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Abstract

One of the most powerful ways to boost learning is to require students to self-explain—to generate written or verbal explanations of their study material as they are studying. Although self-explaining is known to enhance learning across a wide range of ages and study materials, this empirical work has focused almost exclusively on optimal study conditions. Here we explore if self-explaining is similarly effective in the presence of background music, a distraction students commonly elect to incorporate into their study routines. In the first study, 32 university students were asked to learn about neuronal action potentials while we varied both self-explaining and the presence of loud background music. Results indicated self-explaining enhanced learning during silent study but actually impaired learning while listening to loud background music. To determine a threshold for this interaction, a second experiment was conducted (N=64) in which the music variable was manipulated at 4 levels: silent, quiet, moderate, and loud. We found increasing music volume impaired learning overall, and that this effect was particularly pronounced when students were instructed to self-explain. Overall, self-explaining is a powerful but potentially brittle learning technique, one which may not mesh well with common study habits.

Keywords: self-explanation effect, study habits, metacognitive strategy

Introduction

Cognitive psychology has yielded a range of practical applications to optimize student learning. One of the most useful findings to emerge is the robust increase in student learning that occurs through "self-explaining"—generating written or verbal explanations of study materials (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Good students often self-explain spontaneously while studying (Chi et al., 1989), and this seems directly related to their ability to understand the material better compared to their peers. Furthermore, all students can be encouraged to self-explain while studying. This consistently leads to better learning across the entire spectrum of initial ability—a finding which has been called the "self-explanation effect" (Chi et al. 1989).

Chi et al. (1989) has proposed self-explaining benefits learning for at least two reasons: 1) it may help students detect and repair deficiencies in their own understanding of a topic, 2) it may help students bridge gaps and omissions in their study materials. Consistent with both interpretations, self-explaining seems to increase the quantity of information students encode and retain from their study materials (Calin-Jageman & Ratner, 2005; Van Lehn, Jones, & Chi, 1992)

Whatever the mechanism, self-explaining has several characteristics that suggest it is an ideal study tool. First, self-explaining works across all levels of formal education. Beneficial effects have been observed in preschoolers (Siegler, 1995), kindergarteners (Calin-Jageman & Ratner, 2005), fourth-graders (Kastens & Liben, 2007), sixth-graders (Tajika et al., 2007), and quite extensively in college students (Ainsworth & Burcham, 2007; Ainsworth & Loizou, 2003; Chi et al., 1989; Nenman & Schwartz, 1998; Schworm & Renkl, 2007).

Equally impressive, self-explaining boosts learning across a wide range of learning domains and materials. Work has primarily focused on procedural, structured domains such as physics (Chi et al., 1989), analogical problem-solving (Neumann & Schwarz, 1998), mathematics (Tajika et al., 2007), and chess (De Burin et al., 2007). In addition, there is increasing evidence that self-explaining can also foster learning in non-procedural and ill-structured domains. For example, Katsens and Liben (2007) found that self-explaining enhances fourth-graders' abilities to accurately use maps. At the other end of the age spectrum, Schworm and Renkl (2007) found that self-explaining helped student teachers develop better argumentation skills.

A third important characteristic of self-explaining is that students can easily grasp the strategy and seem to enjoy using it. O'Rielly, Symons, & Maclatchy-Gaudet (1998) compared self-explaining, rote memorization, and elaborative explanation as study strategies for learning basic facts from a biology textbook. They found not only that self-explaining promoted the greatest retention, but that this strategy was rated most likely to be used in the future, though this was not a significant difference relative to rote memorization. Moreover, self-explaining was not rated significantly more difficult or more time-consuming than rote memorization.

Overall there is considerable empirical evidence that self-explaining is an ideal study strategy for students—it is easy to use, effective in many contexts, and works for students of almost any age (cf.,Kuhn & Katz, 2009). Most of this empirical literature has recommended wider dissemination of this technique: tutoring systems, video games, and other self-learning tools now regularly incorporate prompts for students to self-explain while learning (Aleven & Koedinger, 2002; Hausmann & Chi, 2002;Johnson & Mayer, 2010) .

As self-explaining is incorporated into pedagogy, an important question is whether it will have the same robust benefits in the real world as it has in the lab. Surprisingly, the voluminous literature on self-explaining has not addressed this question directly. Although most studies have recruited real students and offered authentic learning materials, there has been an exclusive focus on optimal study conditions—students studying in silence and under experimenter supervision for a prescribed amount of time. Realistically, however, students often employ less optimal study habits. Thus, it is essential to determine if self-explaining can effectively boost learning in more realistic conditions.

As a start towards addressing this issue, we examined the ability of self-explaining to improve learning while varying exposure to background study music. Although the effects of music on cognition can be somewhat varied, music played during encoding is generally found to have a negative impact on learning complex material, particularly if the music contains vocals. This is known as the irrelevant speech or sound effect, and has been well-documented in the literature (Boyle & Coltheart, 1996; Farley, Neath, Albritton, & Surprenant, 2007; Perham & Vizard, in press; Salamé & Baddeley, 1989). For example, rock and popular music played during a test decreases scores (Kiger, 1989), hinders writing quality (Ransdell & Gilroy, 2001), and impairs both recognition and recall (Furnham & Bradley, 1997;Hallam, Price, & Katsarou, 2002). In a study designed specifically to mimic typical student study and test experiences, Kanter (2009) found, in two experiments, that vocal music played during study impaired later test performance. Recent work has identified heavy metal music as having a particularly strong negative effect on serial recall (Perham and Vizard, in press). We thus selected this style of music as our study distracter.

Although the drawbacks of studying with music are well documented, it is unclear how this might interact with the self-explanation effect. We envisioned three possibilities: 1) self-explaining could better engage students with their studies and lessen the drawbacks of studying while listening to music, 2) the benefits of self-explaining and drawbacks of music could simply cancel out, or 3) the enhanced cognitive demands of self-explaining could make students more sensitive to distractions and thus enhance the drawbacks of studying to music. Although the first two outcomes would endorse the ongoing adoption of the self-explanation effect, the possibility of a negative interaction would suggest some caution in student adoption of self-explaining. Thus, determining the pattern of interaction between self-explaining and study music seems particularly important.

Here we present two simple experiments showing self-explanation can magnify the deleterious impact of study music. In both studies, students unfamiliar with neuroscience were presented with information related to the neuronal action potential. Study strategy was varied by asking students either to self-explain their study materials (self-explanation groups) or to review their study materials twice (repetition groups). The repetition strategy served as a control. As a music distraction we chose the heavy metal song "It's Darker than You Think" by Carpathian Forest. The music was selected because it contains vocals, but the specific words are not distinguishable. In both experiments, self-explaining fostered learning during silent study but had either no impact or a negative impact for students studying to music.

Method

Participants

Ninety-six (n=96) undergraduate college

students from several Midwestern universities. In experiment 1, 10 males and 22 females were recruited via convenience sampling; their mean age was 22.6 years. In experiment 2, 20 males and 44 females participated; their mean age was 20. Individuals recruited were from lower-level psychology classes, and received extra credit or course credit for their participation. Further, all participants were treated in accordance with APA ethical guidelines.

Materials

Learning Materials. Participants learned about the neuronal action potential. Each group looked over a 329 word passage taken from an online tutorial on neuronal communication (http://faculty.washington.edu/chudler/ap.html) supplemented with a figure of the ionic currents that occur during the action potential (http://www.answers.com/topic/action-potential).

Prior Knowledge. In the first study, prior knowledge was measured via self-report. Specifically, participants rated their agreement with the statement "I know what a neuronal action potential is" on a Likert Scale from 1 ("strongly disagree") to 4 ("strongly agree"). An exclusion criterion was set at a rating of 4, however no participants met this criterion.

For the second study, prior knowledge was measured via a 4- question test (see Appendix A). Questions were adopted from a website featuring a quiz on neuronal communication (http://www.miracosta.edu/home/sfoster/neurons/salquiz3.htm, Foster, n.d). An exclusion criterion was set for scores of 100%, but no participants met this criterion.

Post-Test. To measure learning, a seven-question post-test was administered. Questions were adapted from a popular biopsychology study guide (see appendix B; Hull, 2000). The questions were a mixture of recognition and cued recall questions covering the text and figure. Each question was given equal weight, providing a possible range of scores from 0-7.

Self-Explanation. To familiarize students with self-explaining, a handout was adopted from Ainsworth and Burcham (2007). The first page of the document explained the concept of self-explaining and provided two examples of types of self-explanations. The second page was left blank for students to record their self-explanations of the study materials.

Study Music. For the music conditions, "It's Darker Than You Think" from the black-metal band Carpathian Forest was played on a small Memorex 2extreme boom box. This music was selected because 1) it has vocals but specific words are not easily decipherable, and 2) previous work has shown that this style of music, though somewhat popular with students, decreases performance on cognitive tasks (Kiger, 1989; Perham & Vizard, in press; Hallam et al., 2002).

In experiment 1, the study conditions were either silence or loud. For the loud condition, music played at full volume on a standard boom box (Memorex 2xtreme). Sound levels were approximately 100db.

In experiment 2, music levels were set with the assistance of a portable analog SPL meter (Nady Systems Inc., Emeryville, CA). For the silent condition, ambient room noise was ~60db. For the music conditions, volume on the boom box was adjusted to reach a steady reading of either 75db, 86, or 100db, representing quiet, moderate, or loud music.

Procedures

Experiment 1 utilized a 2 (Study Strategy: Self-Explain, Control) x 2 (Study Environment: Silence, Loud Music) between subjects design. In Experiment 2, the study environment variable was expanded to 4 levels: silence, quiet, moderate, and loud music.

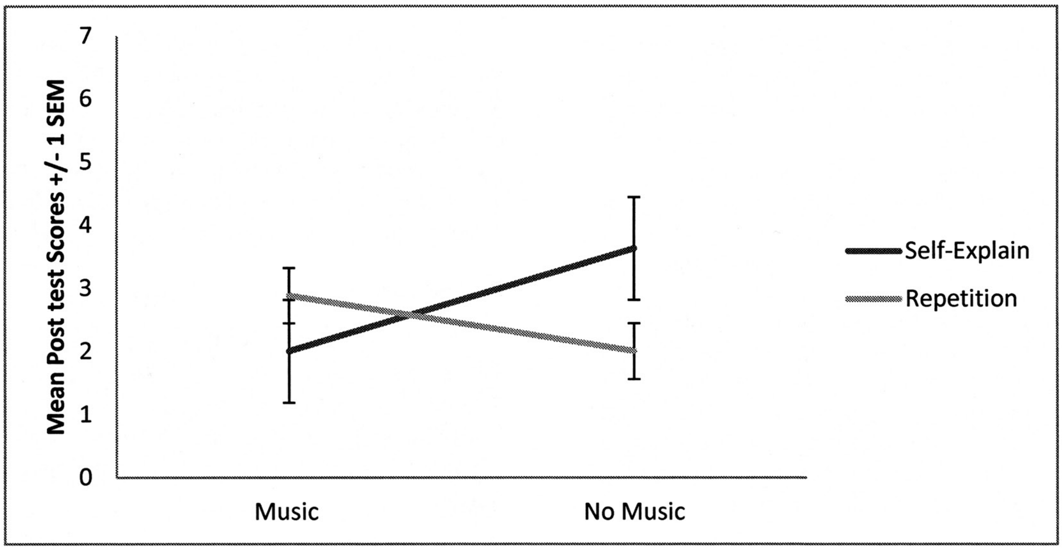
Individuals were run in groups of no more than five. As each participant entered the testing room, they were assigned a number, randomly, corresponding to a particular experimental condition. Then, each individual was split into different study groups with different sound levels. After completing a measure of prior knowledge, participants were given instructions on study strategy (self-explain or repetition). Students were then given six minutes to review study materials. For music conditions, music was played during this entire study period. Next, students were given three minutes to complete the post-test. No music was played during the post-test.

Data Analysis

In the first experiment, post-test scores did not approximate a normal distribution. This data was transformed (each score was squared so that skewness and kurtosis was no more than two times the standard error. However, we found that analyses conducted on this transformed data were not substantially different from analyses conducted with the raw data. For ease of interpretation, data and analyses using raw data are reported here.

In experiment 1, a 2 (Music: music, no music) x 2 (Strategy: self-explanation, repetition) factorial analysis of the variance (ANOVA) assessed mean differences between groups. In experiment 2, mean difference scores (pre-test-post-test) were analyzed with a 2 (Strategy: self-Explain and repetition) x 4 (Study Music: Silent, Quiet, Moderate, Loud) ANOVA to detect differences between groups.

Figure 1. Mean Posttest Scores (± 1 SEM) by Condition Study Strategy and Environment



Results

Experiment 1

Participants recruited for this study self-reported a relatively low initial knowledge of action potentials (*M*=1.84, *SD*=.76). Moreover, these self-reported assessments of prior knowledge had minimal variability and did not correlate with post-test scores , $r = -0.02$, $p = 0.91$, $N = 32$. Therefore, we did not use this measure to adjust post-test scores.

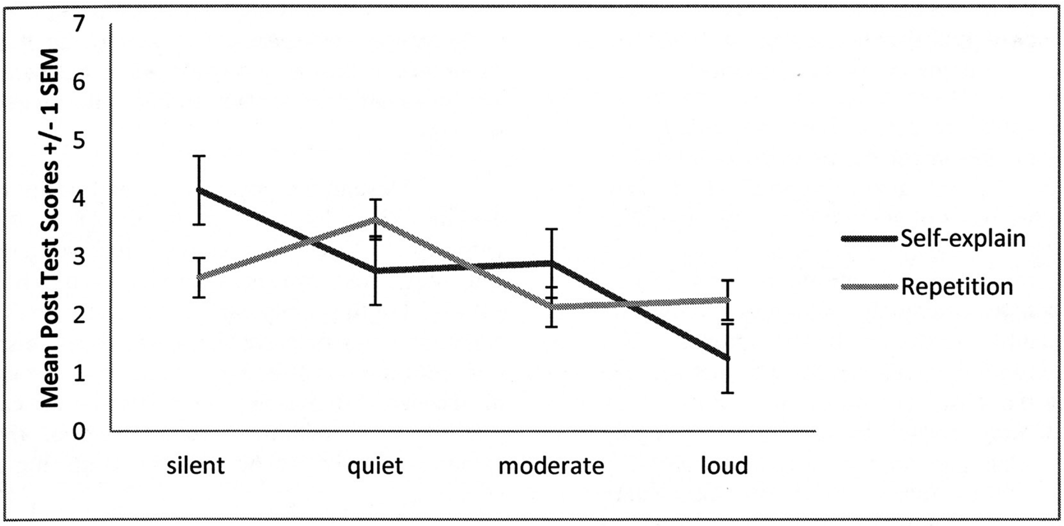
Analysis of post-test scores showed a significant interaction between study strategy and study environment, $F(1,28) = 4.33$, $p = 0.047$, partial $\eta^2 = 0.36$), with no significant main effect for either factor (strategy: $F(1,28) = 0.39$, $p = 0.54$; music: $F(1,28) = 0.39$, $p = 0.54$). The interaction arose due to contrasting effects of self-explaining in the different music conditions. In the silent conditions, self-explainers had better post-test scores ($M = 52\%$, $SD = 0.25$) than students who simply repeated the material ($M = 29\%$, $SD = 0.20$). This pattern was reversed in the music groups: self-explainers had lower post-test scores (M = 29%, SD = 0.27) than students who used repetition (M = 41%, SD = 0.23).

Experiment 2

Study 1 showed that exposure to loud music during study can actually reverse the self-explanation effect, causing this normally advantageous strategy to impede learning relative to rote memorization. To replicate and extend this finding, we next conducted a 'dose-response' experiment, varying music level from silent to loud in 4 steps to better determine the threshold for disrupting the self-explanation effect. We also developed an objective 4-point test of prior knowledge to allow calculation of difference scores and better capture learning across the experiment.

Scores on the initial pre-test showed little initial knowledge of the action potential (M=26%, SD=0.25). Moreover, prior knowledge did not vary by experimental condition (Strategy: $F(1,56) = 0.97$, *ns.*; Music: $F(3,56) = 0.36$, *ns*; Strategy x Music: $F(3,56) = 1.33$, *ns*). Although this experiment used an objective measure of prior knowledge, there was still no correlation with post-test scores , $r = 0.23$, $p = 0.07$, $N = 64$. This was likely due to the extreme restriction of range in pre-test scores. As the lack of significant correlation precluded use of pre-test scores as a covariate, we adjusted for prior knowledge by calculating difference scores (post-test – pre-test) for each participant.

Figure 2. Mean Scores (± 1) SEM by Study Strategy and Study Environment



The main effect of strategy was not significant, $F(1,56) = 1.39$, $p = 0.24$. There was, however, a significant main effect of study music, $F(3,56) = 4.65$, $p = 0.008$, partial $\eta^2 = 0.18$) as well as a significant interaction between strategy and music, $F(3,56) = 4.43$, $p = 0.04$, partial $\eta^2 = 0.14$.

The main effect of music was due to an inverse relationship with volume and learning: performance gains were highest in the groups with no study music (M = +20%) or quiet music (M = +21%). With moderate music, performance did not greatly change (M = +3%), and with loud music there was an average decline from pre-test to post-test (M = -8%).

The significant interaction represented a complex pattern of results, but the overall trend seemed to be that self-explaining enhanced the deleterious effects of music. In the repetition groups, there was a modest main effect of music, $F(3,28) = 3.61$, $p = 0.03$, accounting for 28% of the variance in learning. In the self-explaining groups, on the other hand, music had a stronger effect on performance, $F(3,28) = 5.68$, $p = 0.004$, accounting for 38% of the variance in learning. Consistent with the first experiment, these results suggest that the self-explanation effect can be blocked and even reversed when moderate or loud music accompanies study.

Discussion

The results confirm that self-explaining is a potent strategy for enhancing learning, but reveal that this effect can be disrupted and even reversed when music accompanies learning. In both studies, self-explaining was superior to repetition during silent study, but this trend was eliminated or reversed when study was accompanied by quiet or loud music. Given the high frequency in which students elect to incorporate music into their study routines, this suggests that self-explaining may not be as effective in the real world as it has proven to be in the laboratory.

This negative interaction between self-explaining and study music was somewhat surprising. Although prior literature shows that study music impairs learning of complex materials (Kiger, 1989; Hallam et al., 2002; Furnhame & Bradley, 1997; Ransdell & Gilroy, 2001; Kanter, 2009), we expected that this might attenuate all study strategies equally. It is worth considering, then, why self-explaining might be more susceptible to disruption than rote memorization with repetition. One possible explanation for the observed effects is cognitive load. It takes more effort and resources to self-explain than rote memorization. The addition of loud music could thus selectively overload self-explainers relative to rote memorization, making it difficult to generate self-explanations and reap benefits from this strategy. The irrelevant sound literature notes similar effects (Boyle & Coltheart, 1996; Farley, Neath, Albritton, & Surprenant, 2007; Perham & Vizard, 2010; Salamé & Baddeley, 1989).

Given the large literature demonstrating the benefits of self-explaining, it would be premature for these two studies to temper the considerable enthusiasm for enjoining this study strategy to students. First, this negative interaction could be prevented simply by urging students to choose quiet study environments, a habit that is wise no matter what study strategy is employed. Second, this is only an initial investigation of how distractions influence the self-explanation effect. Still, the results are intriguing and may explain the curious lack of published literature on the impact of self-explanation training in real study settings.

To better determine how concerning this negative interaction might be, it would be useful to expand the current study along two parallel lines: 1) to the use of other types of study distractions, and 2) to more realistic study/test cycles. In terms of distractions, music may be one of the most benign study distractions commonly encountered—students also frequently study with background TV, conversation, and/or intermittent social interactions. Even within the domain of music, the current study used only 1 song, chosen in part for being highly distracting. One particularly intriguing possibility would be to allow students to choose their study environment, as familiarity with their common distractions may actually be less damaging to the self-explanation effect.

In terms of study/test cycle, these experiments used a highly artificial procedure in which students studied for only 6 minutes and were then immediately tested. Although this may be a fair representation of cramming behavior, it would be useful to examine the effectiveness of self-explaining over more realistic study/testing circumstances. It may be that self-explaining is not as disrupted when measured over longer retention intervals and/or with more study sessions.

Despite the power, ease, and utility of self-explaining as a study strategy, there is a curious lack of empirical evidence that it works in real world settings. This initial study was not a perfect test of ethological validity, but the results raise some concerns that self-explaining may be particularly sensitive to disruption and therefore less effective in real-world settings than in the lab. Certainly, these results indicate the importance of additional road-testing of the self-explanation effect to help guide efforts for student adoption.

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Appendix A

Age____________________ Gender______________________

Pretest

1. **Action potential can be defined as:**

   A) a neuron getting ready to fire

   B) a neuron becoming harder to fire

   C) a neuron having an electro-chemnical impulse that sweeps down its axon

   D) a neuron becoming more permeable to potassium

2. **An action potential occurs when:**

   A) a neurotransmitter binds at receptor sites

   B) the cell membrane of a nerve becomes depolarized and opens gates allowing sodium ions to enter the cell

   C) stimulation of the neuron causes the cell to become more negatively charged

   D) sodium ions escape from the cell through the sodium channels

3. **If a neuron's membrane depolarizes to the point of threshold and an action potential occurs,**

   A) it will travel the length of the axon in an all or none fashion.

   B) it will increase in strength as it reaches the terminal

   C) it will travel some distance and then peter out

   D) it will stop if it reaches closed sodium gates

4. **When it becomes harder for the neuron to fire, is has become:**

   A) polarized

   B) hyperpolarized

   C) depolarized

   D) repolarized

Appendix B

Test

1. An action potential occurs when its_____________is reached.

2. Hyperpolarization
   a. refers to a shift in the cell's potential in a more negative direction.
   b. refers to a shift in the cell's potential in a positive direction.
   c. can trigger an action potential if it is large enough.
   d. occurs in an all-or none fashion.

3. The down slope of the action potential graph
   a. is largely a result of sodium ions being pumped back out again
   b. is the result of potassium ions flowing in briefly.
   c. is the result of sodium ions flowing in briefly.
   d. usually passes the level of the resting potential, resulting in a brief hyperpolarization due to potassium freely leaving the cell.

4. Depolarization of a neuron can be accomplished by having
   a. a negative ion, such as chloride (Cl-),flow into the cell.
   b. potassium (K+) ions flow out of the cell.
   c. sodium (Na+) ions flow into the cell.
   d. sodium ions flow out of the cell.

5. True or False-Neurons can fire both small and large action potentials.

6. The all-or none law

   a. applies only to potentials in dendrites
   b. states that the size, shape, and velocity of the action potential are independent of the intensity of the stimulus that initiated it.
   c. makes it impossible for the nervous system to signal intensity of a stimulus.
   d. all of the above.

7. Depolazization
   a. refers to a shift in the cell's potential in a more negative direction.
   b. refers to a shift in the cell's potential in a positive direction.
   c. can trigger an action potential if it is large enough.
   d. occurs in an all-or none fashion.