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Attention Spreads Between Students in a Learning Environment

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We propose a novel phenomenon, *attention contagion*, defined as the spread of attentive (or inattentive) states among members of a group. We examined attention contagion in a learning environment in which pairs of undergraduate students watched a lecture video. Each pair consisted of a participant and a confederate trained to exhibit attentive behaviors (e.g., leaning forward) or inattentive behaviors (e.g., slouching). In Experiment 1, confederates sat in front of participants and could be seen. Relative to participants who watched the lecture with an inattentive confederate, participants with an attentive confederate: (a) self-reported higher levels of attentiveness, (b) behaved more attentively (e.g., took more notes), and (c) had better memory for lecture content. In Experiment 2, confederates sat behind participants. Despite confederates not being visible, participants were still aware of whether confederates were acting attentively or inattentively, and participants were still susceptible to attention contagion. Our findings suggest that distraction is one factor that contributes to the spread of inattentiveness (Experiment 1), but this phenomenon apparently can still occur in the absence of distraction (Experiment 2). We propose an account of how (in)attentiveness spreads across students and discuss practical implications regarding how learning is affected in the classroom.

Public Significance Statement
We found that attentiveness spreads from one student to another in learning environments, affecting note-taking and memory for lecture content. Importantly, this finding was obtained in the absence of electronic devices and other overt visual distractions; the spread of attentiveness in the classroom may therefore be more pervasive than instructors and students realize.

Keywords: attention, learning, memory, simulated classroom, note-taking

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Attention is essential for effective learning (e.g., Keogh & Margolis, 1976; Samuels & Turnure, 1974; Wammes et al., 2016). Supporting this claim, research finds a positive relation between undergraduate students' attentiveness during lectures and their retention of lecture content, both for live lectures (e.g., Cameron & Giuntoli, 1972; Lindquist & McLean, 2011; Wammes et al., 2016) and for video lectures (e.g., Kane et al., 2017; Risko et al., 2012; Wammes & Smilek, 2017). Attentive students also tend to outperform less attentive peers on quizzes and exams (e.g., Wammes et al., 2016), and they achieve higher SAT scores (Unsworth et al., 2012).

The relation between attention and academic performance underscores the importance of *attention-aware classrooms*—in which the instructor is well-versed in factors that influence attentiveness and can apply that knowledge to bolster students' attentiveness (Risko et al., 2012). Central to cultivating an attention-aware classroom is understanding how students' behaviors can influence peers' attentional states. In this article, we propose that both attentive behaviors (e.g.,

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frequent note-taking) and inattentive behaviors (e.g., fidgeting) can spread across students. We begin with an overview of three theories that support our "attention contagion" account: (a) social appraisal theory, (b) goal contagion theory, and (c) cognitive load theory.

Social Appraisal Theory

According to social appraisal theory (Manstead & Fischer, 2001), people take into account others' appraisals (inferred from their expressions and behaviors) when evaluating events. For example, after observing peers responding anxiously to the announcement of a surprise quiz, a student may appraise the quiz as being particularly important, prompting them to also experience anxiety. Thus, individual social appraisals converge in a group, consistent with social learning theory (e.g., Bandura, 1977).

We therefore posit that social appraisals regarding the *value* of an event can influence one's attentional engagement—resulting in attentional states converging in a group. In particular, students may observe their peers' attentive and inattentive behaviors when appraising the value of learning material. Students who observe peers engaging in attentive behaviors (e.g., note-taking) may appraise that material as important, and consequently increase their own attentional engagement (converging with the attentive state of their peers). Likewise, students who observe inattentive peers may appraise the material as unimportant, decreasing attentional engagement (again converging with the inattentive state of their peers). This kind of influence is particularly plausible given research showing that in social settings people tend to pay more attention to information that they perceive as important (Parkinson, 2011).

Goal Contagion Theory

Connected to the concept of social appraisal is evidence indicating that the attentional system prioritizes goal-relevant information (Dijksterhuis & Aarts, 2010). For example, thirsty people pay more attention to drinks than do people who are not thirsty (Aarts et al., 2001). Relatedly, students with the appropriate learning goals in their classroom engage in fewer goal-irrelevant behaviors (e.g., disrupting the classroom; Meece et al., 2006), and students who report less interest and effort in completing long-term goals also report less attentiveness in class (Ralph et al., 2017). Given that goals direct attention, a process resulting in the spread of learning goals should also result in the spread of attentiveness.

In this regard, *goal contagion theory* (Aarts et al., 2004; for reviews, see Aarts et al., 2008; Laurin, 2016) is clearly relevant. Aarts et al. (2004) describe goal contagion as a two-stage process. First, when people observe others' goal-directed behavior, they infer the underlying goal (Hassin et al., 2005; McClure, 2002). For example, in learning environments, attentive behaviors (e.g., frequently taking notes) may signal a learning goal. Second, this same goal is activated in observers, who then pursue the goal themselves—even in a different context that requires different goal-directed behaviors (i.e., goal contagion is not driven by behavioral mimicry; Aarts et al., 2004). This may manifest as a peer inferring that the learning goal (or the achievement from that goal) is valuable. These inferences may activate the same learning goal in the observer, who may then also engage in attentive behaviors. Thus, goal contagion would also contribute to the spread of attentiveness in learning environments.

Cognitive Load Theory

A central tenet of cognitive load theory (Lavie, 2010; Murphy et al., 2016; Van Merrienboer & Sweller, 2005) is that people have limited attentional resources. Information irrelevant to the material being taught imposes an "extraneous cognitive load" that consumes the learner's attentional resources. Learning is hindered when the learner has insufficient remaining attentional resources to deeply process information relevant to the material being taught.

In the classroom, *peer distraction* constitutes an extraneous cognitive load (Frisby et al., 2018) that could account for the spread of inattention across students. This claim starts with the uncontroversial premise that inattentive students tend to engage in off-task behaviors. Although recent research on peer distraction has focused primarily on the use of electronic devices (Phillips et al., 2016), inattentive students engage in other distracting off-task behaviors (Frisby et al., 2018). For example, inattentive students are more likely to fidget (Farley et al., 2013), which could distract peers, as could visible boredom or sleepiness. Perceptual distractions impose an extraneous cognitive load on nearby peers via two distinct paths (Phillips et al., 2016). First, perceptual distractions capture spatial attention, diverting attentional resources from lecture material (Phillips et al., 2016). Second, to successfully ignore these distractions, peers must engage in top-down *selective attention* processes that consume attentional resources (Murphy et al., 2016), leaving fewer resources available to process the lecture material. In either case, the outcome is fewer attention resources and more shallow processing of lecture content, resulting in diminished learning (Sana et al., 2013; see also Varao-Sousa et al., 2018). In this manner, distracting off-task behaviors could drive the spread of inattention across students.

The Influence of Attention Contagion on Memory

For each of the three theories just outlined, we described the cognitive mechanisms by which (in)attentive states can spread across students. Here, we will explain how this spread of (in)attention can subsequently affect memory for the educational material (e.g., lecture content). In line with Craik and Lockhart (1972) levels of processing framework, when an attentive state spreads from Student A to Student B, Student B invests more attentional resources in the educational material and processes that material more elaboratively. Several behaviors are indicative of elaborative processing, including eye gaze on relevant information (Hutt et al., 2017), an alert forward-leaning posture (Chisholm et al., 2013), and detailed note-taking (Lindquist & McLean, 2011). Elaborative processing increases the likelihood that the material is stored in long-term memory and can be successfully retrieved (e.g., on a multiple-choice test). For example, note-taking involves elaboration that enhances memory for lecture content (i.e., the "encoding effect" of note-taking; see Kobayashi, 2005).

Conversely, when an inattentive state spreads from Student A to Student B, Student B invests fewer attentional resources in the educational material, thereby reducing elaboration and decreasing the likelihood of encoding into long-term memory. The result is worse academic performance. Several behaviors indicate low investment of attentional resources/limited elaboration including infrequent eye gaze on relevant information, disengaged posture (i.e., slouching), infrequent note-taking, and fidgeting (e.g., Carriere et al., 2013).

The Present Research

The purpose of the present research was to investigate the proposed phenomenon of "attention contagion"—which we define as the spread of attentive or inattentive states across members of a group—in the context of students in a learning environment. We aimed to establish the existence of this phenomenon and to elucidate how it influences students' attention and memory. It is important to advance knowledge of factors that influence students' attention given that they frequently are inattentive: Wammes et al. (2019) found that undergraduate students were, on average, inattentive 30% of the time during lectures, and that their inattention was costly, resulting in worse memory for lecture content and worse academic performance.

To our knowledge, prior research has not examined the spread of (in)attention in learning environments, beyond the limited scope of *distraction* due to peers' behavior (e.g., Frisby et al., 2018) and use of electronic devices (e.g., Glass & Kang, 2019; Sana et al., 2013). The present research therefore fills an important gap in the literature by investigating the spread of (in)attention between students in a device-free classroom, and the downstream consequences for memory. As well, we aimed to show that, although distraction may play a role, it is not the only factor contributing to attention contagion.

We examined attention contagion between student dyads in a laboratory room set up to resemble a small section of a classroom. In each experimental session, one undergraduate research participant and one confederate (posing as a participant) watched a lecture video on ancient Roman architecture. We experimentally manipulated the confederate's behavior to be attentive (attentive-confederate condition) or inattentive (inattentive-confederate condition), and we used both self-report and behavioral measures of attentiveness to examine the extent to which (in)attentive states spread from the confederate to the participant.

Our preregistration plan for data collection (see https://osf.io/3ncsm) had two phases. In *Phase 1*, the confederate always sat (diagonally) in front of the participant and was visible for the duration of the lecture video. We expected the participant to perceive the (in)attentiveness of the confederate, which would lead to attention contagion (via one or more of the mechanisms described above). If we found evidence of attention contagion, then we would proceed with *Phase 2*, in which the confederate sat *behind* the participant. We expected that the participant now would not perceive the (in)attentiveness of the confederate, which would preclude attention contagion. If the participant did not detect the attentiveness of the confederate in Phase 2, then our plan was to use the Phase 2 data (collapsing the attentive and inattentive conditions) as a baseline against which the Phase 1 data could be compared to assess the extent to which attentiveness (vs. inattentiveness) spread when confederates were visible.

To foreshadow, we unexpectedly found that participants readily perceived the attentiveness of confederates who sat behind them; the Phase 2 data therefore could not serve as a proper baseline level of attentiveness. Instead, we modified our preregistered plan to conduct exploratory analyses on our Phase 2 data—analyses that addressed the intriguing research question of whether attention contagion occurs even in the absence of distraction. For the sake of enhancing the organization and clarity of our results, we present our first phase of data collection as Experiment 1 and our second phase of data collection (following our modified research plan) as Experiment 2.

Experiment 1

Our four main research questions (RQs) are summarized in Table 1, alongside our corresponding hypotheses. For brevity, we simply state the predicted effect of the attentive condition.

> *RQ1: Does (in)attentiveness spread from one student to another during a lecture ("attention contagion")?*

All three theories—social appraisal, goal contagion, and cognitive load—support the notion that "attention contagion" occurs in learning environments. Therefore, participants who watch the lecture with an attentive confederate will be more attentive.

> *RQ2: Does attention contagion affect the quantity of lecture notes?*

More detailed note-taking is indicative of more elaborative processing and/or sustained attention in the lecture, and should be strongly influenced by attention contagion. Thus, participants who watch the lecture with an attentive confederate will take more lecture notes.

> *RQ3: Is attention contagion driven by factors other than distraction?*

The three theories suggest that distraction is only one factor plausibly contributing to attention contagion. While distraction may contribute to the spread of *inattentiveness* between students, social appraisals, and goal contagion may contribute to the spread of *attentiveness*. We therefore attempted to minimize the influence of peer distraction on our results by (a) prohibiting smartphones and laptops in the learning environment and (b) training confederates not to display distracting behaviors. Nonetheless, we included distraction measures both during and after the lecture. We expected that confederates' (in)attentiveness would still affect participants' (in)attentiveness after controlling for distraction.

> *RQ4: Does attention contagion affect memory for lecture content?*

When students are attentive during lectures, they process relevant information more elaboratively, resulting in better memory (Gallo et al., 2008). Thus, we hypothesized that as a consequence of attention contagion, participants who watched the lecture with an attentive confederate should have better memory for the lecture content.

Method

Here we include essential methodological details. The interested reader can find details needed for an exact replication of this experiment in our supplemental online materials (SOM; see also https://osf.io/3ncsm). This study was approved by the Office of

Table 1
Research Questions and Hypotheses Across Experiments 1 and 2

Research question (RQ)	Hypothesis
RQ1: Does (in)attentiveness spread from one student to another? ("attention contagion")	Greater attention will be reported in the attentive condition.
RQ2: Does attention contagion affect the quantity of lecture notes?	Greater note-taking will occur in the attentive condition.
RQ3: Is attention contagion driven by factors other than distraction?	Results from RQ1 and RQ2 will persist when controlling for distraction.
RQ4: Does attention contagion affect memory for lecture content?	Greater memory for content will be demonstrated in the attentive condition.
RQ5: Can students "catch" the (in)attentive states of peers who are not visible to them?	None (exploratory).

Note. Hypotheses for each corresponding research question were developed through a consideration of the social appraisal, goal contagion, and cognitive load theories discussed in the introduction. Implications of our results for corresponding theories are discussed further in the General Discussion. RQ1-RQ4 were assessed in Experiments 1 and 2. RQ5 was assessed in Experiment 2.

Research Ethics at the University of Waterloo, protocol #22492, titled "Attention while watching a lecture."

Participants

To determine a suitable sample size, we ran an *a priori power* analysis using G*Power (Erdfelder et al., 1996), which revealed that 64 participants per condition were needed to have 0.80 power to detect an effect as small as $d = 0.50$ (at $\alpha = .05$) between the attentive-confederate and inattentive-confederate conditions. (Given that there was no prior research on attention contagion, there were no extant effect sizes on which we could base an effect size estimate.) We considered this our minimum acceptable sample size. However, to maximize statistical power, our objective was to run as many participants as possible during the Fall 2018 semester while still leaving enough time to run a roughly equivalent number of participants in Phase 2 of our data collection, presented below as Experiment 2.

We ran a total of 171 undergraduate students at the University of Waterloo, who participated in exchange for course credit. Participants were recruited from a pool of students who enrolled in a psychology course. We did not impose any exclusion criteria on recruitment: anyone in the participant pool could sign up (including non-native English speakers). Individual differences were addressed via random assignment.

We excluded the data of four participants due to noncompliance (one retroactively withdrew consent, two used smartphones during the study despite the instructions, and one did not fill out the "Post Lecture Questionnaire"). Our final sample therefore consisted of 167 participants (female = 119, male = 45, nonbinary = 3; $M_{\text{age}} = 19.29$, $SD = 2.34$), 80 in the attentive-confederate condition and 87 in the inattentive-confederate condition. A sensitivity analysis using G*Power showed that our final sample size had adequate statistical power (0.80) to detect an effect size as small as $d = 0.44$ (at $\alpha = .05$) between conditions.

Design

Each experimental session consisted of a dyad (a participant and a confederate posing as a second participant) and took place in a laboratory room set up to resemble a small section of a classroom—with four desks positioned in 2×2 formation. Each participant was randomly assigned to watch a lecture video with a confederate, with the participant seated behind, and diagonally across from the confederate (see Figure S1 in the SOM). Confederates had been trained to behave attentively or inattentively for the duration of the lecture. To avoid confounding confederates with conditions, individual confederates alternated between acting attentively and inattentively across successive participants.

Confederates

Ten undergraduate research assistants (seven female, three male) served as confederates; 71 participants completed the experiment with a male confederate, 96 with a female confederate. The confederates were 19–34 years old and of diverse ethnic backgrounds (five South Asian, two Caucasian, one East Asian, one East African, and one South Asian/Caucasian), enhancing the generalizability of our results. In the attentive-confederate condition, for the entire duration of the video, confederates leaned forward (see Chisholm et al., 2013, for evidence that leaning forward conveys attentiveness), had their gaze predominantly focused on the video, and frequently took notes. Conversely, in the inattentive-confederate condition, confederates slouched in their chair, shifted their gaze (e.g., glanced at the clock), and infrequently took notes. To ensure that our results were not driven by distraction, confederates were trained to avoid visually or auditorily distracting behavior (e.g., leg-bobbing, restless shifting, audible yawning). We emphasized to confederates that their inattentive behaviors should be *less* active and engaged (e.g., taking fewer notes) than their attentive behaviors. To ensure that participants behaved in accordance with their training, we conducted a treatment fidelity assessment of their behavior using hypothesis-blind coders. Those analyses, which show that confederates admirably adhered to their training, are reported in the SOM.

Lecture Video

We used a Yale Open Courses lecture titled "Civic Life Interrupted: Nightmare and Destiny on August 24, A.D. 79" (https://oyc.yale.edu/history-art/hsar-252/lecture-4). The video shows Professor Diana Kleiner lecturing to her Roman Architecture undergraduate class on the history and architecture of ancient Pompeii. We chose this lecture because it contained obscure information so that participants' memory for the lecture would more likely be attributable to their attentiveness than to their prior knowledge. Additional details related to our use of the lecture video are provided in the SOM. The lecture video was abridged to 48:05 min and divided into 16 sections that varied from 1:51 to 3:28 min in length. During each section, the video was briefly interrupted with a thought probe (described below).

Measures

Thought Probes

Thought probes served as a self-report measure of attentiveness. Immediately following each of the 16 video sections, participants were given 10 s to respond to a single thought probe:

"Just prior to the lecture pausing, where was your attention directed? (circle a letter below)"

1. to the lecture (i.e., *on task*),
2. to thoughts unrelated to the lecture and unrelated to the current environment (i.e., *mind-wandering*),
3. to information in the environment unrelated to the lecture (i.e., *sights and sounds in the lab*)."

Per the recommendation of Seli et al. (2018), we operationalized mind-wandering as thoughts unrelated to the lecture and to the current environment (e.g., the lab room and/or the other participant). The "sights and sounds" response option was included with the goal of potentially being able to distinguish the influence of attention contagion from that of distraction on participants' attentiveness to the lecture video. The internal consistency of the probe responses (Cronbach's α = .73) was in the "acceptable" range (DeVellis, 1991), signifying that there was some fluctuation in students' attentiveness during the lecture.

Video-Coded Participant Behavior

To obtain a representative sample of participants' behavior throughout the lecture, we sampled four 70-s segments, one segment from each quadrant of the lecture duration. These segments included the 60 s prior to thought probes 3, 7, 11, and 15, and the 10 s during which each of these thought probes was presented (during which these behaviors were also evident). Each video was randomly assigned to one of two trained coders who were blind to the study purpose and hypotheses. Coders rated participants on three behaviors: (a) attentiveness; (b) fidgeting; and (c) sleepiness. We chose these behaviors because they were readily observable and related to our attention contagion hypothesis. Fidgeting is associated with inattention (e.g., Carriere et al., 2013; Farley et al., 2013) and so is sleepiness (e.g., McVay et al., 2009). Coders used a piece of cardboard to block their view of the confederate, so that the confederate's behavior would not influence their ratings.

Samples of each behavior—selected from a pilot test of our study—were used to train coders. These samples, and the coding scheme, are provided in the SOM. Each behavioral category was coded on a scale from 1 (*Not at all*) to 5 (*Very*) according to how often participants exhibited the behaviors in the category. To ensure reliability, a third hypothesis-blind research assistant was assigned to code a random 25% of each coder's responses (Hallgren, 2012). Inter-rater agreement was assessed through the average measures of a one-way random, intra-class correlation coefficient (ICC; Landers, 2015). As a reliability index measure, ICC scores between 0.5 and 0.75, 0.75–0.90, and above 0.90 are considered moderate, good, and excellent scores, respectively (Koo & Li, 2016). By this standard, the scores for attentiveness ($ICC_{attentiveness}$ = .78) and sleepiness ($ICC_{sleepiness}$ = .78) were good, while the score for fidgeting was moderate ($ICC_{fidgeting}$ = .56). The results for fidgeting should therefore be interpreted with caution.

Note-Taking

Participants were given two blank sheets of paper and a pen that they could use to take notes during the lectures. We subsequently counted the number of words in notes.

Multiple-Choice Test

Immediately following the lecture, participants answered 16 four-alternative multiple-choice questions (see https://osf.io/3ncsm) regarding the lecture content. These questions corresponded to the 16 sections of video, each of which pertained to a disparate landmark or historical detail of ancient Pompeii.

Post Lecture Questionnaire

After the multiple-choice questions, as a manipulation check, participants (as part of a "Post Lecture Questionnaire") rated how attentive the "other participant" was, on an 11-point Likert scale from 0 ("*Not at all attentive*") to 10 ("*Extremely attentive*"). Participants also rated how distracting the "other participant" was from 0 ("*Not at all distracting*") to 10 ("*Extremely distracting*"). This allowed us to examine whether participants found the inattentive confederate more distracting (which could contribute to our hypothesized attention contagion effects). Five additional items were included in the questionnaire and are reported in the SOM. Last, participants typed an open-ended response to the question, "What do you think this study was about?", which we used to identify any participant who was suspicious of the other participant being a confederate.

Results

Prior to analyses, we assessed participant responses for potential concerns regarding outliers and missed thought probe responses. We report these analyses in the SOM: adjusting for these concerns did not affect our primary results.

Manipulation Check

A treatment fidelity assessment of our confederates reported in the SOM indicated that attentive confederates behaved more attentively than inattentive confederates. On a 0 (*not at all*) to 10 (*very much*) scale, participants in the attentive-confederate condition gave significantly higher ratings of attentiveness of the "other participant" in the room (M = 8.88, SD = 1.18) than did those in the inattentive-confederate condition (M = 4.29, SD = 2.35), $t(129.39) = 16.13$, $p < .001$, $d = 2.45$. Thus, participants perceived attentive confederates to be substantially more attentive than inattentive confederates.

Analytic Approach

Our planned analyses targeted the four RQs in Table 1. Table 2 shows the means of our main DVs in each condition. We tested for

Table 2
Experiments 1 and 2: Means (With Standard Deviations) in Each Condition and Independent-Sample t-*Tests*

Measure	Attentive *M (SD)*	Inattentive *M (SD)*	Overall *M (SD)*	*t*-test
Experiment 1				
"On task" probe response	79.73 (17.31)	72.93 (19.47)	76.19 (18.72)	$t(165) = 2.38$, $p = .019$, $d = 0.37$
Attentive behavior rating	3.85 (0.69)	3.36 (0.75)	3.59 (0.76)	$t(161) = 4.27$, $p < .001$, $d = 0.67$
Fidgety behavior rating	1.72 (0.51)	1.96 (0.65)	1.84 (0.60)	$t(159.40) = 2.72$, $p = .007$, $d = 0.42$
Sleepiness behavior rating	1.46 (0.49)	1.77 (0.80)	1.63 (0.69)	$t(145.61) = 3.00$, $p = .003$, $d = 0.46$
Word count of notes	342.93 (187.31)	220.98 (181.30)	279.40 (193.79)	$t(165) = 4.27$, $p < .001$, $d = 0.67$
Test performance	58.75 (16.20)	53.14 (18.39)	55.83 (17.55)	$t(165) = 2.08$, $p = .039$, $d = 0.32$
Distraction rating	2.19 (2.12)	3.16 (2.61)	2.69 (2.43)	$t(162.59) = 2.66$, $p = .009$, $d = 0.41$
Experiment 2				
"On task" probe response	79.17 (22.15)	75.15 (23.76)	77.13 (22.91)	$t(83) = 0.81$, $p = .422$, $d = 0.18$
Attentive behavior rating	3.94 (0.63)	3.23 (0.68)	3.58 (0.74)	$t(82) = 4.92$, $p < .001$, $d = 1.07$
Fidgety behavior rating	1.63 (0.53)	1.85 (0.59)	1.75 (0.57)	$t(82) = 1.78$, $p = .079$, $d = 0.39$
Sleepiness behavior rating	1.40 (0.42)	1.92 (0.77)	1.67 (0.69)	$t(65.65) = 3.85$, $p < .001$, $d = 0.83$
Word count of notes	382.86 (201.18)	204.86 (163.28)	292.81 (202.73)	$t(83) = 4.48$, $p < .001$, $d = 0.97$
Test performance	55.86 (14.48)	53.67 (16.83)	54.75 (0.16)	$t(83) = 0.63$, $p = .534$, $d = 0.14$
Distraction rating	1.83 (2.07)	2.49 (2.00)	2.16 (2.05)	$t(83) = 1.22$, $p = .224$, $d = 0.32$

Note. Dependent measures include: the mean percentage of probe responses in which participants indicated that they were on task; mean video-coded attentive behavior rating (1–5 scale); mean fidgety behavior rating (1–5 scale); mean sleepiness behavior rating; mean word count of notes taken during the lecture; mean percentage of correct responses on multiple-choice test of lecture content; and mean rating of how distracting the "other participant" (i.e., the confederate) was.

significant differences between conditions using independent-samples *t*-tests (also reported in Table 2). When applicable, we adjusted for unequal variances (revealed by a Levene's test). To isolate the influence of confederate-attentiveness on our main DVs (RQ3), we conducted some analyses that statistically controlled for this difference in distraction between conditions.

RQ1 Analyses

"On Task" Probe Responses

As predicted, participants who watched the lecture with an attentive confederate reported being "on task" for a significantly higher percentage of probes than did participants who watched the lecture with an inattentive confederate.[1] Appendix explores trends in "on-task" probe responses over time.

Video-coded Behavior (Attentiveness, Fidgeting, Sleepiness)

Averaging across the four segments of the participant videos, those in the attentive-confederate condition were rated as behaving significantly more attentively, significantly less fidgety, and significantly less sleepily. In the SOM, we analyze the video-coded behavioral ratings over time (i.e., over the four segments).

RQ2 Analysis

Participants who watched the lecture with an attentive confederate took significantly more words of notes than did those who watched the lecture with an inattentive confederate.

RQ3 Analyses

As shown in Table 2, participants in the inattentive-confederate condition rated the confederate as significantly more distracting than did participants in the attentive-confederate condition. Although our confederate-attentiveness manipulation was not entirely effective in controlling for confederate distraction, distraction ratings were quite low in both conditions, and the mean difference was small. Given this significant difference in distraction between conditions, we proceeded as planned to include the distraction measure covariate in ANOVA models that included our main attentiveness measures as outcomes. When "on task" probe responses was the outcome, the effect of condition (attentive vs. inattentive confederate) retained its significance, $F(1, 164) = 4.10$, $MSE = 0.03$, $p = .045$, $\eta_p^2 = .02$. This was also the case for video-coded ratings of attentive behaviors, $F(1, 160) = 17.42$, $MSE = 0.53$, $p < .001$, $\eta_p^2 = .10$, fidgeting, $F(1, 160) = 6.77$, $MSE = 0.35$, $p = .01$, $\eta_p^2 = .04$, and sleepiness, $F(1, 160) = 8.23$, $MSE = 0.46$, $p = .005$, $\eta_p^2 = .05$, and for note-taking, $F(1, 164) = 19.02$, $MSE = 34060.89$, $p < .001$, $\eta_p^2 = .10$.

RQ4 Analyses

We excluded the three questions not covered by the abbreviated lecture video (see Table S1 in our SOM) in our analyses of the multiple-choice test.[2] Internal consistency of the remaining 13 items was poor (Cronbach's $\alpha = .54$) due to the low-interrelatedness of our test items (see Tavakol & Dennick, 2011). Average test performance ($M = 55.83\%$) was well above chance (25%, given four

[1] Regarding the other two probe response options, participants in the attentive-confederate condition reported mind-wandering on a nonsignificantly different percentage of probes ($M = 15.27$, $SD = 14.71$) than did participants in the inattentive-confederate condition ($M = 18.84$, $SD = 15.98$), $t(165) = 1.50$, $p = .136$, $d = 0.23$, and participants in the attentive-confederate condition reported attending to unrelated sights and sounds on a non-significantly different percentage of probes ($M = 5.00$, $SD = 8.34$) than did participants in the inattentive-confederate condition ($M = 6.94$, $SD = 7.89$), $t(165) = 1.54$, $p = .125$, $d = 0.24$.

[2] A one-sample *t*-test revealed that participants' mean performance on these questions ($M = .22$, $SD = .24$) was nonsignificantly different from chance, $t(166) = 1.43$, $p = .154$. Although unintended, this result suggests that participants in fact had little prior knowledge of the lecture topic, as we had intended.

response options). Of main interest, participants in the attentive-confederate condition ($M = 58.75\%$ correct) performed significantly better than participants in the inattentive-confederate condition ($M = 53.14\%$ correct). There was also a significant positive correlation between the proportion of probes for which participants reported having been "on task" and their later performance on the multiple-choice test, $r(165) = .37$, $p < .001$.

Exploratory Mediation Models

We conducted mediation models using the Hayes PROCESS Macro version 3.4 (see Figure 1). Post-hoc power analyses are reported in the SOM. Indirect effects were deemed to be significant if 0 did not fall between the 95% confidence intervals generated by 5,000 bootstrapped samples (Hayes, 2017). In all models, the confederate-attentiveness manipulation was the IV and the DV was test performance; the confederate distraction measure was a mediator. Each of the three main participant attention measures was a second, parallel mediator: "on task" probe responses (Figure 1a), video-coded attentive behavior ratings (Figure 1b), and note-taking (Figure 1c). Because these measures were highly intercorrelated, we did not include all three of them in the same mediation model (see Table 3). Significant indirect paths through the attentive measures suggest that confederates' attentiveness affected participants' attentiveness (controlling for distraction), which, in turn, affected test performance.

The results were consistent across the three models, revealing that when controlling for distraction, "on task" probes (95% CI [0.01, 0.12]), attentive behavior ratings (95% CI [0.03, 0.17]), and note-taking (95% CI [0.02, 0.14]) were significant, indirect effects. The indirect path of distraction was only marginal when alongside "on task" probes, 95% CI [−0.002, 0.07], but was significant when in parallel with attentive behavior ratings, 95% CI [0.003, 0.17], and note-taking, 95% CI [0.004, 0.09]. Together, these mediation models suggest that our confederate-attentiveness manipulation influenced test performance via two separate indirect paths: by influencing participant attentiveness and by influencing participant distraction.

Discussion

In Experiment 1, our findings indicated that the (in)attentive state of the confederate did spread to the participant, clearly supporting our "attention contagion" account. Relative to participants who watched the lecture with an inattentive confederate, participants with an attentive confederate (a) reported being "on task" more often, (b) behaved more attentively, and (c) took more lecture notes. The effect size of the self-report measure was fairly small ($d = 0.37$) while the effect sizes of the behavioral measures were moderate-large ($d = 0.42$–0.67). Notably, each of these significant differences retained their significance after statistically controlling for how distracting participants indicated that the confederate was—demonstrating that the attentiveness of confederates influenced the attentiveness of participants above and beyond the influence of distraction.

Temporal analyses of the self-reported attentiveness measure (Appendix) suggest that the effect of attention contagion strengthened gradually over the first half of the lecture (with increased exposure to the confederate); the behavioral coding measures suggest that the behavioral effects of attention contagion emerged by the third section of the lecture video (see SOM).

Furthermore, consistent with our hypothesis that attention contagion influences memory, we found that participants who watched the lecture with an attentive (vs. inattentive) confederate had better memory for lecture content (as assessed by performance on a multiple-choice test). Indeed, a series of mediation models (see Figure 1) consistently revealed a significant indirect path whereby attentive (vs. inattentive) confederates increased the attentiveness of participants which, in turn, resulted in participants performing better on the test. The positive relation between participants' attentiveness and their test performance can be explained in terms of attentive participants more deeply processing relevant lecture information (e.g., by taking detailed notes), resulting in more elaborative encodings in memory (Gallo et al., 2008). In sum, the results of Experiment 1 supported all four of our main hypotheses (see Table 1).

The mediation models also revealed that distraction was a significant mediator: Inattentive (vs. attentive) confederates resulted in participants being more distracted which, in turn, resulted in worse test performance. The mediating effect of distraction is consistent with cognitive load theory (Murphy et al., 2016): The more distracting behavior of the inattentive confederates may have imposed an extraneous cognitive load on some participants by either (a) diverting their attention away from the lecture, or (b) causing them to expend cognitive resources to ignore the distraction. Either of these outcomes would have resulted in participants investing fewer attentional resources in the lecture, resulting in poorer memory for lecture content.

Experiment 2

As previewed in the Introduction, we present the results of the confederate-behind conditions (Phase 2 of our data collection) as Experiment 2 to parallel those of Experiment 1 and to enhance the organization of our results. We posed a new research question (RQ5).

> *RQ5: Can students "catch" the (in)attentive states of peers who are not visible to them?*

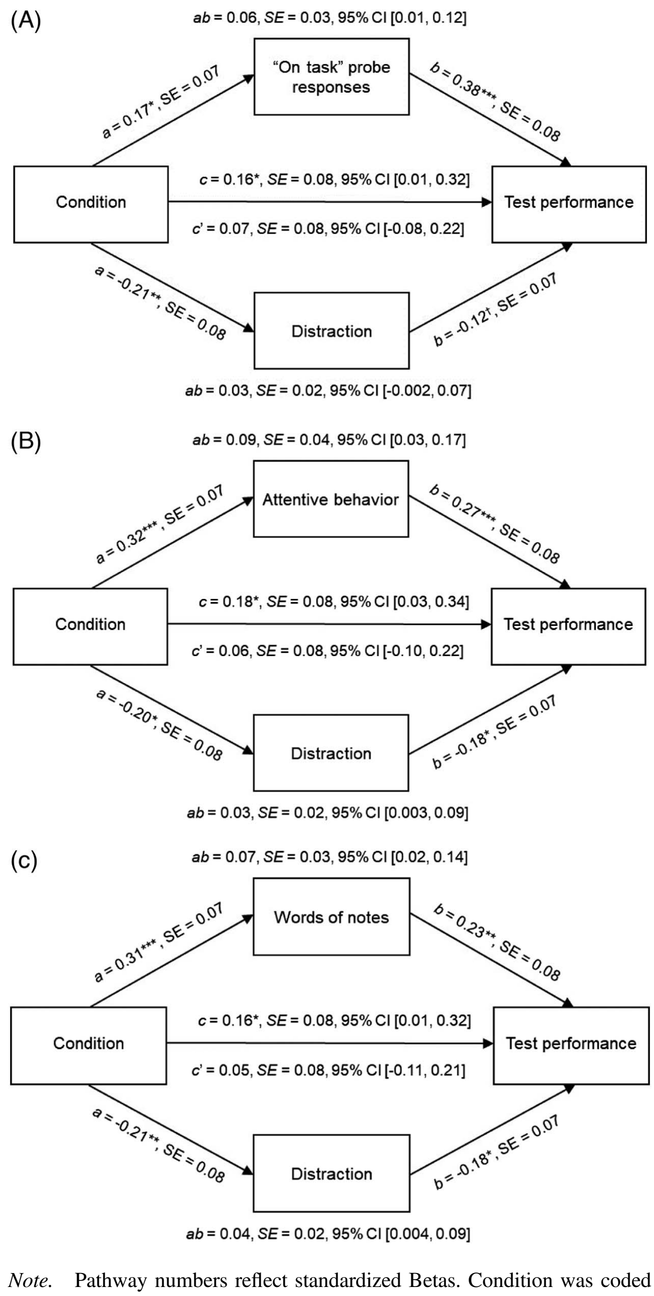
The unexpected result of our manipulation check—that participants were aware of the confederates' level of attentiveness despite not being able to see them (perhaps because confederates' note-taking was audible)—suggested two of the potential mechanisms underlying our attention contagion account were still viable when confederates sat behind participants: (a) participants could form *social appraisals* about the importance of the lecture based on confederates' level of attentiveness (in line with social appraisal theory), and (b) confederates' attentiveness signaled a *learning goal that could be unconsciously activated* in participants (in line with goal contagion theory).

Experiment 2 also permits us to more directly address RQ3 (*"Is attention contagion driven by factors other than distraction?"*) because attention contagion would ostensibly be more weakly driven by distraction when the confederate is out of view. In this sense, Experiment 2 (confederates behind) served as a stringent replication of Experiment 1 (confederates in front) to test the boundaries of the attention contagion effect. Thus, the same RQs that were posed for Experiment 1 (see Table 1) were also addressed for Experiment 2.

We wish to be clear that we formed our new research question (RQ5) *after* collecting these data. Because we collected data for

Figure 1

Parallel Mediation Models from Experiment 1. Depicting the Relation Between Condition and Test Performance When Simultaneously Mediated by Distraction Ratings, and the Indirect Effect of "on task" Probes (Panel A), Video-coded Attentive Behavior Ratings (Panel B), and Words of Notes (Panel C)



Note. Pathway numbers reflect standardized Betas. Condition was coded with higher numbers reflecting the attentive-confederate condition. Solid lines represent significant (or marginal) paths and dashed lines represent non-significant paths.

fewer participants in the confederate behind conditions (intending to collapse these conditions into a control condition), we had insufficient statistical power to detect between-subjects differences for some of our dependent measures. This was especially true for measures for which we obtained relatively small effect-size estimates in Experiment 1—in particular the "on task" probe response measure ($d = 0.37$) and the test performance measure ($d = 0.32$). Thus, even if these attention contagion effects were of comparable

Table 3
Experiments 1 and 2: Bivariate Correlation Coefficients (Pearson's r) Between the Main Dependent Measures

Measure	1	2	3	4	5
1 "On task" probe response	—	.52***	.40***	.38***	−.15*
2 Attentive behavior rating	−.02	—	.59***	.30***	−.06
3 Word count of notes	−.03	.27*	—	.24**	.00
4 Test performance	−.15	.36***	.59***	—	−.19*
5 Distraction rating	−.16	.46***	.31**	.61***	—

Note. The coefficients above the diagonal are for Experiment 1 and those below are for Experiment 2.
* $p < .05$. ** $p < .01$. *** $p < .001$.

size in the two experiments, we had low statistical power to detect them in Experiment 2 (see below for a posthoc power analysis). Moreover, if these attention contagion effects were smaller in Experiment 2—which is plausible given that distraction was better controlled between conditions—then this would exacerbate the statistical power issue. Accordingly, all analyses in Experiment 2 should be considered post-hoc and exploratory.

Method

Participants

Eighty-eight different undergraduate students were recruited from the same pool as in Experiment 1 and took part in exchange for course credit. Individual differences were again addressed via random assignment.

Data of three participants were excluded due to experimenter error or participant noncompliance (one mistakenly received the debriefing letter before the experiment began, one used their smartphone during the study, and one selected multiple response options on several thought probes). Our final sample therefore consisted of 85 participants (female = 54, male = 30, nonbinary = 1; $M_{\text{age}} = 19.34$, $SD = 3.13$), 42 in the attentive-confederate condition and 43 in the inattentive-confederate condition. A sensitivity analysis using G*Power showed that our final sample size had adequate statistical power (0.80) to detect an effect size as small as $d = 0.61$ (at $\alpha = .05$) between conditions.

Design, Procedure, and Measures

Using the same room configuration as in Experiment 1, the positions of the participant and the confederate were reversed (see Figure S1 in the SOM). Nine of the ten confederates from Experiment 1 were used for Experiment 2. Sixty-three participants completed the experiment with a male confederate, and 22 with a female confederate. The confederates were instructed to behave identically to how they had behaved in Experiment 1. The lecture video was unchanged as were the note-taking set-up and the multiple-choice test. Again, the internal consistency of the 13 items was poor (Cronbach's $\alpha = .41$), which was not surprising given the difficulty of the test and the low-interrelatedness of the items.

Thought probes and video coding were identical to Experiment 1. The internal consistency of the probe responses (Cronbach's $\alpha = .85$) was in the "good" range (DeVellis, 1991), signifying that there was modest fluctuation in students' attentiveness during the lecture. Video coding ICC scores for each category were acceptable: $\text{ICC}_{\text{attentiveness}} = .73$; $\text{ICC}_{\text{fidgeting}} = .70$; $\text{ICC}_{\text{sleepiness}} = .74$. All measures were identical to those in Experiment 1.

Results

Manipulation Check

Participants in the attentive-confederate condition rated the "other participant" as significantly more attentive ($M = 8.74$, $SD = 1.19$) than did those in the inattentive-confederate condition ($M = 4.58$, $SD = 2.79$), $t(57.11) = 8.98$, $p < .001$, $d = 1.93$.

Analytic Approach

As in Experiment 1, we conducted independent-samples *t*-tests to test for significant effects of confederate-attentiveness on our main DVs (see Table 2, which also shows mean values in each condition).

RQ1 Analyses

"On Task" Probe Responses

The percentage of probes for which participants reported being "on task" was non-significantly different between the attentive- and inattentive-confederate conditions.[3]

Video-Coded Participant Behavior (Attentiveness, Fidgeting, Sleepiness)

Averaging across the four video segments, participants were rated as behaving significantly more attentively in the attentive-confederate condition. Participants were also rated as marginally less fidgety in the attentive-confederate condition, and as significantly less sleepy. In the SOM, we provide analysis of the video-coded behavioral ratings over time (i.e., over the four segments of video).

RQ2 Analysis

Participants who watched the lecture with an attentive confederate took significantly more words of notes.

RQ3 Analyses

Participants' ratings of how distracting the confederate were non-significantly different between the two conditions.

RQ4 Analyses

As in Experiment 1, we excluded the three questions not covered by the truncated lecture video segments (see Table S1 at https://osf.io/3ncsm) in our analyses of the test performance data. Performance

[3] Regarding the other probe-response options, the difference in the percentage of probes for which participants reported mind-wandering also was nonsignificantly different between the attentive-confederate ($M = 15.48$, $SD = 19.68$) and inattentive-confederate ($M = 18.60$, $SD = 16.90$) conditions, $t(83) = 0.79$, $p = .434$, $d = 0.17$, and the percentage of probes for which participants reported attending to unrelated sights and sounds was nonsignificantly different between the attentive-confederate ($M = 4.46$, $SD = 6.66$) and inattentive-confederate ($M = 4.80$, $SD = 6.93$) conditions, $t(83) = 0.23$, $p = .822$, $d = 0.05$.

was non-significantly different between the attentive-confederate condition (M = 55.86% correct) and the inattentive-confederate condition (M = 53.67% correct). However, there was a significant positive correlation between percentage of "on task" probes and performance on the multiple-choice test, $r(83) = .456$, $p < .001$.

Mediation Models

Due to the reduced sample size in Experiment 2, we had low statistical power (see SOM) to test the mediation models used in Experiment 1. However, for consistency, we performed identical mediational analyses to those in Experiment 1 and report the results in the SOM.

Discussion

Experiment 2 tested the boundaries of our attentive contagion account by having the confederate (who behaved either attentively or inattentively) sit behind the participant in each dyad. Otherwise, the experiment replicated the methodology of Experiment 1 (where the confederate was seated in front). Contrary to our initial expectations, participants were clearly aware of whether the confederate behaved attentively or inattentively—despite the confederate being out of view. Possibly, this was because participants heard note taking frequently in the attentive-confederate condition and infrequently in the inattentive-confederate condition. Note-taking sounds (i.e., pen to paper) likely served as an auditory signal of attentiveness, while the absence of those signals may have conveyed inattentiveness (though perhaps to a lesser extent). In short, auditory cues conveyed by note-taking (or its absence) may account for why attention contagion was evident in note-taking and our other behaviors measures: Participants took more notes when with the attentive (vs. inattentive) confederate and appeared to be more attentive, less fidgety, and less sleepy. Thus, even when the confederate sat behind the participant, there was clear behavioral evidence of attention contagion.

The generalizability of our attention contagion account is strengthened by the finding that the effect endured across multiple participant-attentiveness measures when confederates sat behind participants and therefore could not have been visually distracting. Moreover, as noted in the Method section, confederates were trained to avoid being auditorily distracting (e.g., audible fidgeting). Importantly, our online and retrospective distraction measures were low and non-significantly different across conditions, which confirms that confederates were not more distracting when behaving inattentively (vs. attentively). Thus, Experiment 2 demonstrates that distractions—whether visual or auditory—are not necessary for attention contagion to occur between students (though they may strengthen the effect).

In the absence of distraction, attention contagion may still occur via goal contagion: For example, the participant may have heard the confederate frequently taking notes which may have unconsciously activated a learning goal in the participant (consistent with goal contagion theory; Aarts et al., 2004), resulting in the participant becoming more attentive. Alternately—or as well—the sound of note-taking may have led participants to form a social appraisal that the lecture information was important, which may also have boosted participants' attentiveness (in line with social appraisal theory; Manstead & Fischer, 2001).

Attention contagion was not evident, however, in our self-report measure of attentiveness (i.e., "on task" probe responses) or in our measure of memory for lecture content (i.e., test performance) in Experiment 2. The power analysis reported in the Method section suggests that these null effects may simply reflect Type II errors arising from a reduced sample size. Another possibility is that attention contagion was weaker when the confederate was not visible (Experiment 2) compared to when the confederate was visible (Experiment 1), perhaps because distraction only contributed to the spread of inattention when the confederate was visible. Alternately, the effect of attention contagion may have been larger when the confederate was visible because participants were able to observe more attentive/inattentive behaviors (e.g., confederate posture and gaze direction), increasing the likelihood that a learning goal was activated.

General Discussion

Across two experiments, we found broad support for our attention contagion hypothesis. When confederates sat in front of participants (Experiment 1), we found consistent evidence in support of all of our RQs that attention spread from the confederate to the participant, in terms of both an online self-report measure of attentiveness ("on task" probe responses) and video-coded behavioral measures of attentiveness, fidgeting, and sleepiness. When confederates sat behind participants (Experiment 2), exploratory analyses revealed surprising evidence of attention contagion, though only in the behavioral measures (including note-taking), possibly reflecting a Type II error arising from an underpowered sample size.

The results of Experiment 1 supported our hypothesis that attention contagion affects memory for lecture content. First, participants with an attentive (vs. inattentive) confederate had better memory for lecture content (per multiple-choice test performance). Second, our self-report and behavioral attentiveness measures were both strongly positively correlated with test performance (see Table 3). And third, each attentiveness measure significantly mediated the relation between experimental condition and test performance. In Experiment 2, there were also significant positive correlations between the attentiveness measures and test performance (Table 3) despite the confederate-attentiveness manipulation not affecting test performance.

Theoretical Implications

The results of both experiments converged to support our hypothesis that attention contagion is driven by factors other than distraction. Two results undergird this conclusion. First, when we statistically controlled for confederate distraction in Experiment 1, we still found that (in)attentiveness spread from confederates to participants, beyond the effect of distraction. Second, when confederates were seated behind participants (in Experiment 2)—and distraction was therefore minimized—we still obtained evidence of attention contagion across our behavioral attention measures (including note-taking).

What other factors, apart from distraction, could have contributed to the attention contagion effects observed in Experiment 1? Social appraisals and goal contagion (two factors described in the Introduction) are plausible candidates. Consistent with social learning theory (Bandura, 1977), social appraisal theory (Manstead &

Fischer, 2001) suggests that participants who were aware of the confederate in their dyad acting attentively—whether those attentive behaviors were observed visually (e.g., saw the confederate take lecture notes) or auditorily (e.g., heard the confederate take lecture notes)—would have been more likely to have appraised the lecture as important/valuable and therefore to have invested more attentional resources. Goal contagion theory, on the other hand, presumes that participants who observed the confederate engaging in attentive behaviors would have been more likely to have unconsciously activated learning goals that would have caused an increase in attentive behavior. Note that social appraisal theory and goal contagion theory may be related insofar as students who appraise a lecture as important (on the basis of observing a classmate's attentive behaviors) may be more likely to have learning goals activated.

For both social appraisals of value and the contagion of learning goals, the putative outcome is that students invest more attentional resources in lecture content (or other information relevant to learning). We posited that this elaborative processing (Craik & Lockhart, 1972) would be evident in attentive behaviors (e.g., note-taking) and would result in better memory for lecture content—and our results strongly supported this prediction. In particular, the mediation models in Experiment 1 (see Figure 1) provided consistent evidence of a causal chain whereby the attentiveness of the confederate influenced the attentiveness of the participant which, in turn, influenced their test performance. This result replicated the link between attention and memory for lecture content found in prior research (e.g., Lindquist & McLean, 2011; Wammes et al., 2016) while establishing a new link between the attentiveness of a student and the attentiveness of his or her peer.

Situating the Concepts of Attention Contagion, Joint Attention, and Shared Attention

Here we have defined *attention contagion* as the transfer of attentive states (and corresponding behaviors) across individuals. In comparison, *joint attention* (for a review, see Mundy & Newell, 2007) refers to a specific process by which the attention of two individuals "triangulates" on a stimulus. An observer first notices the direction of someone else's attention and then orients their own attention in that same direction. This explains why joint attention frequently arises from gaze following (Scaife & Bruner, 1975), which has been observed both in the laboratory—using images of faces (Frischen et al., 2007; Kuhn & Kingstone, 2009; Ricciardelli et al., 2009) and live social interactions (Lachat et al., 2012; Macdonald & Tatler, 2018)—and in public settings including city streets (Milgram et al., 1969) and college campuses (Gallup et al., 2012). Thus, joint attention is another factor that may contribute to attention contagion in educational settings.[4] For example, gaze following could spread inattentiveness when a student follows the gaze of an inattentive classmate who glances periodically at the clock or their phone. Future research could examine this putative relation between joint attention and attention contagion using eye-tracking equipment.

Last, *shared attention*, as defined by Shteynberg (2015, 2018), refers to the experience of collective attention (of two or more individuals) on an object or event. Shteynberg (2015) highlights the main difference between joint attention and shared attention. In joint attention, a person first observes the direction of another's attention and then orients their own attention in that same direction, whereas shared attention does not require this attention-orienting process: A person need only be *aware* that others are attending to the same event (see, e.g., Shteynberg et al., 2016). In the classroom, recent research (Bevilacqua et al., 2019; Dikker et al., 2017) monitoring the brain waves of high school students (using EEGs) during a biology class found evidence of neural synchronicity that was suggestive of *shared attention*. In contrast, our study of *attention contagion* focused on how attentive states can spread between students (using behavioral measures). We suspect, however, that these two concepts are related: the spreading of attentive behaviors would ostensibly strengthen shared attention, whereas the spreading of inattentive behaviors would ostensibly weaken shared attention.

Limitations

As in any initial investigation of a phenomenon, our research had a number of limitations.

1. We employed a self-report measure of distraction (i.e., participants rated on a Likert scale how distracting the confederate was), which was susceptible to self-report biases and metacognitive appraisals. For example, participants in the inattentive-confederate condition may have attributed their own flagging attention to the confederate's lack of engagement in the lecture, leading them to infer that they were "distracted" by the confederate (even though the confederate's behavior may not have been overtly distracting). This limitation could be addressed in future research by using eye-tracking (e.g., Zhang et al., 2006) or gaze direction (e.g., Phillips et al., 2016) to measure visual distraction.

2. Aside from distraction, we did not measure other factors that could plausibly drive the spread of (in)attention across students. We recommend that future studies measure: (a) students' impressions of the value of lecture content (to assess whether social appraisals contribute to attention contagion), and/or (b) the strength of learning goals (to assess whether goal contagion contributes to attention contagion).

3. We were not able to obtain a suitable baseline measure of attentiveness (which would allow determination of the extent to which attention contagion reflects the spread of attentiveness vs. the spread of inattentiveness). Future research could obtain a reasonable baseline of attentiveness by measuring participants' attentiveness when they watch a lecture alone.

4. Although Experiment 2 yielded enticing results suggesting that attention contagion occurs even in the absence of visual distraction (converging with the results of Experiment 1), its analyses were exploratory and limited by

[4] Even when seated behind classmates—and unable to see their eyes—a student could nonetheless infer those classmates' gaze direction based on their head orientation. Indeed, Gallup et al. (2012) found that people are more likely to follow the gaze direction of others when they are situated behind those others than when facing them, perhaps due to civil inattention norms (i.e., the norm to avoid prolonged eye-contact with strangers).

reduced statistical power. Future research should pursue this finding with a more robust sample.

5. We exerted tight control over our experiments to isolate the effect of confederates' attentiveness on participants' attentiveness (while controlling for distraction as much as possible). Having established the internal validity of the effect, future research should study attention contagion in more ecologically valid settings (e.g., in a lecture hall with a large group of students), and across several different subjects and lectures, to establish generalizability.

Considering the Influence of Attention Contagion in Real Classrooms

We have found compelling evidence of attention contagion in a laboratory experiment that simulated a small section of a classroom. But would attention contagion also occur in a real classroom? In this section, we consider this question, addressing six main differences between our simulated learning environment and a real classroom.

First, participants in our learning environment were periodically interrupted by "thought probes" (our online self-report measure of attentiveness) during the lecture. These thought probes may have elicited metacognitive processes that influenced participants' attention to the lecture video, processes that would not occur during a lecture in a real classroom. However, recent research (Wiemers & Redick, 2019) found that thought probes are a "nonreactive" method of measuring attention/mind-wandering during a sustained attention task (i.e., the inclusion vs. exclusion of probes did not affect task performance), which lessens this concern.

Second, students in a real classroom could be more motivated than were the students in our learning environment. Highly motivated students may be less susceptible to attention contagion: they may be unaffected by others' attentive behaviors because they are already at "ceiling" attentiveness, and unaffected by the inattentive behaviors because they are so intently focused on the lecture. That said, we presume that most classes have plenty of students whose motivation (and attention) wavers, and who would thus be susceptible to attention contagion.

Third, students in real classrooms typically have alternate sources (e.g., a textbook, websites) from which they could learn the material taught in class. The availability of these other learning materials could increase students' tendency to appraise the value of the lecture (e.g., "Should I take a lot of notes or is reading the textbook sufficient?"). We have posited that such appraisals may be social in nature (Manstead & Fischer, 2001)—with the classmates' attentive behaviors signaling that a lecture has high value but their inattentive behaviors signaling that a lecture has low value—and may affect students' allocation of attentional resources. Thus, students may more frequently make social appraisals of a lecture's value in a real classroom (with multiple sources for learning) than they did in our learning environment (which had a single source). Following this logic, the effect of attention contagion could actually be stronger in a real classroom.

Fourth, social interactions can occur in real classrooms (e.g., class activities and discussions), but were not permitted in our learning environment. The potential for social interaction in real classrooms raises the possibility of another mechanism that could contribute to attention contagion: behavioral mimicry. Behavioral mimicry refers to the imitation of movements, gestures, facial expressions, speech, and eye gaze (for reviews see Chartrand & Van Baaren, 2009; Chartrand & Lakin, 2013), which can be reflexive and difficult to suppress (e.g., Dimberg et al., 2000). Mimicry occurs spontaneously in social interactions (Chartrand & Bargh, 1999) and is thought to be motivated by affiliation goals (Duffy & Chartrand, 2015). Thus, it is possible that in a real classroom in which social interaction can occur, students are susceptible to non-consciously mimicking various behaviors of their peers; presumably this would not have occurred in our experiments.

Fifth, participants in our learning environment watched a lecture video whereas participants in a real classroom typically watch a live lecture taught by an instructor (although that is changing). It is plausible that instructors can be influenced by the attentiveness of their students (which was one reason that we opted for a video lecture). This raises another possible mechanism by which attention can spread across students in real classrooms: The attentive behavior of a student could serve as positive reinforcement that motivates the instructor; consequently, the instructor may become more enthusiastic, thereby increasing the attentiveness of other students in the class. In this manner, attention contagion could operate indirectly—from student, to teacher, to other student—in a real classroom.

Sixth, distraction is almost certainly more prevalent in a real classroom than in our learning environment (in which there was only one other person and we banned smartphones and laptops). The use of technology for media multitasking is a source of overt distraction in the classroom (e.g., Glass & Kang, 2019; Sana et al., 2013), and therefore could be responsible for spreading inattention. Additionally, we posit that a student's use of technology for media multitasking signals to classmates that the student appraises the lecture as having low value, which (in line with social appraisal theory) could result in a corresponding decrease in classmates' value appraisals of the lecture. Moreover, a student's use of social media may activate similar social goals in classmates (in line with Aarts et al., 2004, goal contagion theory), which could also result in the spread of inattention.

To summarize, although there are several differences between the learning environment used in our experiment and a real classroom, there is little reason to suspect that the attention contagion effect that we observed would be eliminated (or even attenuated) in a real classroom. Thus, the present results and extant theoretical frameworks provide strong justification for conducting future research examining attention contagion in real classrooms.

Practical Implications

The present research has several notable practical implications. First, in establishing the existence of attention contagion in a learning environment, our findings suggest that there are cascading benefits to an instructor boosting the attentiveness of one student in the class (that student's attentive state could then spread to other students) and, likewise, cascading costs to allowing an inattentive student to maintain and transmit their inattentiveness (as an inattentive state could also spread). To have a truly attention-aware classroom (Risko et al., 2012), instructors should thus be aware of the potential influence of attention contagion.

Second, Experiment 2 (though underpowered) suggests that attention contagion occurs even in the absence of distraction. Thus, even in classrooms that reduce overt visual distractions (e.g., by banning technology use), inattention may still spread by other mechanisms (e.g., via a social appraisal that the lecture content is unimportant). Indeed, students' attentiveness may be influenced by the attentiveness of peers not in their line of sight and not engaged in any overtly distracting behaviors. In short, attention contagion is not only driven by distraction, and may be more pervasive in classrooms than most instructors presume.

Third, and relatedly, we have proposed two theoretical accounts—social appraisal theory and goal contagion theory—that both suggest that *attentiveness* (not just inattentiveness) spreads between students. Individual inattentive students may therefore benefit from being grouped with several attentive students for class activities.

Fourth, students should also be aware of the attentional challenges that they face, and perhaps even opt to sit near dedicated, attentive students to optimize their learning.

And fifth, although we obtained broad evidence of attention contagion in the context of student dyads watching a lecture video, we posit that this same phenomenon would occur in other educational settings—and indeed in other contexts that feature an audience and a performative element (e.g., among colleagues watching a presentation at a conference or television viewers watching a political debate).

Conclusion

In carefully controlled experiments, with multiple behavioral measures, we have observed consistent and compelling evidence of attention contagion in a learning environment. Our findings should help educators to be aware of the spread of attention and consequently to develop more attention-aware classrooms (Risko et al., 2012), thereby paving the way for classroom management strategies that foster the spread of attentive behaviors and suppress the spread of inattentive behaviors.

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Appendix

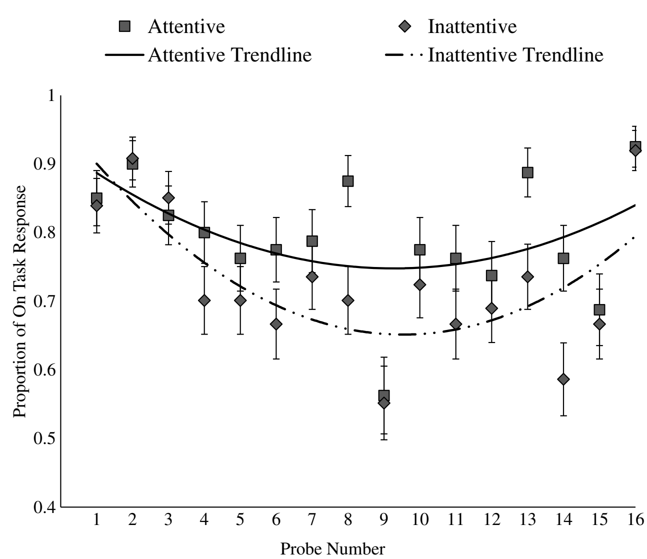
On-Task Probe Responses Over Time in Experiment 1

We analyzed probe responses over time using generalized estimating equations (GEE) to explore whether "on task" probe responses changed over the span of the lecture and, if so, whether this change was moderated by the presence of attentive (vs. inattentive) others. GEE is used for binary data responses over time (Landerman et al., 2011). We used a binary probit model and a first-order autoregressive working correlation matrix (Shults et al., 2009), with the 16 binary probe responses treated as repeated measures over time. This analysis revealed a significantly decreasing rate of on-task responses as the lecture progressed, $B = .013$, $SE = .004$, Wald $X\chi^2(1) = 9.63$, $p = .002$. Condition (attentive confederate vs. inattentive confederate) did not significantly interact with this linear trend, $B = -.01$, $SE = .012$, Wald $\chi^2(1) = 0.76$, $p = .383$. Figure A1 displays the proportion of "on task" responses across the 16 probe responses by condition. Given the observed quadratic pattern in Figure A1, with "on task" responses decreasing over the first half of the lecture and rising toward the end, we tested whether a significant quadratic relation emerged over the span of the lecture. The quadratic relation was robust, $B = -.01$, $SE = .001$, Wald $\chi^2(1) = 93.69$, $p < .001$, and the moderation of the quadratic trend by condition was marginal, $B = .005$, $SE = .003$, Wald $\chi^2(1) = 3.00$, $p = .083$.

Given the observed quadratic pattern, and the ongoing debate concerning student attention span (Bradbury, 2016), we decided to perform further exploratory analyses of the probe responses over

Figure A1

Proportion of "On-Task" Responses by Experimental Condition Across the 16 Probes

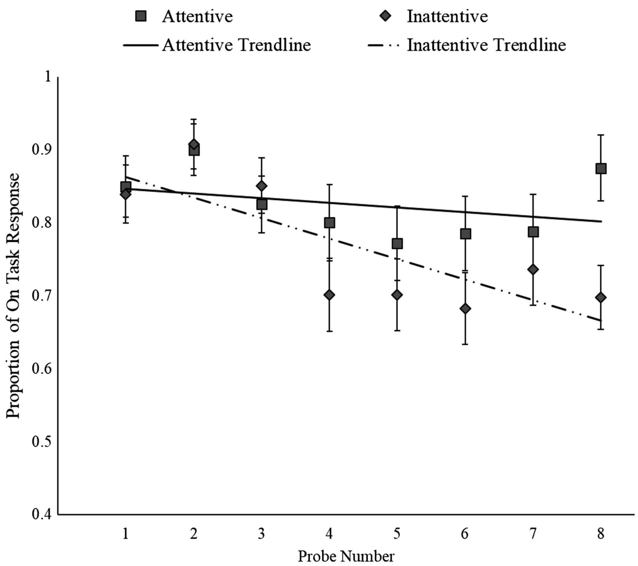


Note. Trend lines represent the least squares fit quadratic function for probe responses. Error bars represent standard errors.

(*Appendix continues*)

Figure A2

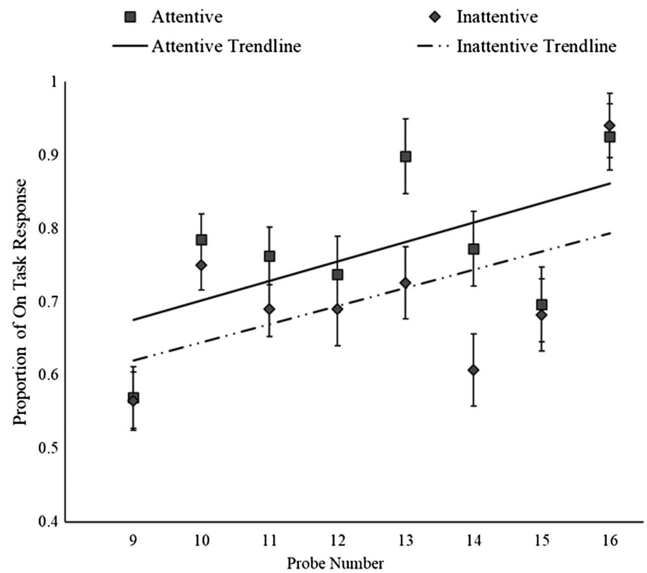
Proportion of "On-Task" Responses by Experimental Condition Across the First Eight Probes



Note. Trend lines represent the least squares fit linear function for probe responses. Error bars represent standard errors.

Figure A3

Proportion of "On-Task" Responses by Experimental Condition Across the Last Eight Probes



Note. Trend lines represent the least squares fit linear function for probe responses. Error bars represent standard errors.

the first half of the lecture and the second half of the lecture—approximately two separate 22-min intervals. For the first half of the lecture, participants with an inattentive confederate showed a steeper decline in on-task responses than did those with an attentive confederate (see Figure A2), $B = -.07$, $SE = .03$, Wald $\chi^2(1) = 4.69$, $p = .030$. This moderation was not apparent in the second half of the lecture, $B = -0.005$, $SE = 0.03$, Wald $\chi^2(1) = .03$, $p = .874$; participants in both the attentive-confederate and inattentive-confederate conditions increased in their reports of being on task as the lecture came to an end (see Figure A3), $B = -.01$, $SE = 0.01$, Wald $\chi^2(1) = 92.65$, $p < .001$.

The observed decrease in "on task" probe responses over time replicated several prior studies that have found that students' attentiveness declines during video lectures (e.g., Farley et al., 2013; Risko et al., 2012, 2013; Seli et al., 2016). Given that students were aware of the length of the lecture, the rebound in "on task" responses toward the end of the lecture suggests that students' awareness of time plays a pivotal role in when their attention may wax and wane. Of course, this is one lecture: Further research using a variety of different lectures would be required to test this account (to rule out the alternate explanation that the quadratic function observed here arose because our lecture video became more interesting toward the end).

Initial investigation into these trends over time suggested that they were not influenced by the presence of an attentive versus inattentive other. However, subsequent exploratory analyses revealed that, in the first half of the lecture, the presence of an attentive other buffered against the monotonic decline in being on task. There is ongoing debate in the literature over what factors contribute to students' dropping rates of attention during a class. Wilson and Korn (2007), for instance, discuss the notion that students' attention spans drop in 10–15 min intervals during a class, but that many different variables can influence whether this occurs. Our findings suggest that the presence of attentive others in our environment can buffer against drops in attention for at least the first 20 min of a lecture.

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