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RESEARCH ARTICLE

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# Learning in double time: The effect of lecture video speed on immediate and delayed comprehension

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## Abstract

We presented participants with lecture videos at different speeds and tested immediate and delayed (1 week) comprehension. Results revealed minimal costs incurred by increasing video speed from 1x to 1.5x, or 2x speed, but performance declined beyond 2x speed. We also compared learning outcomes after watching videos once at 1x or twice at 2x speed. There was not an advantage to watching twice at 2x speed but if participants watched the video again at 2x speed immediately before the test, compared with watching once at 1x a week before the test, comprehension improved. Thus, increasing the speed of videos (up to 2x) may be an efficient strategy, especially if students use the time saved for additional studying or rewatching the videos, but learners should do this additional studying shortly before an exam. However, these trends may differ for videos with different speech rates, complexity or difficulty, and audiovisual overlap.

**KEYWORDS**
comprehension, metacognition, online learning, video speed

## 1 | INTRODUCTION

The use of technology in the classroom and as a learning aid has become ubiquitous, particularly during the COVID-19 pandemic (Pokhrel & Chhetri, 2021; see also Belt & Lowenthal, 2021). Additionally, even before the COVID-19 pandemic, many teachers and professors turned to asynchronous online classes to disseminate course material (Barbour, 2013), with lecture videos being the foundation for learning the material in these classes. Specifically, compared with quizzes, assignments, discussions, and other course activities, students spend the most time watching lecture videos (Breslow et al., 2013). Thus, watching and remembering information from online lecture videos is imperative for course performance and successful learning.

Although asynchronous online classes provide students with the flexibility to choose when and how to learn the material, self-regulating studying can be problematic for some students (see Boekaerts, 1997; Panadero, 2017; Thiede & De Bruin, 2017; Wong et al., 2019; see also Bjork et al., 2013). Specifically, without clearly structured in-person classes, students may struggle to effectively and efficiently allocate their study time and study choices (see Zimmerman, 1989, 1990). For example, students who have less time to devote to academia (e.g., working a part-time job, family obligations) may not allocate sufficient study time to their coursework, leading to impaired memory for to-be-learned material.

In addition to other obligations, students' study regulation may be influenced by instruction pace, perception of the difficulty of the material, and motivation to learn (Sinha et al., 2014). In light of these influences to study regulation, asynchronous online lectures may allow students to bolster their studying efficacy by allowing them to customize when and how they watch pre-recorded lectures. Compared with live lectures, students sometimes claim that their needs are better satisfied when lectures are pre-recorded such that they can learn and retain more of the information, find more time for other

The experiments reported in this article were formally preregistered and the stimuli, data, and analysis code have been made available on the Open Science Framework here.

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activities, manage stress, and stay focused (Cardall et al., 2008). Specifically, one way that students can conserve their time and cope with the demands of online courses is by watching lectures at an increased playback speed. By watching lectures at a faster speed, students can study the same amount of material in a condensed amount of time, giving them more time to allocate to other courses and activities.

Watching asynchronous lectures at a higher speed may be a useful and efficient study strategy if it results in similar or better comprehension than when watching lectures at a normal speed; however, there has been some disagreement regarding the effect of video speed on comprehension. For example, some work has found that increasing the speed of videos can preserve or even enhance comprehension (Lang et al., 2020; Nagahama & Morita, 2017; Wilson et al., 2018) while others suggest that increased speed impairs comprehension (Foulke & Sticht, 1969; Song et al., 2018; Vemuri et al., 2004). These disagreements may be the product of using limited stimuli, measuring comprehension immediately after watching the video (rather than a delayed test), allowing for note-taking and participant control of the videos (i.e., pausing, rewinding), using very short video clips (i.e., 20 s), and small sample sizes.

Regardless of the veridical effect of video speed on comprehension, students may believe that watching videos at an increased speed does not impair learning or may even be an advantageous study technique (see Wilson et al., 2018). Thus, examining learners' awareness of their memory processes (i.e., metacognition; Nelson & Narens, 1990; see also Dunlosky et al., 2016; Nelson, 1996) when watching asynchronous lectures is crucial in understanding how students monitor and regulate their learning. Specifically, students' potentially misguided beliefs about the effect of video speed on learning could result in less effective regulation of study time and poor learning outcomes.

If students watch lecture videos at a faster than normal speed, this could reduce subsequent memory for the material as a result of a cognitive overload (i.e., the amount of information that can be held in working memory at a given time). According to the Cognitive Load Theory (see Sweller, 1988, 1989), when new information is being learned, this information is stored in working memory before being transferred to long-term memory. Although long-term memory capacity is generally considered to be relatively limitless, working memory capacity is much more restricted (Baddeley & Hitch, 1974; Cowan, 2010; Gilchrist et al., 2008; Miller, 1956; also see the Cognitive Theory of Multimedia Learning; Mayer, 2002). Thus, a surplus of information in working memory can hinder transfer to long-term memory, preventing learning (Sweller et al., 2011). Specifically, both the difficulty or complexity of the information (intrinsic cognitive load) and how the information is presented (extraneous cognitive load) can increase cognitive load and impair learning (Paas et al., 2003, 2004; Sweller et al., 1998; van Merriënboer & Sweller, 2005). Applied to playback speed, if lecture videos are watched at a rate that overwhelms our limited cognitive resources, learners' comprehension of the material may be impaired.

Additionally, different modalities of instruction (i.e., audio-visual) may be differentially impacted by increased playback speeds. Specifically, the transient information effect suggests that complex information should not be provided in auditory form as working memory is likely to be overwhelmed. Rather, if to-be-learned material is particularly complex, it may be better learned via reading (whereby critical information can be re-accessed) rather than listening (see Leahy & Sweller, 2011). Thus, as to-be-learned information becomes increasingly complex, the potential costs of increased playback speed may be more pronounced.

At normal speed, lecture videos are easily comprehensible but increasing the playback speed increases the number of words spoken per minute, potentially making the videos too cognitively taxing. For example, humans generally speak at a rate of 150 words per minute (Peelle & Davis, 2012), and prior work suggests that speech comprehension begins to decline at around 275 words per minute if the information is encoded just audibly (see Foulke & Sticht, 1969). However, audiovisual materials (i.e., videos that consist of both visual and audible content) may be more comprehensible at increased presentation speeds due to benefits from the visually presented information. Thus, high-speed lecture videos may lead to deficits in later remembering as a result of decreased speech comprehension and increased cognitive load, but the visual component of lecture videos could compensate for these potential deficits (e.g., Pastore & Ritzhaupt, 2015). However, increased video speeds would result in less time to encode any visually presented information. Taken together, if lecture videos are played at too fast of a speed, memory for the material may be impaired.

## 2 | THE CURRENT STUDY

In the current study, we investigated how watching lecture videos at various speeds affects comprehension and metacognitive monitoring of learning. Specifically, in Experiment 1, participants watched lecture videos at either normal (1x) speed or increased speeds (1.5x, 2x, or 2.5x) and were tested on the video content both immediately and after a delay (1 week). To further investigate the most efficient methods for watching lecture videos, in Experiment 2, we examined whether watching a video twice at 2x speed results in better learning outcomes than watching a single time at 1x speed. In Experiment 3, we tested how different study schedules (watching first at normal speed and again at 2x speed or first at 2x speed and then again at normal speed) affect comprehension. Ultimately, the results of these experiments will provide insight into effective and efficient methods of learning when watching asynchronous online lecture videos.

## 3 | EXPERIMENT 1

In Experiment 1, we investigated how memory for information from asynchronous lecture videos is affected by playback speed. Specifically, participants watched lecture videos on real estate appraisals and the history of the Roman Empire at either 1x speed or increased speeds (1.5x, 2x, or 2.5x) and were tested on the video content both immediately after watching and after a delay (1 week). Additionally, we solicited metacognitive predictions of immediate and delayed

performance to determine whether participants were metacognitively aware of any potential effects of video speed on comprehension. Although we expected that immediate comprehension may be preserved or even enhanced at faster video speeds (see Lang et al., 2020; Nagahama & Morita, 2017), after a delay, we expected increased video speeds to lead to poorer memory performance compared with normal speed. In terms of participants' metacognitive predictions of performance, consistent with a stability bias in memory (cf. Kornell et al., 2011), we expected participants to predict that both immediate and delayed retention would be minimally affected by video speed, as some work suggests that participants may not use retention interval information when making metacognitive judgments (cf. Koriat et al., 2004; Kornell et al., 2011).

## 3.1 | Method

### 3.1.1 | Participants

After exclusions, participants were 231 undergraduate students (aged 18–41: $M = 20.83$, $SD = 2.80$) recruited from the University of California, Los Angeles (UCLA) Human Subjects Pool. All participants were fluent in English and 68% were native English speakers. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., looking up answers) in a post-task questionnaire (participants were told they would still receive credit if they cheated). This exclusion process resulted in two exclusions. Additionally, at the end of the study, if participants self-reported having prior expertise on either video topic (four participants reported having expertise on appraisals and 19 reported having expertise on the Roman Empire), their scores on that topic were excluded from analysis. An a priori power analysis indicates that for an omnibus, one-way analysis of variance (ANOVA) with four groups (video speed), assuming alpha = .05, power = .80, 212 participants would be needed to reliably detect a small effect ($\eta 2 = .05$).

### 3.1.2 | Materials

Participants watched two lecture videos judged by the experimenters to likely present novel material to participants. The videos were on real estate appraisals (12 min and 56 s with 2031 spoken words) and the history of the Roman Empire (14 min and 27 s with 2403 spoken words). The videos were accessed through YouTube and modified to play at four different speeds (1x, 1.5x, 2x, and 2.5x; see Table 1 for video durations and speech rates at each speed). Each video consisted of presentation slides along with a video of the lecturer on the left side of the screen; the videos did not contain captions or subtitles.

To measure learning, we created two comprehension tests (20 questions each; one for immediate comprehension and one for delayed comprehension) for each lecture consisting of multiple-choice and true or false questions; the multiple-choice questions contained four options for participants to select from. Of the 80 total comprehension questions, 51 of the answers appeared verbally only, 1 only appeared visually, and 28 appeared both verbally and visually. Test order was counterbalanced between the immediate and delayed sessions. Comprehension was calculated as the proportion of questions answered correctly across video topics.

**TABLE 1** Video duration (minutes, seconds) and words per minute for each video topic and speed

| | Real estate appraisals | History of the Roman Empire |
|---|---|---|
| 1x duration | 12:56 | 14:27 |
| 1x words per minute | 157 | 166 |
| 1.5x duration | 8:40 | 9:38 |
| 1.5x words per minute | 210 | 234 |
| 2x duration | 6:28 | 7:14 |
| 2x words per minute | 314 | 332 |
| 2.5x duration | 5:10 | 5:47 |
| 2.5x words per minute | 393 | 416 |

### 3.1.3 | Procedure

The procedure used in Experiment 1 is shown in Figure 1. Participants were randomly assigned to watch both videos at either 1x speed ($n = 57$), 1.5x speed ($n = 58$), 2x speed ($n = 59$), or 2.5x speed ($n = 57$). Participants were told that they would be watching a short video and then taking a comprehension test on the material covered in the video. They were also instructed to watch the video in full-screen mode and not to pause the video or take any notes. Participants then watched the video on real estate appraisals, made a prediction of their immediate test performance, took a comprehension test, and made a prediction of their performance on a similar exam in 1 week. When making predictions, participants were asked how many of the 20 questions they expected to get correct.

Next, participants repeated this procedure for the Roman Empire lecture at the same speed as the first video. After a 1-week delay, participants were given 1 week to complete the second part of the experiment. In the second (final) part of the experiment, before taking a similar comprehension test on appraisals, participants predicted their performance. Participants were then tested on real estate appraisals and repeated this procedure for the Roman Empire content. A control group[1] ($n = 123$) who did not watch the lecture videos also completed the comprehension tests to serve as a comparison group to the experimental groups watching videos at either 1x, 1.5x, 2x, or 2.5x speed. Informed consent was acquired, and the study was completed in accordance with UCLA's Institutional Review Board.

## 3.2 | Results

In each experiment, we collapsed predictions and performance across topics to control for variance in learning different subjects and ensure that effects were domain general.

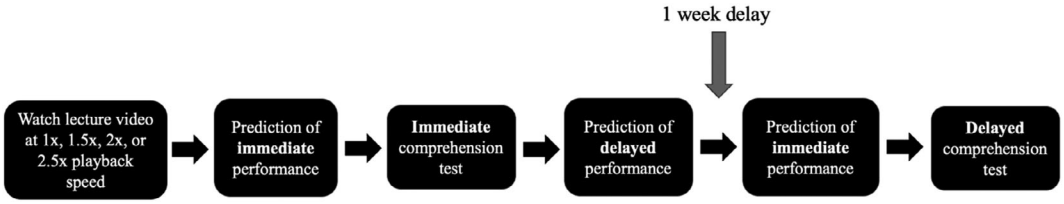


**FIGURE 1** The sequence of events in each trial in Experiment 1. The first trial used the video on real-estate appraisals and the second trial used the video on the Roman Empire

**TABLE 2** Means and *SD* (in parentheses) for predictions and performance at each video speed in Experiment 1

| Video speed | Immediate predictions | Immediate performance | Delayed predctions | Delayed performance | Delayed immediate predctions |
|---|---|---|---|---|---|
| 1x | .54 (.19) | .65 (.13) | .36 (.18) | .59 (.13) | .31 (.17) |
| 1.5 | .49 (.19) | .60 (.16) | .35 (.20) | .54 (14) | .29 (.19) |
| 2 | .48 (.18) | .62 (.14) | .32 (.19) | .53 (.15) | .29 (.12) |
| 2.5x | .43 (.20) | .55 (.15) | .35 (.22) | .50 (.15) | .32 (.20) |

### 3.2.1 | Predictions

Descriptive statistics for predictions and performance at each video speed (1x, 1.5x, 2x, and 2.5x) are shown in Table 2. To investigate possible differences in participants' predictions of performance, we computed a four (video speed: 1x, 1.5x, 2x, 2.5x) x 3 (time: immediate, delayed, immediately before the delayed test) mixed ANOVA. Results revealed a main effect of time ($F[2, 404] = 134.59$, $p < .001$, $\eta 2 = .39$) such that participants' predictions of immediate performance were greater than their predictions of delayed performance, ($p_{bonf} < .001$, $d = .78$) as well as participants' predictions of performance immediately before the delayed test, ($p_{bonf} < .001$, $d = 1.09$); additionally, participants' predictions of delayed performance were greater than their predictions of performance immediately before the delayed test ($p_{bonf} < .001$, $d = .26$). However, results did not reveal a main effect of video speed ($F[3, 202] = .95$, $p = .418$, $\eta 2 = .01$) but there was an interaction between time of predictions and video speed ($F[6, 404] = 2.50$, $p = .022$, $\eta 2 = .02$). A post-hoc ANOVA indicated that for the predictions regarding the immediate test, participants in the 2.5x speed group expected to do worse than participants watching at normal speed ($p_{bonf} = .022$, $d = .19$). However, participants in the 2.5x speed group expected to do similarly as other participants on the delayed test and following the delay, maintained this expectation of performing similarly as the other groups (all $p_{bonf} > .609$, all $d < .08$).

### 3.2.2 | Performance

To examine performance on the immediate and delayed comprehension tests (see Figure 2), we computed a four (video speed: 1x, 1.5x, 2x, 2.5x) x 2 (time of test: immediate, delayed) mixed ANOVA. Results revealed a main effect of test time ($F[1, 202] = 98.96$, $p < .001$, $\eta 2 = .33$) such that performance on the immediate test ($M = .60$, $SD = .15$) was greater than on the delayed test ($M = .54$, $SD = .15$). Additionally, results revealed a main effect of video speed ($F[3, 202] = 3.98$, $p = .009$, $\eta 2 = .06$) such that the 1x group performed better than the 2.5x group ($p_{bonf} = .004$, $d = .24$) but there were no other pairwise differences (all $p_{bonf} > .385$, all $d < .13$). Moreover, time of test and video speed did not interact ($F[3, 202] = .78$, $p = .504$, $\eta 2 = .01$) such that learning outcomes for participants watching at various video speeds did not differ as a function of the time of the test.

### 3.2.3 | Control group

To further elucidate the effect of video speed on immediate and delayed comprehension, we collected an additional sample of 123 undergraduates who did not watch the videos. These participants completed all 80 comprehension questions, and their average performance ($M = .41$, $SD = .49$) is represented by the dashed line in Figure 2. We also asked these participants at what speed they usually watch pre-recorded lecture videos and 15% reported watching at normal speed, 60% reported watching at 1.5x speed, 23% reported watching at 2x speed, and 3% reported watching at 2.5x speed (see Figure 3a). Lastly, we asked participants what lecture video speed they think is the best for learning and 42% selected normal speed, 49% selected 1.5x speed, 8% selected 2x speed, and 2% selected 2.5x speed (see Figure 3b).

## 3.3 | Discussion

In Experiment 1, participants watched lecture videos at either 1x, 1.5x, 2x, or 2.5x speed and took comprehension tests both

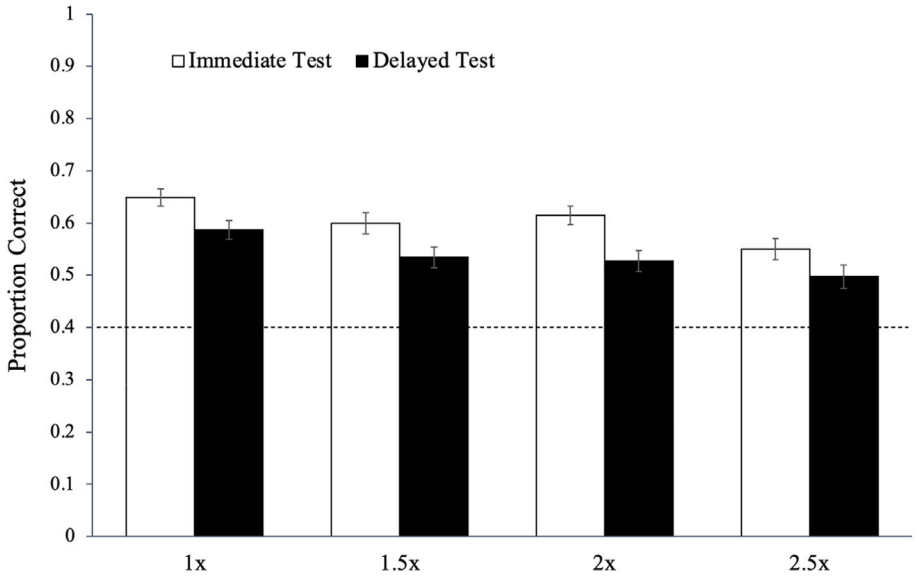


**FIGURE 2** Performance on the immediate and delayed comprehension tests as a function of video speed in Experiment 1. The dashed line represents the mean performance of participants who did not watch the videos. Error bars reflect the *SEM*

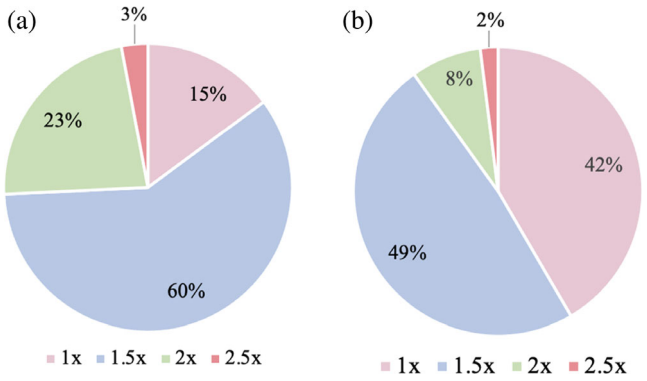


**FIGURE 3** Control group participants' reported speed at which they usually watch lecture videos (a) and the speed that they think is the best for learning

immediately after watching the videos and after a 1-week delay. We also asked participants to predict their immediate and delayed performance to determine whether participants are metacognitively aware of video speed's potential effects on learning. Surprisingly, results revealed that video speed had little effect on both immediate and delayed comprehension such that learning was not significantly impaired in participants watching videos at 1.5x and 2x speed; comprehension was only impaired in participants watching at 2.5x speed. However, despite some learning impairments, participants who watched the videos at 2.5x speed still successfully encoded some of the material.[2]

Finally, participants' predictions of performance did not show any significant differences between the 1x, 1.5x, and 2x speeds; the only pairwise difference was between the immediate performance predictions of the 1x and 2.5x speed groups. Collectively, the results of Experiment 1 revealed that watching lecture videos at 1.5x or 2x does not result in learning impairments, and students could save time and more efficiently learn by watching pre-recorded lectures at faster speeds, but they should not exceed 2x speed.

## 4 | EXPERIMENT 2A

In Experiment 1, results revealed no significant differences in comprehension between participants watching at 1x, 1.5x, and 2x speed. Given that the cost of watching lectures at an increased speed can be minimal, it may be advantageous for students to allocate the time saved from watching videos at a higher speed toward another class or additional studying (Cermak et al., 1996). For example, rather than watching lectures a single time at normal speed, students may be able to enhance learning by watching lectures twice (see Greene, 1989; Hintzman, 1976; Hintzman & Block, 1971; Raajimakers, 2003 for the memory benefits of repetition). Although at normal speed this would take twice the time, if participants watch the videos at 2x speed, they may be able to harness the benefits of repetition without spending additional time studying. In Experiment 2a, we investigated whether participants could enhance learning outcomes without spending additional time studying by watching lecture videos twice at 2x speed compared with once at a normal speed. We expected participants to predict higher performance and demonstrate better learning outcomes after repeated study opportunities (watching twice at 2x speed compared with once at 1x speed).

### 4.1 | Method

#### 4.1.1 | Participants

After exclusions, participants were 106 undergraduate students (aged 18–36: $M = 20.52$, $SD = 2.03$) recruited from the UCLA Human Subjects Pool. All participants were fluent in English and 67% were native English speakers. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., looking up answers) in a post-task questionnaire (participants were told they would still receive credit if they cheated). This exclusion process resulted in one exclusion.

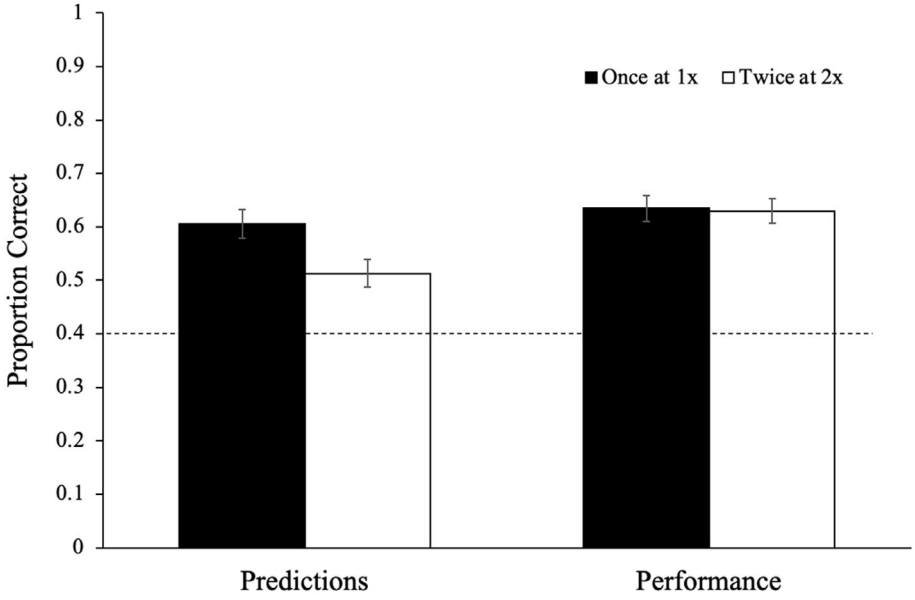


**FIGURE 4** Predictions of performance immediately before the comprehension test and test performance as a function of viewing schedule in Experiment 2a. The dashed line represents the mean performance of participants who did not watch the videos. Error bars reflect the *SEM*

Additionally, at the end of the study, if participants self-reported having prior expertise on either video topic (one participant reported having expertise on appraisals and 20 reported having expertise on the Roman Empire), participants' scores on that topic were excluded from analysis. An a priori power analysis indicated that for a two-group test of independent means, assuming alpha = .05, power = .80, for a two-tailed test, 90 participants would be needed to reliably detect a medium effect size ($d = .60$).

### 4.1.2 | Materials and procedure

The materials were similar to Experiment 1. Participants were randomly assigned to either watch both videos once at 1x speed ($n = 53$) or twice at 2x speed ($n = 53$). After watching the video on real estate appraisals either once at 1x speed or twice at 2x speed (participants watching the videos twice watched them in immediate succession but were not told that they would watch each video twice), participants predicted their performance on the comprehension test. Participants then completed the comprehension test (20 questions) and repeated this procedure for the Roman Empire video.

## 4.2 | Results

Predictions of immediate performance and comprehension test performance as a function of viewing schedule are shown in Figure 4. To investigate possible differences in participants' predictions of performance, we computed an independent samples *t* test. Results revealed that participants watching the videos a single time at 1x speed expected to perform better on the comprehension test ($M = .61$, $SD = .20$) than participants watching the videos twice at 2x speed ($M = .51$, $SD = .18$), ($t[104] = 2.50$, $p = .014$, $d = .49$). However, an independent samples *t* test on test performance did not reveal differences in comprehension between participants watching the videos a single time at 1x speed ($M = .64$, $SD = .18$) and participants watching the videos twice at 2x speed ($M = .63$, $SD = .17$), ($t[104] = .16$, $p = .876$, $d = .03$).

## 4.3 | Discussion

In Experiment 2a, we investigated whether participants could improve learning outcomes without spending additional time studying by watching lecture videos twice (in immediate succession) but at a faster speed. Specifically, we hypothesized that with the time saved as a result of watching at 2x speed, students could take advantage of the repetition effect (improved memory performance due to repeated studying compared with studying a single time, see Greene, 1989; Hintzman, 1976; Hintzman & Block, 1971; Raajimakers, 2003) to enhance learning by watching the videos a second time (still at 2x speed). However, although results revealed that participants expected better learning outcomes after only watching the videos a single time at normal speed, there were no group differences in comprehension test performance.

The lack of comprehension benefits as a consequence of watching the videos twice (compared with a single time) may be the result of participants having watched the videos in immediate succession. Rather than watching the videos back-to-back, spacing learners' multiple viewings of the videos may be a more effective study strategy. Specifically, participants may be able to harness both the benefits of repetition and the spacing effect (improved memory when studying is spaced in time rather than in immediate succession; Bjork & Allen, 1970; Cepeda et al., 2006; Greene, 2008; Karpicke & Bauernschmidt, 2011) by waiting until after a delay to watch the videos a second time. Additionally, learners could strategically distribute their study time (but keep study time constant) by rewatching lectures shortly before an exam to benefit from recency effects (see Murdock Jr., 1962). For example, if a learner were to initially watch lectures at 2x speed and then rewatch the videos again at 2x speed

immediately before an exam, this may result in better test performance than only watching the video once initially at 1x speed and having a longer delay before the exam.

## 5 | EXPERIMENT 2B

To further investigate whether learners can enhance comprehension without increasing study time, in Experiment 2b, participants again watched lecture videos either once at normal speed or twice at 2x speed, similar to Experiment 2a. However, participants watching the videos twice at 2x speed spaced their viewing of the lectures and their second viewing occurred immediately before the exam. Specifically, participants initially either watched the videos at normal or 2x speed and after a 1-week delay, participants in the 2x speed group watched the videos a second time immediately before taking the comprehension tests. In contrast, after watching the videos, the 1x speed group had a 1-week delay before comprehension tests without any additional viewing of the lectures. We expected that spacing the second viewing of the videos and watching them immediately before the comprehension test (even at 2x speed) would result in better learning outcomes than watching the videos once at normal speed with a long delay before the exam, and for participants' judgments to map on to this pattern.

### 5.1 | Method

#### 5.1.1 | Participants

After exclusions, participants were 110 undergraduate students (aged 18–35: $M = 21.08$, $SD = 2.88$) recruited from the UCLA Human Subjects Pool. All participants were fluent in English and 69% were native English speakers. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., looking up answers) in a post-task questionnaire (participants were told they would still receive credit if they cheated). This exclusion process resulted in zero exclusions. Additionally, at the end of the study, if participants self-reported having prior expertise on either video topic (two participants reported having expertise on appraisals and 15 reported having expertise on the Roman Empire), participants' scores on that topic were excluded from analysis. An a priori power analysis indicated that for a two-group test of independent means, assuming alpha = .05, power = .80, for a two-tailed test, 90 participants would be needed to reliably detect a medium effect size ($d = .60$).

#### 5.1.2 | Materials and procedure

The materials were similar to Experiment 2a. Participants were randomly assigned to either watch both videos once at 1x speed ($n = 58$) or twice at 2x speed ($n = 52$). However, rather than taking the comprehension tests immediately after watching the videos, we added a 1-week delay ($M = 8.59$ days, $SD = 1.29$). Additionally, for participants watching the videos twice at 2x speed, rather than rewatching the videos in immediate succession, participants watched each video once then a second time after the 1-week delay (immediately preceding the delayed comprehension test; participants were not aware that they would watch the videos a second time). Participants also made predictions of how they would perform after a 1-week delay after watching the video the first time and again predicted their performance immediately before taking the comprehension test (but after watching the video a second time for the 2x speed group).

### 5.2 | Results

Predictions of performance following a delay, predictions of performance immediately before the test, and performance as a function of

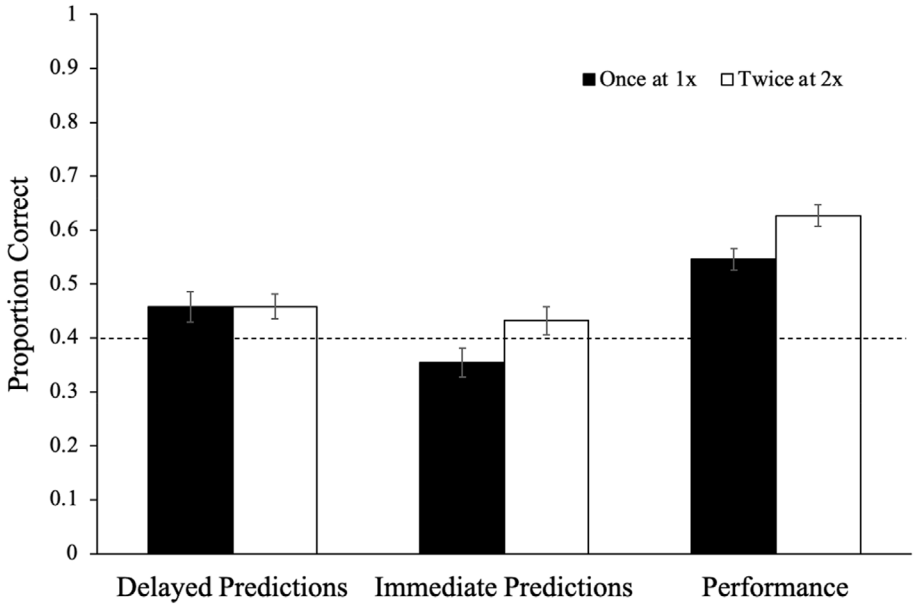


**FIGURE 5** Predictions of performance following a delay, predictions of performance immediately before the comprehension test, and test performance as a function of viewing schedule in Experiment 2b. The dashed line represents the mean performance of participants who did not watch the videos. Error bars reflect the *SEM*

viewing schedule are shown in Figure 5. To investigate possible differences in participants' predictions of performance following a delay, we computed an independent samples *t* test. Results revealed that after initially watching the videos at 1x speed ($M = .46$, $SD = .21$) or 2x speed ($M = .46$, $SD = .16$), participants expected to perform similarly (delayed predictions) on the comprehension test regardless of viewing speed ($t[108] = .01$, $p = .991$, $d < .01$). However, following the 1-week delay, participants' predictions of immediate performance (immediate predictions) revealed that the once at 1x speed group ($M = .36$, $SD = .21$) expected to do worse on the tests than participants who just rewatched the videos at 2x speed ($M = .43$, $SD = .19$), ($t[108] = 2.08$, $p = .040$, $d = .40$). Finally, participants watching the videos twice at 2x speed ($M = .63$, $SD = .14$) performed better on the comprehension tests than participants watching the videos a single time at 1x speed ($M = .55$, $SD = .15$), ($t[108] = 2.85$, $p = .005$, $d = .54$).

### 5.3 | Discussion

In Experiment 2b, we examined whether watching lecture videos twice at 2x speed (but spaced in time with the second viewing occurring immediately before the exam) would result in better learning outcomes than watching lecture videos a single time at normal speed with a delay before the exam. In contrast to Experiment 2a when videos were watched twice in immediate succession, results revealed that watching the videos initially at 2x speed and then again at 2x speed after a 1-week delay but immediately before the exam resulted in better test performance than watching a single time 1 week before the exam at normal speed. Thus, learners can improve learning outcomes while keeping study time constant by watching videos twice at 2x speed and strategically distributing their viewing of lecture videos.

Again, Experiment 1 indicates that watching the videos at 2x speed does not impair comprehension and if learners watch the videos a second time at 2x speed immediately before an exam, they may be able to harness the benefits of the spacing effect (Bjork & Allen, 1970; Carpenter et al., 2012; Cepeda et al., 2006; Greene, 2008; Karpicke & Bauernschmidt, 2011) and the recency effect (Murdock Jr., 1962; see also Eitel & Scheiter, 2015). However, there is a potential confound of test delay and video speed. Specifically, it is possible that watching a video in normal speed once immediately before an exam could have a similar benefit as watching at double speed immediately before an exam. Still, in Experiment 1, there were no significant differences in performance on the immediate tests between participants watching at normal and double speed. Thus, watching videos twice at double speed (with viewings spaced in time and the second viewing occurring immediately before an exam) resulted in enhanced performance but a condition whereby participants watch the video once at normal speed immediately before the test may serve as a better comparison group and may better represent how students actually prepare for exams.

## 6 | EXPERIMENT 3A

In Experiment 3a, we investigated whether watching lecture videos multiple times but at various speeds could improve learning outcomes. Specifically, participants either watched lecture videos initially at normal speed before watching again but at a faster speed (2x) or watched initially at a faster speed (2x) before watching a second time at normal speed. We were unsure as to which study schedule would lead to better performance as there are potential benefits to each study schedule. For example, it is possible that watching initially at a faster speed may prime memory for the information (see Baddeley & Hitch, 1993), making it easier to encode during the second viewing of the video. Specifically, having already been exposed to the information, learners may be more prepared to engage in elaborative encoding strategies to better remember the information on their second viewing. Alternatively, watching at normal speed initially and then again at a faster speed may result in retrieval practice benefits (see Bjork, 1988; Roediger III & Butler, 2011) whereby after having already encoded the information, a second exposure to the content serves as an opportunity for learners to practice recalling the information, leading to better retention and test performance. However, both study schedules could potentially benefit from priming and/or retrieval practice and it remains unclear how different viewing schedules impact comprehension.

### 6.1 | Method

#### 6.1.1 | Participants

After exclusions, participants were 108 undergraduate students (aged 18–27: $M = 20.42$, $SD = 1.62$) recruited from the UCLA Human Subjects Pool. All participants were fluent in English and 61% were native English speakers. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., looking up answers) in a post-task questionnaire (participants were told they would still receive credit if they cheated). This exclusion process resulted in two exclusions. Additionally, at the end of the study, if participants self-reported having prior expertise on either video topic (two participants reported having expertise on appraisals and 23 reported having expertise on the Roman Empire), participants' scores on that topic were excluded from analysis. An a priori power analysis indicated that for a two-group test of independent means, assuming alpha = .05, power = .80, for a two-tailed test, 90 participants would be needed to reliably detect a medium effect size ($d = .60$).

#### 6.1.2 | Materials and procedure

The materials were similar to Experiment 1. Participants watched each video twice but were randomly assigned to either watch the videos

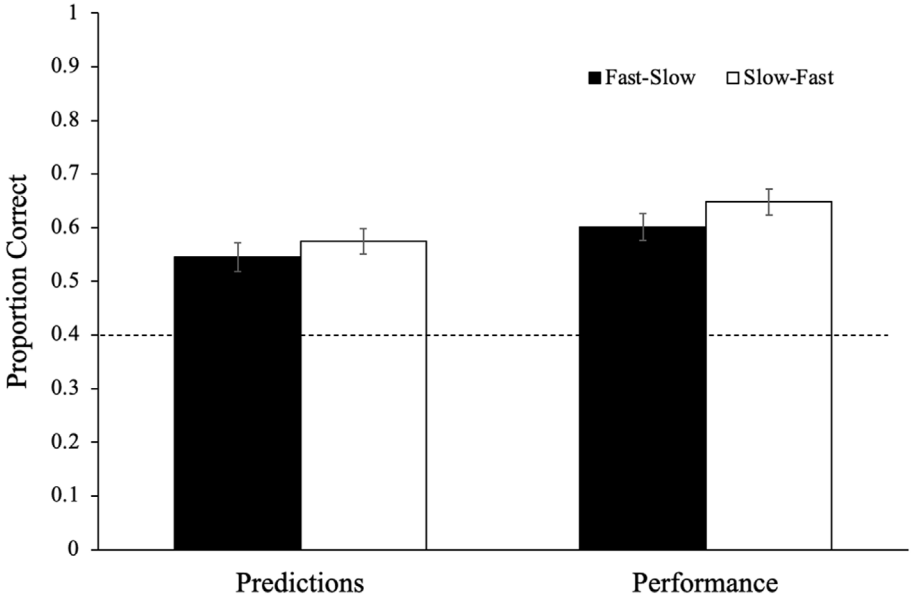


**FIGURE 6** Predictions of performance immediately before the comprehension test and test performance as a function of viewing schedule in Experiment 3a. The dashed line represents the mean performance of participants who did not watch the videos. Error bars reflect the *SEM*

first at 1x speed then again at 2x speed ($n = 57$) or first at 2x speed then again at 1x speed ($n = 51$). After watching the video on real estate appraisals twice in immediate succession (participants were not aware that they would watch the video a second time), participants predicted their performance on the comprehension test. Participants then completed the comprehension test and repeated this procedure for the Roman Empire video. At the conclusion of the task, we asked participants which study schedule they think is better for learning.

### 6.2 | Results

Predictions and performance as a function of viewing schedule are shown in Figure 6. To investigate potential differences in participants' predictions of performance, we computed an independent samples *t* test. Results revealed that participants watching the videos at 1x speed then again at 2x speed expected to perform similarly on the comprehension test ($M = .58$, $SD = .18$) as participants watching at 2x speed then again at 1x speed ($M = .55$, $SD = .19$), ($t[106] = .86$, $p = .393$, $d = .17$). Additionally, an independent samples *t* test on test performance did not reveal differences in comprehension between participants watching the videos at 1x speed then again at 2x speed ($M = .65$, $SD = .19$) and participants watching the videos at 2x speed then again at 1x speed ($M = .60$, $SD = .18$), ($t[106] = 1.31$, $p = .195$, $d = .25$).

Although the two study schedules did not result in different predictions of performance or comprehension, on the post-task questionnaire, most participants (76%) indicated that they believed that watching first at normal speed then rewatching at 2x speed is better for learning than watching first at 2x speed before rewatching at normal speed (24%); a Chi-square goodness of fit test indicated that the frequency of these answer choices differed ($\chi^2[1] = 29.04$, $p < .001$).

### 6.3 | Discussion

In Experiment 3a, participants watched each video twice: once at normal speed and once at 2x speed. However, results revealed that the order of watching the videos (i.e., fast then slow or slow then fast) did not affect comprehension, indicating that either (1) the benefits of priming and retrieval practice were similar or (2) learners may have not benefitted from priming when watching first at 2x speed then at 1x speed and not benefitted from retrieval practice when watching first at 1x speed then at 2x speed. Considering this second explanation, although a second viewing may serve as an informal test of the information encoded from the initial viewing at normal speed, simply watching lecture videos may be too passive (i.e., participants are not explicitly instructed to retrieve any information during the second viewing) to result in performance benefits. Rather, more active forms of retrieval practice such as comprehension questions embedded within the video may be necessary to harness any benefits of retrieval practice. Thus, although students may prefer certain study schedules or techniques, there are instances where their beliefs about self-regulated learning do not enhance learning outcomes (see Azevedo, 2005).

## 7 | EXPERIMENT 3B

In Experiment 3a, watching the lectures first at 1x speed then again at 2x speed or vice versa did not impact predictions of performance or comprehension. Despite not observing any group differences on an immediate comprehension test, spacing learners' viewing of the videos may result in better performance. In Experiment 3b, we investigated how delayed repetitions of varying playback speeds impacts comprehension. Specifically, rather than watching the videos in immediate succession, the second viewing of the videos occurred after a

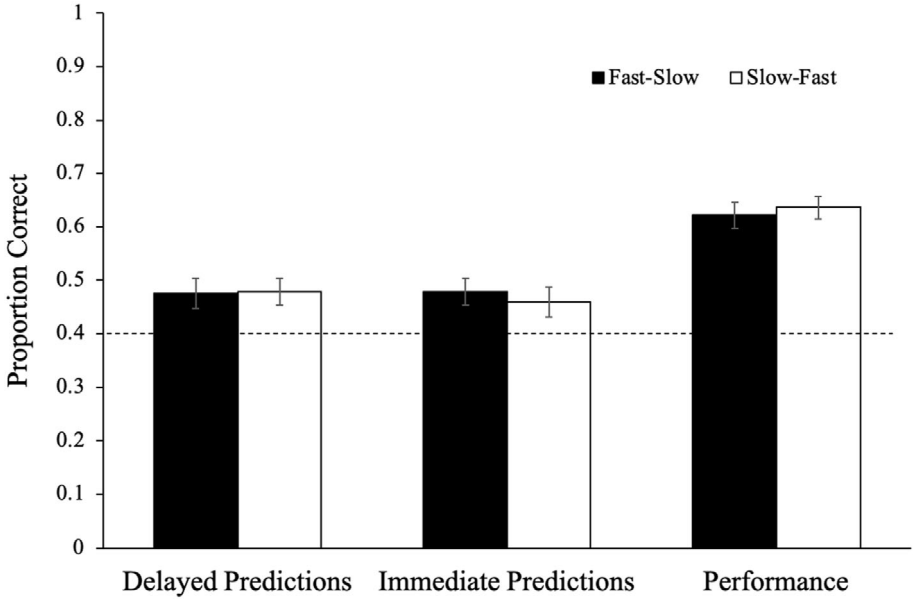


**FIGURE 7** Predictions of performance following a delay, predictions of performance immediately before the comprehension test, and test performance as a function of viewing schedule in Experiment 3b. The dashed line represents the mean performance of participants who did not watch the videos. Error bars reflect the *SEM*

1-week delay. Similar to Experiment 3a, we were unsure as to how the different study schedules would impact learners' predictions and performance.

## 7.1 | Method

### 7.1.1 | Participants

After exclusions, participants were 113 undergraduate students (aged 18–35: $M = 20.87$, $SD = 2.92$) recruited from the UCLA Human Subjects Pool. All participants were fluent in English and 66% were native English speakers. Participants were tested online and received course credit for their participation. Participants were excluded from analysis if they admitted to cheating (e.g., looking up answers) in a post-task questionnaire (participants were told they would still receive credit if they cheated). This exclusion process resulted in one exclusion. Additionally, at the end of the study, if participants self-reported having prior expertise on either video topic (five participants reported having expertise on appraisals and 15 reported having expertise on the Roman Empire), participants' scores on that topic were excluded from analysis. An a priori power analysis indicated that for a two-group test of independent means, assuming alpha = .05, power = .80, for a two-tailed test, 90 participants would be needed to reliably detect a medium effect size ($d = .60$).

### 7.1.2 | Materials and procedure

The materials were similar to Experiment 3a. Participants watched each video twice but were randomly assigned to either watch the videos first at 1x speed then again at 2x speed ($n = 65$) or first at 2x speed then again at 1x speed ($n = 48$). However, participants' second viewing of the videos occurred after a 1-week delay ($M = 9.44$ days, $SD = 2.35$). After initially watching each video (at either 1x or 2x speed), participants predicted their performance following a 1-week delay (participants were not aware that they would watch the video a second time). After the 1-week delay, participants watched each video again (at either 1x or 2x speed) and predicted their performance before taking the comprehension test. At the conclusion of the task, we asked participants which study schedule they think is better for learning.

## 7.2 | Results

Predictions and performance as a function of viewing schedule are shown in Figure 7. To investigate potential differences in participants' predictions of delayed performance, we computed an independent samples *t* test. Results revealed that participants watching the videos at 1x speed then again at 2x speed expected to perform similarly on the delayed comprehension test ($M = .48$, $SD = .21$) as participants watching at 2x speed then again at 1x speed ($M = .48$, $SD = .20$), ($t[111] = .09$, $p = .928$, $d = .02$). Similarly, an independent samples *t* test on participants' predictions after rewatching the videos a week later revealed that participants watching the videos at 1x speed then again at 2x speed expected to perform similarly on the delayed comprehension test ($M = .46$, $SD = .23$) as participants watching at 2x speed then again at 1x speed ($M = .48$, $SD = .18$), ($t[110.7] = .52$, $p = .602$, $d = .10$). Finally, an independent samples *t* test on test performance did not reveal differences on the delayed comprehension test between participants watching the videos at 1x speed then again at 2x speed ($M = .64$, $SD = .18$) and participants watching the videos at 2x speed then again at 1x speed ($M = .62$, $SD = .17$), ($t[111] = .45$, $p = .653$, $d = .09$).

Additionally, consistent with Experiment 3a, on the post-task questionnaire, most participants (76%) indicated that they believed that watching first at normal speed then rewatching at 2x speed is better for learning than watching first at 2x speed before rewatching at normal

speed (24%); a Chi-square goodness of fit test indicated that the frequency of these answer choices differed ($\chi^2[1] = 30.81$, $p < .001$).

### 7.3 | Discussion

In Experiment 3b, participants again watched each video twice: once at normal speed and once at 2x speed. However, participants' second viewing session occurred after a 1-week delay. Results revealed that the order of watching the videos (i.e., fast then slow or slow then fast) did not affect performance, similar to Experiment 3a. Together, Experiment 3 suggests that if learners watch lecture videos twice at different speeds, the order of viewing (e.g., 1x speed before 2x speed or 2x speed then 1x speed) does not seem to impact comprehension.

## 8 | GENERAL DISCUSSION

Video streaming platforms (e.g., YouTube) often allow users to manipulate the playback speed of videos, allowing up to 2x faster consumption of a video. In addition to streaming media content, students often manipulate the speed of asynchronous lecture videos. For example, we surveyed 123 undergraduate students and 85% reported watching lecture videos at quicker than normal speeds (see Figure 3a). However, 91% of students reported that they believed watching at normal or slightly faster than normal (1.5x) as opposed to faster speeds (2x, 2.5x) was best for learning (see Figure 3b). Thus, understanding how video speed affects short and long-term comprehension is essential to ensure that people employ the most efficient and effective techniques to successfully learn new information.

Previous work on the effect of video speed on learning has yielded mixed results. For example, there is some evidence that increasing the speed of videos leads to preserved or enhanced comprehension (Lang et al., 2020; Nagahama & Morita, 2017; Wilson et al., 2018) while other work suggests that increased speed impairs comprehension (Foulke & Sticht, 1969; Song et al., 2018; Vemuri et al., 2004). To further examine the impact of lecture video speed on comprehension, in Experiment 1, we tested learners' immediate and delayed (1 week) comprehension after watching videos at either 1x, 1.5x, 2x, or 2.5x speed. As predicted by participants, results revealed that video speed had little effect on both immediate and delayed comprehension such that participants only showed comprehension deficits when watching at 2.5x speed compared with 1x speed. Such learning impairments are consistent with the Cognitive Load Theory (see Sweller, 1988, 1989) and the Cognitive Theory of Multimedia Learning (Mayer, 2002) such that when the material is presented at faster than 2x speed, the rate of presentation results in a cognitive load that exceeds learners' limited cognitive resources. However, because there appear to be minimal costs incurred by increasing video playback speed up to 2x speed, it is possible that faster presentation speeds do not overly tax working memory as long as the speeds do not exceed 2x speed.

Since the present findings suggest that learners can watch videos at up to 2x speed without accompanying performance deficits, students may be able to use the saved time advantageously. Specifically, students may be able to harness the memory benefits of repetition (see Greene, 1989; Hintzman, 1976; Hintzman & Block, 1971; Raajimakers, 2003) by watching videos twice at 2x speed without spending additional time studying. In Experiment 2, we investigated whether watching a video twice at 2x speed rather than a single time at normal speed resulted in better learning outcomes. In Experiment 2a, despite participants watching once at 1x speed predicting better performance than participants watching twice at 2x speed (in immediate succession), the two groups performed similarly on the comprehension test.

However, in Experiment 2b, participants either watched the videos initially at 1x speed or 2x speed but following a 1-week delay, participants who watched at 1x speed took the comprehension test while participants who initially watched at 2x speed rewatched the videos before taking the comprehension test. After the initial viewing session, both groups predicted similar performance but following the 1-week delay and some participants rewatching the videos at 2x speed, participants watching the videos twice at 2x speed expected to perform better than participants watching once at 1x speed. Mirroring the latter predictions, when the study sessions were spaced in time (i.e., when there was a 1-week delay between encoding sessions) and the second 2x viewing occurred immediately before the test, watching the videos twice at 2x speed led to better performance. Thus, students may be able to study more efficiently and enhance learning outcomes by watching their asynchronous lectures initially at 2x speed and again at 2x speed immediately before the test rather than watching a single time at 1x speed with a long delay before the exam.

Again, superior exam performance only occurred when the twice at 2x speed group's second viewing occurred shortly before the exam. Thus, learners may be able to strategically distribute their study time to increase performance by watching lecture videos twice at 2x speed but watching for the second time shortly before an exam. For example, in a standard college course, there may be around 10 h of lecture video covered on a midterm exam. If students watch the lectures as they are released each week, the time between viewing the lectures and being tested on the material will be relatively long. Additionally, rewatching all 10 h of content shortly before the exam may not be feasible. However, if students watch the lectures at 2x speed as they are released, then spend just 5 h rewatching the videos shortly before the exam, they may be able to benefit from this shorter retention interval without spending extra time on the videos. Future work should examine various retention intervals between encoding sessions and comprehension tests to better understand this effect and delineate under what conditions watching videos twice at 2x speed improves performance to a greater degree than watching the videos once at 1x speed.

Lastly, to investigate whether learners can enhance the benefits of repetition, participants in Experiment 3 watched each video twice: either initially at normal speed and then again at 2x speed or initially at 2x speed and then again at normal speed. However, both predictions and performance did not differ as a function of study schedule

whether participants watched the videos in immediate succession or with a 1-week delay between viewings. Thus, Experiment 3 indicates that watching lecture videos multiple times at different speeds may not be an effective study strategy to enhance comprehension.

Collectively, the present experiments indicate that increased video speed (up to 2x) does not negatively impact learning outcomes and watching at faster speeds can be a more efficient use of study time. Thus, as long as to-be-remembered information can be effectively perceived and encoded, learning outcomes may not be affected by playback speed. However, previous work has indicated that speech comprehension begins to decline at around 275 words per minute (Foulke & Sticht, 1969; see also Goldhaber, 1970; Pastore & Ritzhaupt, 2015; Vemuri et al., 2004) and the videos in the current study exceeded this threshold when played at 2x speed. Although the elevated speech rates at 2x speed may initially be less comprehensible to students, researchers have been able to train participants to understand speech at rates up to 475 WPM (Orr et al., 1965). Therefore, with practice, higher rates of speech may not be completely incomprehensible and since 85% of students reported watching lecture videos at quicker than normal speeds (see Figure 3a), they may be better able to process the material as a result of experience.

Additionally, although the audible material presented by an instructor is impacted by playback speed in terms of speech rates, the visual properties of an instructor's PowerPoint slides containing still images or bulleted information should be resistant to video speed, allowing this information to be effectively encoded if presented for sufficient time. However, if information in a lecture video is presented only very briefly or as an animation or moving graphic, increased speeds may decrease the perceptibility of visual information (but see Fischer et al., 2008). Despite having less time to encode accompanying visually presented information at faster video speeds, the shorter durations may make it easier for participants to sustain focused attention throughout the learning period (see Guo et al., 2014). Thus, even if the speech rates of a video surpass the rate of what is typically perceptible, participants may still be able to encode visually presented information (see Pastore & Ritzhaupt, 2015) and benefit from a shorter duration with which they need to allocate attentional resources.

The present findings provide preliminary evidence of how to study more efficiently and illustrate that participants seem generally aware of the effects of video speed on immediate and delayed comprehension as well as the benefits of rewatching lectures shortly before the exam. However, participants' predictions prior to taking any examinations seemed generally underconfident in relation to how much they ended up remembering. Furthermore, learners may sometimes prefer study schedules that do not enhance performance and future work should further examine how video speed influences metacognitive monitoring of learning. Future work will also benefit from investigating the factors that likely affect the efficacy of remote learning beyond video speed. The ability to pause and take notes, amount of audiovisual overlap, complexity or difficulty of content, presence of subtitles, video length, embedded questions within a video, and instructor fluency are just some of the factors that should be further examined to bolster students' success with remote learning. Additionally, there may be boundary conditions to the effects of video speed on comprehension such as complexity or difficulty of the topic, audiovisual overlap, and instructor fluency. Nevertheless, in the present study, using two videos on different topics with different instructors and collapsing results across these topics may increase the generalizability of the findings.

In sum, remote learning has become ubiquitous in recent times and asynchronous learning formats may allow for more efficient learning. Specifically, the current study revealed that there are minimal costs incurred as a result of watching pre-recorded lectures at up to 2x speed and if learners watch these asynchronous lectures multiple times (perhaps rewatching the videos shortly before an exam), learning outcomes can be enhanced. Thus, remote learning may offer students the opportunity to learn both more effectively and more efficiently.

## CONFLICT OF INTEREST

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

## ENDNOTES

[1] This sample was not preregistered.

[2] A one-sample $t$ test revealed that participants watching at 2.5x speed performed better on both the immediate ($t[56] = 7.00$, $p < .001$, $d = .93$) and delayed comprehension tests ($t[48] = 4.01$, $p < .001$, $d = .57$) compared with control participants who did not watch the videos.

## DATA AVAILABILITY STATEMENT

The experiments reported in this article were formally preregistered and the stimuli, data, and analysis code have been made available on the Open Science Framework https://osf.io/zqg4k/?view_only=c95e34ff910b41ebbaa5d86b7002881a.

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## REFERENCES

Azevedo, R. (2005). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist*, *40*(4), 199–209. https://doi.org/10.1207/s15326985ep4004_2

Baddeley, A. D., & Hitch, G. (1974). Working memory. In *Psychology of learning and motivation* (Vol. 8, pp. 47–89). Academic press. https://doi.org/10.1016/S0079-7421(08)60452-1

Baddeley, A. D., & Hitch, G. (1993). The recency effect: Implicit learning with explicit retrieval? *Memory & Cognition*, *21*(2), 146–155. https://doi.org/10.3758/BF03202726

Barbour, M. K. (2013). The landscape of K-12 online learning: Examining what is known. In M. G. Moore (Ed.), *Handbook of distance education* (3rd ed., pp. 574–593). Routledge.

Belt, E. S., & Lowenthal, P. R. (2021). Video use in online and blended courses: A qualitative synthesis. *Distance Education*, *42*, 410–440. https://doi.org/10.1080/01587919.2021.1954882

Bjork, R. A. (1988). Retrieval practice and the maintenance of knowledge. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues, Vol. 1. Memory in everyday life (p. 396–401)*. John Wiley & Sons.

Bjork, R. A., & Allen, T. W. (1970). The spacing effect: Consolidation or differential encoding? *Journal of Verbal Learning and Verbal Behavior*, *9*(5), 567–572. https://doi.org/10.1016/S0022-5371(70)80103-7

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology*, *64*(1), 417–444. https://doi.org/10.1146/annurev-psych-113011-143823

Boekaerts, M. (1997). Self-regulated learning: A new concept embraced by researchers, policy makers, educators, teachers, and students. *Learning and Instruction*, *7*(2), 161–186. https://doi.org/10.1016/S0959-4752(96)00015-1

Breslow, L., Pritchard, D. E., Deboer, J., Stump, G. S., Ho, A. D., & Seaton, D. T. (2013). Studying learning in the worldwide classroom: Research into edX's first MOOC. *Research and Practice in Assessment*, *8*, 13–25.

Cardall, S., Krupat, E., & Ulrich, M. (2008). Live lecture versus video-recorded lecture: Are students voting with their feet? *Academic Medicine*, *83*(12), 1174–1178. https://doi.org/10.1097/ACM.0b013e31818c6902

Carpenter, S. K., Cepeda, N. J., Rohrer, D., Kang, S. H., & Pashler, H. (2012). Using spacing to enhance diverse forms of learning: Review of recent research and implications for instruction. *Educational Psychology Review*, *24*, 369–378. https://doi.org/10.1007/s10648-012-9205-z

Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin*, *132*(3), 354–380. https://doi.org/10.1037/0033-2909.132.3.354

Cermak, L. S., Verfaellie, L. S., Mather, M., & Chase, K. (1996). Effect of spaced repetitions on amnesia patients' recall and recognition performance. *Neuropsychology*, *10*(2), 219–227. https://doi.org/10.1037/0894-4105.10.2.219

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science*, *19*(1), 51–57. https://doi.org/10.1177/0963721409359277

Dunlosky, J., Mueller, M. L., & Thiede, K. W. (2016). Methodology for investigating human metamemory: Problems and pitfalls. In J. Dunlosky & S. K. Tauber (Eds.), *Oxford library of psychology. The Oxford handbook of metamemory* (pp. 23–37). Oxford University Press.

Eitel, A., & Scheiter, K. (2015). Picture or text first? Explaining sequence effects when learning with pictures and text. *Educational Psychology Review*, *27*, 153–180. https://doi.org/10.1007/s10648-014-9264-4

Fischer, S., Lowe, R. K., & Schwan, S. (2008). Effects of presentation speed of a dynamic visualization on the understanding of a mechanical system. *Applied Cognitive Psychology*, *22*(8), 1126–1141. https://doi.org/10.1002/acp.1426

Foulke, E., & Sticht, T. G. (1969). Review of research on the intelligibility and comprehension of accelerated speech. *Psychological Bulletin*, *72*(1), 50–62. https://doi.org/10.1037/h0027575

Gilchrist, A. L., Cowan, N., & Naveh-Benjamin, M. (2008). Working memory capacity for spoken sentences decreases with adult ageing: Recall of fewer but not smaller chunks in older adults. *Memory*, *16*(7), 773–787. https://doi.org/10.1080/09658210802261124

Goldhaber, G. M. (1970). Listener comprehension of compressed speech as a function of the academic grade level of the subjects. *Journal of Communication*, *20*(2), 167–173. https://doi.org/10.1111/j.1460-2466.1970.tb00874.x

Greene, R. L. (1989). Spacing effects in memory: Evidence for a two-process account. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(3), 371–377. https://doi.org/10.1037/0278-7393.19.1.159

Greene, R. L. (2008). Repetition and spacing effects. In H. L. Roediger (Ed.), *Learning and memory: A comprehensive reference*. Cognitive psychology of memory (Vol. 2, pp. 65–78). Elsevier.

Guo, P. J., Kim, J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos. In *Proc. L&S 2014* (pp. 41–50). ACM Press.

Hintzman, D. L. (1976). Repetition and memory. *Psychology of Learning and Motivation*, *10*, 47–91. https://doi.org/10.1016/S0079-7421(08)60464-8

Hintzman, D. L., & Block, R. A. (1971). Repetition and memory: Evidence for a multiple-trace hypothesis. *Journal of Experimental Psychology*, *88*(3), 297–306. https://doi.org/10.1037/h0030907

Karpicke, J. D., & Bauernschmidt, A. (2011). Spaced retrieval: Absolute spacing enhances learning regardless of relative spacing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1250–1257. https://doi.org/10.1037/a0023436

Koriat, A., Bjork, R. A., Sheffer, L., & Bar, S. K. (2004). Predicting one's own forgetting: The role of experience-based and theory-based processes. *Journal of Experimental Psychology: General*, *133*, 643–656. https://doi.org/10.1037/0096-3445.133.4.643

Kornell, N., Rhodes, M. G., Castel, A. D., & Tauber, S. K. (2011). The ease-of-processing heuristic and the stability bias: Dissociating memory, memory beliefs, and memory judgments. *Psychological Science*, *22*, 787–794. https://doi.org/10.1177/0956797611407929

Lang, D., Chen, G., Mirzaei, K., & Paepcke, A. (2020). Is faster better?: A study of video playback speed. In *Proceedings of the tenth international conference on learning analytics & knowledge* (pp. 260–269). ACM. https://doi.org/10.1145/3375462.3375466

Leahy, W., & Sweller, J. (2011). Cognitive load theory, modality of presentation and the transient information effect. *Applied Cognitive Psychology*, *25*, 943–951. https://doi.org/10.1002/acp.1787

Mayer, R. E. (2002). Multimedia learning. In *Psychology of learning and motivation* (Vol. 41, pp. 85–139). Academic Press.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97. https://doi.org/10.1037/h0043158

Murdock, B. B., Jr. (1962). The serial position effect of free recall. *Journal of Experimental Psychology*, *64*(5), 482–488. https://doi.org/10.1037/h0045106

Nagahama, T., & Morita, Y. (2017). Effect analysis of playback speed for lecture video including instructor images. *International Journal for Educational Media and Technology*, *11*(1), 50–58.

Nelson, T. O. (1996). Consciousness and metacognition. *American Psychologist*, *51*, 102–116.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and some new findings. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 125–173). Academic Press.

Orr, D. B., Friedman, H. L., & Williams, J. C. C. (1965). Trainability of listening comprehension of speeded discourse. *Journal of Educational Psychology*, *56*(3), 148–156. https://doi.org/10.1037/h0021987

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1–4. https://doi.org/10.1207/S15326985EP3801_1

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science*, *32*(1/2), 1–8.

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology*, *8*, 1–8. https://doi.org/10.3389/fpsyg.2017.00422

Pastore, R., & Ritzhaupt, A. D. (2015). Using time-compression to make multimedia learning more efficient: Current research and practice. *TechTrends*, *59*, 66–74. https://doi.org/10.1007/s11528-015-0841-2

Peelle, J. E., & Davis, M. H. (2012). Neural oscillations carry speech rhythm through to comprehension. *Frontiers in Psychology*, *3*, 320. https://doi.org/10.3389/fpsyg.2012.00320

Pokhrel, S., & Chhetri, R. (2021). A literature review on impact of COVID-19 pandemic on teaching and learning. *Higher Education for the Future*, *8*, 133–141. https://doi.org/10.1177/2347631120983481

Raajimakers, J. G. W. (2003). Spacing and repetition effects in human memory: Application of the SAM model. *Cognitive Science*, *27*(3), 431–452. https://doi.org/10.1207/s15516709cog2703_5

Roediger, H. L., III, & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in Cognitive Sciences*, *15*, 20–27. https://doi.org/10.1016/j.tics.2010.09.003

Sinha, T., Jermann, P., Li, N., & Dillenbourg, P. (2014). Your click decides your fate: Inferring information processing and attrition behavior from MOOC video clickstream interactions. In *Proceedings of the 2014 conference on empirical methods in natural language processing (EMNLP)* (pp. 3–14). Association for Computational Linguistics. https://doi.org/10.3115/v1/w14-4102

Song, K., Chakraborty, A., Dawson, M., Dugan, A., Adkins, B., & Doty, C. (2018). Does the podcast video playback speed affect comprehension for novel curriculum delivery? A randomized trial. *The Western Journal of Emergency Medicine*, *19*, 101–105. https://doi.org/10.5811/westjem.2017.10.36027

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1016/0364-0213(88)90023-7

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of Educational Psychology*, *81*(4), 457–466. https://doi.org/10.1037/0022-0663.81.4.457

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Measuring cognitive load. In *Cognitive load theory* (pp. 71–85). Springer. https://doi.org/10.1007/978-1-4419-8126-4_6

Sweller, J., van Merriënboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251–296. https://doi.org/10.1023/A:1022193728205

Thiede, K. W., & De Bruin, A. B. H. (2017). Self-regulated learning in reading. In D. H. Schunk & J. A. Greene (Eds.), *Handbook of self-regulation of learning and performance* (2nd ed., pp. 109–123). Routledge. https://doi.org/10.4324/9781315697048-8

van Merriënboer, J. J., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review*, *17*(2), 147–177. https://doi.org/10.1007/s10648-005-3951-0

Vemuri, S., DeCamp, P., Bender, W., & Schmandt, C. (2004). Improving speech playback using time-compression and speech recognition. In *Proceedings of SIGCHI conference human factors in computing systems* (pp. 295–302). ACM. https://doi.org/10.1145/985692.985730

Wilson, K. E., Martin, L., Smilek, D., & Risko, E. F. (2018). The benefits and costs of speed watching video lectures. *Scholarship of Teaching and Learning in Psychology*, *4*(4), 243–257. https://doi.org/10.1037/stl0000127

Wong, J., Baars, M., Davis, D., Van Der Zee, T., Houben, G., & Paas, F. (2019). Supporting self-regulated learning in online learning environments and MOOCs: A systematic review. *International Journal of Human Computer Interaction*, *35*(4–5), 356–373. https://doi.org/10.1080/10447318.2018.1543084

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology*, *81*(3), 329–339. https://doi.org/10.1037/0022-0663.81.3.329

Zimmerman, B. J. (1990). Self-regulating academic learning and achievement: The emergence of a social cognitive perspective. *Educational Psychology Review*, *2*(2), 173–201. https://doi.org/10.1007/bf01322178

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