Although some occasionally close their laptops and pay full attention, often they later reopen and use them. Device users often look up for unusual events, such as a question asked in mid-lecture, laughter, or a speaker interactively engaging the audience. This supports guidelines that encourage speakers to design more interactive presentations, thereby holding audience attention.

Self perception and observed levels of attentional focus
Six of the 11 laptop users reported that they 'mostly paid attention' to the presentation, but four of the 6 spent more than half their time (and another around 40%) interacting with the laptop. Two reported paying 'full attention' to the presentation; one of these interacted with a laptop 34% of the time. The remaining 3 attendees reported they paid 'moderate' attention to the lecture; two of them spent less than 30% of the time on their laptop while the other interacted with a laptop 68% of the time.

These numbers, though preliminary, suggest that attendees may not accurately perceive how their attention is focused
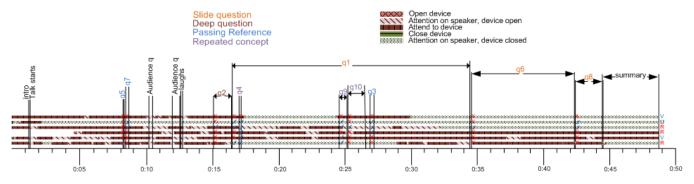

Figure 7. Timeline of distribution of attention to laptops and speaker for six attendees at the same lecture. Times when question topics were generated and other events are marked. The reported levels of motivations are listed to the right of each timeline: V = very interested, U= thought there would be something useful, R= respect for speaker.

when attending a presentation while interacting with a device. Of course, laptop users may at times use the device for presentation-related activities, as our survey suggested, which could account for the discrepancies.

Effects of attention on devices on intake of information
Finally, we wanted to understand more precisely how attention to laptops might relate to recall of presented information. We aligned the status of user attention to moments when specific content addressed in questions was presented and noted responses to those questions. As a baseline, we also examined users who did not have laptops with them. A chi-square test of independence was performed to examine the relationship between the current state of attention (looking at device, looking at speaker, partial) and the response (correct, incorrect). Partial attention was coded when the speaker and a device were each viewed for at least 20% of a given time slice. The relation was significant, $\chi^2(2, N=480) = 53$, $p<0.001$. Post hoc analysis showed that respondents were more likely to answer incorrectly on a topic presented when they were looking at their device. This supports the hypothesis that device use can interfere with the processing of presentation information. We note that multiple factors, beyond device use, can influence information intake. Attendees answered some questions correctly even when apparently focusing on a device when that content was presented and attendees without devices did not answer all questions correctly. We discuss these issues in the next section.

DISCUSSION
Given the increasing use of devices during presentations, the question of the impact on audience members and speakers that motivates this study is important. Speakers report tolerance for device use as long as it is not disruptive, with some concern for how the audience's attention is affected. Device users value the ability to multitask while attending presentations, whether to enhance the presentation experience or to quietly focus on other activities. Device users do express concern for how their behavior affects speakers and report making conscious efforts to demonstrate that they are paying attention.

In practice, laptop users frequently switch attentional focus. perhaps intending to get the best of both worlds by listening and getting other work done, despite the challenges in following two threads simultaneously. However, we found evidence that this may not always be the case. Interactions with a laptop often span significant stretches during which information is missed. An important point to note is our finding showing that motivation for attending significantly affects information uptake by laptop users. Those who are interested in the presentation performed on our challenge questions as well as those without laptops. We do not have data to discern whether or not these viewers were using their devices for presentation-related interactions. Those attending only out of respect for the speaker, who scored lower on the challenge questions, were likely using their device for activities unrelated to the presentation leading to

periods of inattentional blindness. Our survey suggested that people switched to perform unrelated tasks on their devices when the presentation did not meet their expectations, but we do not have direct evidence showing this for the observations. Further studies will be necessary to sort this out.

People were sometimes able to answer questions about topics introduced when they were interacting with a laptop, and the converse was also true. Users missed some questions on topics presented even when they appeared to be paying attention (see Figure 7). This underlines the complexities of human information processing; distractions do not always have a visible source.

Compared to laptop usage during classroom lectures, our findings offer additional insights. Attendees of colloquium-style presentations differ greatly from students who are more obligated to pay attention. Consequently, device use will very likely differ, motivated not only by the desire to perform other, often pressing tasks, but also subject to interest in the presentation. Our audience members were not aware that they would be quizzed, so there was no reason for them to be attentive if they did not wish to do so. The interaction patterns that we report apply to a different multitasking context than a classroom lecture. Hembrooke and Gay [8] describe how the content accessed on devices impacts test scores of students attending lectures. Our work complements this by providing qualitative and quantitative insights into how users divide attention in a more discretionary presentation. We look at how costs and benefits are perceived by audience and speakers in such circumstances, and how they attempt to correct for the purported costs.

The finding that laptop users tend to miss information is consistent with [8]. Of course, competition for attention to a presentation may occur without a device, and attendees focus on aspects of the presentation even when using a device. There may be times when a device user has the processing resources to track and integrate presented information while engaging in other tasks. This can explain why users could sometimes answer arcane questions even though their focus was on a laptop. Further research is required to understand these cognitive issues, including variations in the ability to multitask.

We found that laptop users typically switch attention back to a presentation following an unexpected change of pace. This observed propensity to react to unexpected events might be leveraged by lecturers. For example, speakers could make presentations more interactive, introduce media, changes of tone or pace, and so on. These are familiar recommendations, but our study provides evidence that they may be even more effective in a wired era.

The growing prevalence of laptop use, coupled with findings on its influence on information intake, suggests an opportunity for speakers to harness the devices in a manner that competes with uses that are exogenous to presentations.

Speakers could provide special content and media, available to laptop users, that extends the presented material. In another direction, software utilities running on laptops might provide real-time visualizations of an individual's own focus (similar to figure 6) as well as (anonymized) attention levels of other device users. Software could even track content that may be being missed and make it available later. The survey suggested that knowledge of overall device use could inform people of the collective inattention in the room and allow them to adjust their behavior. Visualizations of behavior, one's own and others', are known to serve as motivating factors in other domains [4, 5]. Such visualizations may provide speakers with useful post hoc feedback on when audience members shifted attention in and out.

LIMITATIONS

A limitation of our study is the focus on colloquium-style presentations and audiences within a culture where device usage is a generally accepted norm. Aspects of the results on attitudes, behaviors, costs, and benefits of multi-tasking likely generalize to other settings (some of which our external speakers came from), additional studies are necessary. Practices may differ significantly in environments where devices are less acceptable or less common. The costs of inattention may differ in educational lectures or meetings.

Another limitation of the observational study is that we did not have a clear sense of what exactly users were doing when they were interacting with a device, though our survey provides insights into what such interactions may entail. We loosely term their interactions to fall into the category of multitasking, where this could include tasks related to the presentation, i.e. taking notes or looking up references, or unrelated such as content generation, communication, web access or focused reading (fig 1).

CONCLUSION

We investigated device use during presentations and the effects of this use on attention and recall. Our work makes three contributions. First, we provide the first evidence of how speakers and audience members perceive the costs and benefits of device usage. Speakers see a risk in device users missing important information. Audience members are more concerned about the social cost of appearing inattentive. Second, we provide evidence of how laptop users shift attention during presentations. Finally, we show that use of laptops during presentations can diminish information intake, especially for those lacking high motivation to attend a presentation to begin with. Speakers and device users alike value devices as a means for enhancing a presentation experience with auxiliary content as well as for performing other tasks. We will continue to explore possible losses and risks associated with divided attention that stem from the use of computing devices in lectures and other settings. We seek an understanding of how lecture composition and content can be made more or less robust to divided attention, and the prospect of tailoring lecture content and presentation styles to transmit information effectively in light of ongoing device usage.

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