THE EFFECT OF NOTE-TAKING MODALITY ON OFFLOADING AND MEMORY UNDER COGNITIVE LOAD

by

CAMI LEIGH CIESIELSKI

Bachelor of Science, 2019
Colorado State University
Fort Collins, Colorado

Submitted to the Graduate Faculty of the
College of Science and Engineering
Texas Christian University
in partial fulfillment of the requirements
for the degree of

Master of Science in Experimental Psychology

August 2022

ACKNOWLEDGEMENTS

During my journey at Texas Christian University, I have received substantial support from others who in part have made my thesis possible. First, I would like to start by thanking my wonderful advisor, Dr. Mary B. Hargis. Her knowledge and encouragement have been extremely valuable for me; she has helped me become a better, researcher, educator, and all-around a better person. The past two years working with Dr. Hargis have been such a gift.

Additionally, I would like to thank my thesis committee, Dr. Sarah "Uma" Tauber and Dr. Naomi Ekas for their ideas in making this thesis stronger. I would also like to acknowledge my fellow lab mate and confidant, Morgan Shumaker. She has always been willing to listen, give advice, laugh with me, and reassure me whenever I needed. Further, I am extremely grateful for my colleagues who have befriended me during the pandemic and made graduate school more enjoyable; you know who you are. This project also would not have been possible without the help of my amazing research assistants.

Last, I would like to extend extra thanks to my family. My husband, Justin, has been incredibly considerate and supportive during this adventure; thanks for leaving the city of your dreams so that I could pursue my goals. Also, many thanks to my parents, sisters, and Gramps for always encouraging me to chase my dreams; you all have believed in me since day one. Finally, I would like to thank my brother-in-law Michael, for his programming ingenuity and willingness to help out. I am tremendously grateful for those who have helped me get to where I am now and truly could not have done this without you all.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

The Effect of Note-taking Modality on Offloading and Memory under Cognitive Load

Each day, individuals experience different environments where they have to remember information. There are two primary strategies that one may use to remember information. One strategy is to store the information internally, using one's own cognitive resources. Alternatively, an individual can choose to store the information using an external tool, an example of *cognitive offloading* (see Risko & Gilbert, 2016 for an overview). People frequently offload information, especially when there is more information presented than they can hope to remember. One primary way individuals offload is by taking notes. For example, more than 90% of students report that they frequently or always take notes on the material that is presented in a class lecture (e.g., Morehead et al., 2019b; Witherby & Tauber, 2019).

One central question in the note-taking literature is whether the modality used for taking notes impacts how well the to-be-remembered material is learned. That is, how memory performance may differ based on whether the information was recorded using a pencil and paper or using an electronic device, such as a computer. There are conflicting findings in the literature (e.g., Bui et al., 2013; Mueller & Oppenheimer, 2014), such that there is not a clear answer of whether handwriting or typing is associated with better learning or performance (see Allen et al., 2020 for a meta-analysis). By using the cognitive load theory (Plass et al., 2010; Sweller, 1994) and a dual-task approach, the current experiments investigated how note-taking modality may influence an individual's memory performance and offloading decisions (Experiment 1) and whether the difficulty of the to-be-learned material influences individuals' cognitive load, and modality use, and performance (Experiment 2).

Use of Offloading

In many cases, offloading is used to achieve a goal by reducing the cognitive demand of the task (e.g., Risko & Gilbert, 2016). In other words, offloading can “take the load off” of an individual’s memory system by alleviating the need to hold the information internally. By offloading information, people are often capable of accomplishing a task more efficiently. Gilbert (2015) found that when participants offloaded an intention (e.g., dragged a circle to a particular side of a box), their performance improved as compared to when they only relied on their own memory to correctly complete the intention. Additionally, people can often store more information when offloading than would be possible when relying on their own internal cognition (e.g., Schönpflug, 1986). Humans have limited working memory capacity, but can often overcome those limitations by using an external storage. For example, when individuals are given the option to take notes and use them on an upcoming test, they often remember more material than participants that were not allowed or chose not to take notes (e.g., Risko & Dunn, 2015).

Additionally, the act of taking notes benefits learning and memory, often referred to as the encoding effect (Di Vesta & Gray, 1972). This theory is supported by research which has found taking notes, even in the absence of a review session, is beneficial for performance outcomes (see Kobayashi, 2005 for a meta-analysis). Relatedly, previous research also has found that information that is recorded by the participant is more likely to be remembered as compared to information that was presented but not recorded (e.g., Aiken et al., 1975; Bretzing & Kulhavy, 1981; Carter & Van Matre, 1975; Peper & Mayer, 1978; Van Matre & Carter, 1975). Offloading information can also be beneficial when learning subsequent, new information such that individuals can remember future to-be-remembered information better when they recorded the previous information (e.g., Storm & Stone, 2015). This pattern of results may be due to the fact that the offloaded information is less likely to interfere with the information that is currently being learned as compared to when the target information is stored internally. Thus, note-taking can be beneficial for a variety of reasons and has been shown to lessen the demands of a task.

While note-taking may alleviate some of the cognitive load of the task, it is also important to consider that the act of note-taking can be cognitively demanding (Jansen et al., 2017; Kellogg, 1987, 2008; Piolat et al., 2005). When a learner is taking notes, they have to listen to or read the material, comprehend its meaning, select the information that they would like to record, and then record it (e.g., Friedman, 2014). It is also important to consider that transcription is often slower than comprehension, tasking learners with mentally storing some of the information that they want to record (e.g., Piolat et al., 2005). Additionally, several behaviors may be occurring when offloading to increase the efficiency of note-taking such as abbreviation, paraphrasing, or organizing (e.g., Jansen et al., 2017; Piolat et al., 2005), all of which may be effortful for the individual. Note-taking is also challenging because individuals should select the important information that will aid their understanding; however, many studies have found that students have trouble identifying the main points of a topic that are important to record (e.g., Hartley & Marshall, 1974; Kiewra & Benton, 1988; Northern et al., 2022).

The benefits and costs associated with note-taking may also depend on the modality (e.g., typing versus writing) used to offload. However, there is disagreement in the literature on the extent to which the note-taking modality affects performance. Some research suggests that taking notes by hand leads to higher subsequent test performance as compared to typing notes (e.g., Aguilar-Roca et al., 2012; Allen et al., 2020; Frangou et al., 2018, 2019; Fried, 2008; Horbury & Edmonds, 2021; Mangen et al., 2015; Mueller & Oppenheimer, 2014; Smoker et al., 2009). One reason that writing may produce better learning outcomes as compared to typing is because individuals who take notes by hand are less likely to copy the materials verbatim (e.g., Mueller & Oppenheimer, 2014). Thus, it is argued that individuals who write may process the information in a more meaningful way (i.e., writing is associated with deeper processing; Mueller & Oppenheimer, 2014; Smoker et al., 2009). This supports some findings which suggest that writing is better than typing for performance on conceptual questions (e.g., Horbury & Edmonds, 2021; Mueller & Oppenheimer, 2014).

Additionally, in the only known study which investigates cognitive load and modality using the dual-task paradigm, Bouriga and Olive (2021), for the primary task, instructed participants to complete a copying task, by writing and typing the selected texts. While participating in the copying task, for the secondary task, participants responded to an auditory tone with a foot pedal. Results revealed that participants were faster to respond to the tones when they were in the writing as compared to the typing, suggesting that typing is associated with more cognitive load. The authors suggest that the physical movements done when handwriting may be more automatic and consume less working memory capacity as compared to typing (see also Piolat et al., 2005). Finally, one reason that writing may be advantageous in the classroom is because technology can often be a distraction to students, with those using devices having to refrain from multitasking to learn optimally (Kay & Lauricella, 2011; Sana et al., 2013; for a review see May & Elder, 2018). These findings have real-world implications: the work described above may have influenced some instructors to ban the use of laptops within their classrooms (e.g., Maxwell, 2007; Yamamoto, 2007).

In contrast, a limited number of studies suggest that typing is associated with more favorable outcomes than writing (e.g., Bui et al., 2013; Fiorella & Mayer, 2017; Gulek &

Demirtas, 2005). One potential explanation in support of typing is that individuals can type faster than they can write (Brown, 1988; e.g., Aragón-Mendizábal et al., 2016; Bui et al., 2013; Luo et al., 2018). Individuals who type notes, therefore, may be able to record more information than is possible when writing. If learners have to process a significant amount of content, those who type may be able to keep up better compared to those who write. As such, previous studies have found that transcription speed is often a predictor for not just the quantity of notes produced, but also the quality (e.g., see Peverly, 2006; Peverly et al., 2007). Traditionally, writing was the prominent transcription method taught to students, but due to the increasing affordability and ease of digital technology, electronic forms of note-taking have become widely accepted and students may be as proficient, or even more proficient, in typing as compared to writing. From this perspective, proficient typists may experience lower cognitive load than writers when note-taking because of the speed at which they can type; however, there is limited research in this area.

Interestingly, other work has found no consistent difference in performance between groups engaging in typing or writing (e.g., Beck, 2015; Luo et al., 2018; Morehead et al., 2019a; Urry et al., 2021). These studies often suggest that other factors surrounding the learning situation may have more impact on memory than the modality being used. For example, Lin and Bigenho (2011) found that when there was an auditory and visual distraction presented during the experiment, participants in a “no notes” condition outperformed both the typing and the writing condition on a final test. However, when the participants did not experience any distractions while taking notes, participants performed better on the final test when they took handwritten notes than when they typed notes or did not take notes at all. Overall, these results may inform why there may be a difference between modalities in some studies but not others, as extraneous variables may be varied between studies. Thus, the current study will address two different variables that may begin to answer the question of what variables influence the effectiveness of an offloading modality. Experiment 1 will investigate one area that has been largely overlooked in the note-taking literature: the demand imposed by the task (i.e., the cognitive load of the note-taking modality). Experiment 2 will extend previous findings by incorporating different levels of difficulty of the to-be-learned material to understand how stimuli may influence the effect of note-taking modality on learning.

Cognitive Load Theory

People use their working memory to process to-be-learned information (e.g., see Baddeley, 1992 for a review). For example, students use their working memory to comprehend the information that is being spoken in a lecture and to decide what information should be recorded (e.g., Piolat et al., 2005). However, working memory can only contain a certain amount of information while concurrently processing the new, incoming material (Baddeley, 1990, 2007; Baddeley et al., 2009; Baddeley & Hitch, 2001; Cowan, 2001; Engle, 2002; Posner, 1982; for a review see Oberauer, 2019). Although the capacity of working memory may differ between individuals, every individual is limited in the amount of information they can work with at one time. Based on this assumption, cognitive load theory (see Chandler & Sweller, 1991; Sweller, 1988, 1989; Sweller et al., 1990) attempts to understand the way in which a learner's cognitive resources are allocated. The theory posits that the design of the learning instructions and task has significant implications for how well individuals can learn. Specifically, cognitive load theory suggests that there are detrimental effects on learning when there is too much cognitive load imposed during the task (e.g., Artino, 2008; Sweller, 1988). Cognitive load theory, which has been incorporated into educational research, proposed that by manipulating the design of the learning environment, and measuring cognitive load, researchers can understand how to minimize cognitive load and thereby improve learning outcomes (Artino, 2008; Sweller, 2005).

There are three primary categories of measurements that researchers use to examine cognitive load: self-report, physiological outcomes, and the dual-task method. Although each measure has its benefits and drawbacks (see DeLeeuw & Mayer, 2008), the current study will utilize the dual-task methodology to measure cognitive load. The dual-task methodology is advantageous because it is an objective way to measure cognitive load (i.e., compared to subjective self-report measures; Brünken et al., 2003; Schoor et al., 2012). The dual-task method is also beneficial because it measures the load *during the task* as compared to a retrospective measurement, such as self-report that is often taken at the end of the study (Schoor et al., 2012).

When a study utilizes a dual-task approach, a primary and secondary task occur concurrently. Specifically, the participant engages in a primary task which is often manipulated so that researchers can examine the effects of the manipulation on learning outcomes (e.g., performance) and cognitive load. The measurement of cognitive load is the secondary task, where participants may respond to an auditory tone or to a change in one key feature of the environment (e.g., a distinguished letter changing colors on the screen where learning materials are located; for examples see Brünken et al., 2002; Chandler & Sweller, 1996). The reaction time to the secondary task is considered a measure of how much cognitive load the primary task requires. Specifically, if the primary task is more demanding of one's memory resources, there is higher cognitive load, and therefore reaction times to the secondary task will be slower. The opposite pattern of results occurs when the primary task is less demanding. Participants are instructed to first attend to the demands of the primary task and then respond to the secondary task. As such, the secondary task should not add any cognitive load in this design (Brünken et al., 2002; Martin, 2014).

Cognitive load theory has become an influential theory within education research (e.g., Schmeck et al., 2015; Sweller et al., 2019) however, the use of the dual-task methodology is still rather sparse (for exceptions, see Ayres, 2001; Brünken et al., 2002; Chandler & Sweller, 1996; Lansman & Hunt, 1982; Madrid et al., 2009; Marcus et al., 1996; Renkl et al., 2003; Sweller, 1988). Further, the dual-task has not yet been utilized when investigating how the offloading modality used to record notes may affect the cognitive load in a learning task. One study done by Ruan and colleagues (2015) investigated the modality of offloading within the framework of cognitive load theory, however, instead of using the dual-task method, they used self-report as a measurement of cognitive load. The participants reported that using a digital tool for note-taking was advantageous for convenience, while taking longhand notes better for reading comprehension. However, they found that cognitive load was higher while writing, as participants' reported that writing took more effort and resources than typing (Ruan et al., 2015). In a more recent study, Bouriga and Olive (2021) applied the dual-task methodology to a copying task. They found that when participants were instructed to copy the provided texts, they were faster to respond to the secondary task tone when writing than when typing. Thus, suggesting that writing induced lower cognitive load as compared to typing. Although this initial experiment was followed by an experiment where participants engaged in memory task that investigated the effect of note-taking modality during recall, the study did not utilize the dual-task methodology in that experiment, thus leaving the question of whether cognitive load may vary by modality within a learning task unanswered. The current study will address this gap by applying the dual-task methodology of cognitive load theory to investigate how the modality of offloading may influence task performance and cognitive load.

The Current Study

The following two pre-registered experiments explored whether the cognitive load theory may elucidate why some studies have found differences in performance between note-taking modalities and some have not. One goal of Experiment 1 was to build upon previous research by investigating whether there is a significant difference between recall performance between the offloading conditions, typing or writing. The other primary goal of Experiment 1 was to use the dual-task methodology to understand if one of the modalities may use more cognitive resources, therefore increasing an individual's cognitive load. If using one modality induces higher cognitive load than the other, then previous findings suggest that the load will negatively impact participants' performance accordingly. The purpose of Experiment 2 was to replicate the findings from Experiment 1, while also furthering the findings to understand how the difficulty of the learning material may influence the cognitive load and use of the offloading modalities. Together, the two experiments will examine whether cognitive load theory is an appropriate framework to explain why the two offloading modalities may be associated with differences in performance.

Experiment 1

The primary goal of Experiment 1 was to investigate the cognitive load induced by offloading modalities. Prior research is not only limited in the dual-task as a measure of cognitive load, but there is only one known study that uses the dual-task to investigate the cognitive load of the note-taking modality when copying a text. In the current experiment, participants studied three different word lists, each followed by a free recall test. Critically, participants were either allowed to write or type the words to record them, creating notes which they were told could be used on a final test. While they were studying each word list, participants also heard a randomized tone and were instructed to respond to a tone by pressing a foot pedal, as a measure of cognitive load. In a similar study, Bouriga and Olive (2021) found that typing resulted in higher reaction times as compared to writing, using the dual-task methodology. Therefore, I hypothesized that participants would have slower reaction times in the typing condition as compared to the writing condition because typing is thought to induce higher cognitive load. Accordingly, I hypothesized that participants under higher cognitive load would have lower free recall performance than those under less cognitive load.

Method

Participants

An *a priori* power analysis using G*Power (Faul et al., 2009) revealed that 86 participants in each group were required to detect a medium effect (d = .50) with two between-subjects groups, an alpha of .05, and power of .90. Therefore, I aimed to recruit a total of 172 undergraduates from Texas Christian University (TCU) who would participate in exchange for partial course credit or extra credit in a psychology course. However, due to the COVID-19 pandemic and the number of participants that were excluded based on pre-registered exclusion criteria, I did not reach the desired number of participants. Specifically, 4 participants did not follow instructions, 10 participants reported taking a similar study or participating in study with similar materials, 3 participants had internet troubles, 47 participants chose not to utilize offloading, and 27 participants did not properly follow the tone directions. Therefore, the final sample included 124 participants (M_{age} = 20 years), primarily female participants (79%; 99 female, 25 males, 1 individual did not report). Of the participants, 79% identified as White, 8%

identified as Asian or Pacific Islander, 6% identified as Black, less than 1% identified as American Indian or Alaskan Native, and the remaining 6% identified as Other/unknown. Sixty-nine of the participants were randomly assigned to the typing condition and 55 participants were assigned to the writing condition. This experiment was approved by the TCU Institutional Review Board and all participants gave written consent to participate.

Design

The dual-task methodology was utilized to understand participants' performance and cognitive load during a memory task. Using this methodology (e.g., Brünken et al., 2002; Lansman & Hunt, 1982; Sweller, 1988), each learning task included a study-test trial, where participants were given the opportunity to offload the words while they studied. Specifically, participants were randomly assigned to one of the two offloading modalities: writing or typing. The goal of the experiment was to investigate if participants' cognitive load, offloading decisions, and memory performance differed between the offloading modalities. The dependent variable for the learning task was the proportion of words recalled on the test following each study trial. The secondary task measured the cognitive load induced by the primary task. The dependent variable for cognitive load was measured by the average reaction time to the auditory probes.

Materials

The study materials for the primary task included 90 words, randomly selected to form three lists of 30 unique nouns taken from previous research (Hargis et al., under review). All the nouns ranged in length from four to six letters (*M* = 5.30 letters, *SD* = .66) and had an average frequency of 8.60 (*SD* = 1.51), as measured by the log-transformed Hyperspace Analogue to Language (HAL) scale (Balota et al., 2007).

Tasks

Operation Span Task. The operation span task was used as a measure of working memory capacity. The specific operation task was developed by Oswald and colleagues (2015) which is a shortened version of the original operation span measurement. Participants saw a series of simple math problems intermixed with a range of letters (e.g., three to five in a single trial). Their goal was to remember all of the letters presented in order and solve the math equations as quickly and correctly as possible. At the end of each trial, participants were given a box of 12 possible letters that they may have seen and were instructed to select the letters in the order that they were presented.

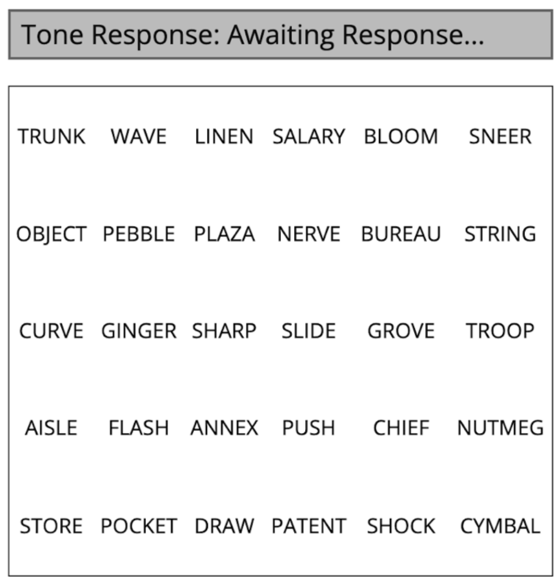
Learning Task. The learning task was a study-test trial, which participants completed three times during the study. Within each learning task, participants had a study session followed by a free recall test. For each study session, participants completed the primary task and the secondary task concurrently (e.g., dual-task).

Primary Task. Participants were told that the goal of the primary task was to try to learn the words that were presented for an upcoming test. Each participant was randomly assigned to either the typing or the writing condition to take notes. In the typing condition, underneath the words to learn, there was a text box where the notes could be typed. In the writing condition, participants were provided with a pencil and paper which was blank besides an outline of a box, similar to the typing condition. Regardless of what condition participants were in, they were told that although they *could not* use their notes on the test following each list, they *could* access their notes on a final test. However, participants did not actually take a final test in which they could access their notes, rather I used this deception to encourage participants to use the offloading tool, without requiring them to do so.

Each list of 30 words was presented on the computer screen in a box at the center of the screen. Within the box, participants saw a 6 x 5 arrangement of the words (see Figure 1). The order in which the words were presented on the screen was randomized. Participants could offload as many of the words as they liked while studying each list. After the list of words had been displayed for 60 s, the words disappeared off the screen.

Figure 1

Example of Learning Task



Secondary Task. The secondary task measured the cognitive load induced by the primary task. However, it is important that the secondary task does not cause more load to the participant, rather just measures the cognitive load induced by the primary task (e.g., Piolat et al., 1999). To avoid causing more load, previous research suggests the secondary task should be in a different modality than the primary task (see Park & Brünken, 2015). Therefore, the secondary task chosen for the experiment was an auditory tone task.

Participants were instructed to respond to the tone by pushing the foot pedal provided using their dominant foot (as done in Madrid et al., 2009). A research assistant set up the foot pedal for them at the beginning of the task and participants were instructed to put on the provided headphones. The tone randomly sounded every 5 to 10 s (as done in Brünken et al., 2002; Schoor et al., 2012) during the duration of the primary task. The computer recorded the time between the onset of the tone and the pushing of the foot pedal in ms. The instructions stated that the participants should push the foot pedal as quickly as possible in response to the tone, however, learning the words was the primary goal of the task. All trials started with a single tone that was not recorded, in order to inform the participant that the trial was beginning. When a tone sounded and participants pushed the pedal, the computer screen would display 'Response Recorded.' If a tone had sounded but participants had not responded by pushing the foot pedal, the computer would read 'Awaiting Response…'.

A baseline measure of the secondary task was taken for each participant before the first learning task began. Specifically, participants were then given the tone-task (i.e., the secondary task) without the primary task to measure their baseline reaction time. This baseline measure was taken so that I could account for individual differences in reaction times. During the baseline trial, the procedure was the same as described above, except that the participants did not have to study any information during this trial (i.e., no primary task; see Brünken et al., 2002 for an example).

Free Recall Test. After studying each list, participants in both conditions were delayed 5 s so that the writing condition could hand their notes to the researcher, then they took a recall test. For the free recall test, participants were instructed to type into a box on the computer as many words from the previous list as possible. The free recall test was self-paced.

Procedure

Participants were welcomed into the lab, gave written consent, and were placed in front of a computer in a private room. After participants filled out a demographic questionnaire, they read instructions and completed the operation span task. Next, a trained research assistant came into the room and helped participants set up the foot pedal and headphones for the learning task. The researcher stayed in the room for the duration of the task. After participants read the instructions for the task, they completed a baseline measurement of their reaction time. Following, all participants took the learning task, which utilized the dual-task methodology (i.e., a primary and secondary task). Each time they completed the learning task, they had a study trial that included the primary and secondary task, followed by a free recall test. All participants completed the learning task three times, once for each word list. Finally, participants answered final questions about their experience with the task and were debriefed.

Results

Although the pre-registered plan was to run a *t*-test on the data of the averaged list scores, it was more optimal and in-line with Experiment 2 to investigate how performance changes over lists instead of using an average across all lists. Therefore, I slightly deviated from the pre-registration and opted to run an Analysis of Variance (ANOVA) on the data. In the following results section, reaction times during the primary task are discussed, followed by free recall performance and then participants' offloading behavior. Additionally, exploratory analyses on working memory capacity are presented.

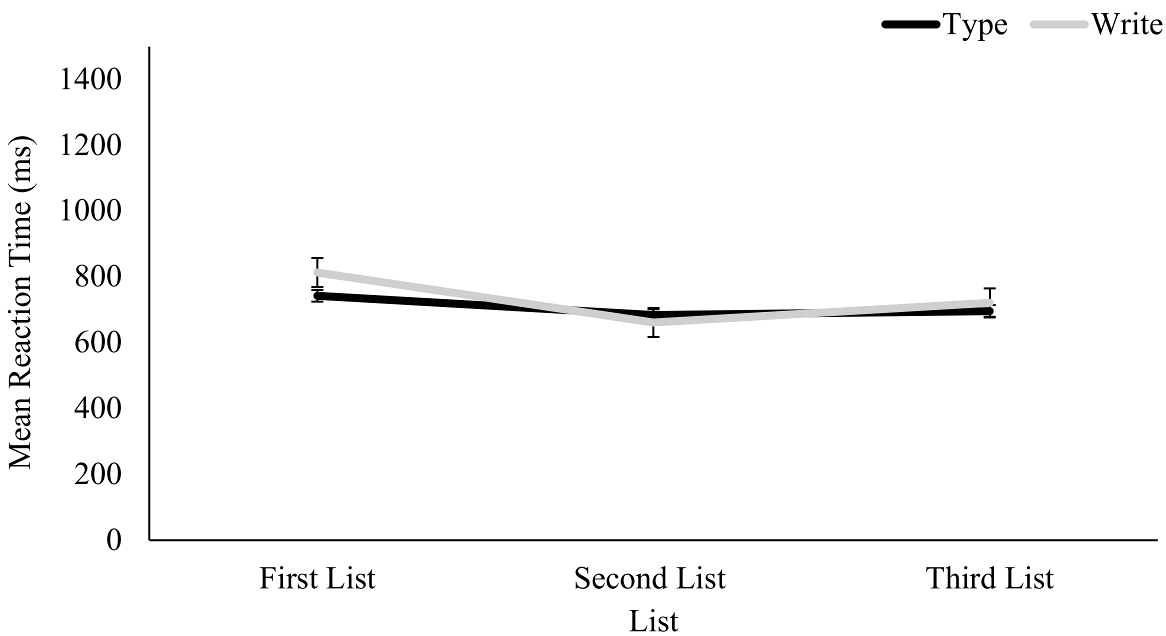
Reaction Times

Although a baseline measure of reaction times was recorded at the beginning of the experiment to account for individual differences in reaction to the tone, the baseline measures of reaction times on average were higher than the reaction times in the actual task (see discussion for a possible explanation). Thus, it did not make sense to use the baseline measures as a way to "subtract out" individuals differences in performance. Importantly though, there was no difference in baseline measure between the two offloading conditions, $t(122) = .53$, $p = .597$, $d = .10$.

A 2 (Offloading Condition: Typing, Writing) x 3 (List) mixed ANOVA was performed, using the Greenhouse-Geisser correction, on reaction times to the tone with the former factor manipulated between-subjects and the latter within-subjects. The results revealed a main effect of list, $F(1.85, 225.39) = 3.04$, $p = .054$, $\eta_p^2 = .024$ (see Figure 2), but no main effect of condition, $F(1, 122) = .12$, $p = .726$, $\eta_p^2 = .001$ or significant two-way interaction, $F(1.85, 225.39) = .58$, $p = .548$, $\eta_p^2 = .005$. Post hoc analyses using the Bonferroni correction revealed that participants' reaction times were faster on the second list ($M =$ 671.63 ms, $SE =$ 42.28 ms) as compared to the first list ($M =$ 776.75 ms, $SE =$ 42.28 ms) they saw, $t(122) = 2.43$, $p = .048$, $d = .22$. However, there was no difference in reaction times for any other comparisons, ts ≤ 1.60, ps $\geq .337$, ds $\leq .14$.

Figure 2

Reaction Times for Experiment 1



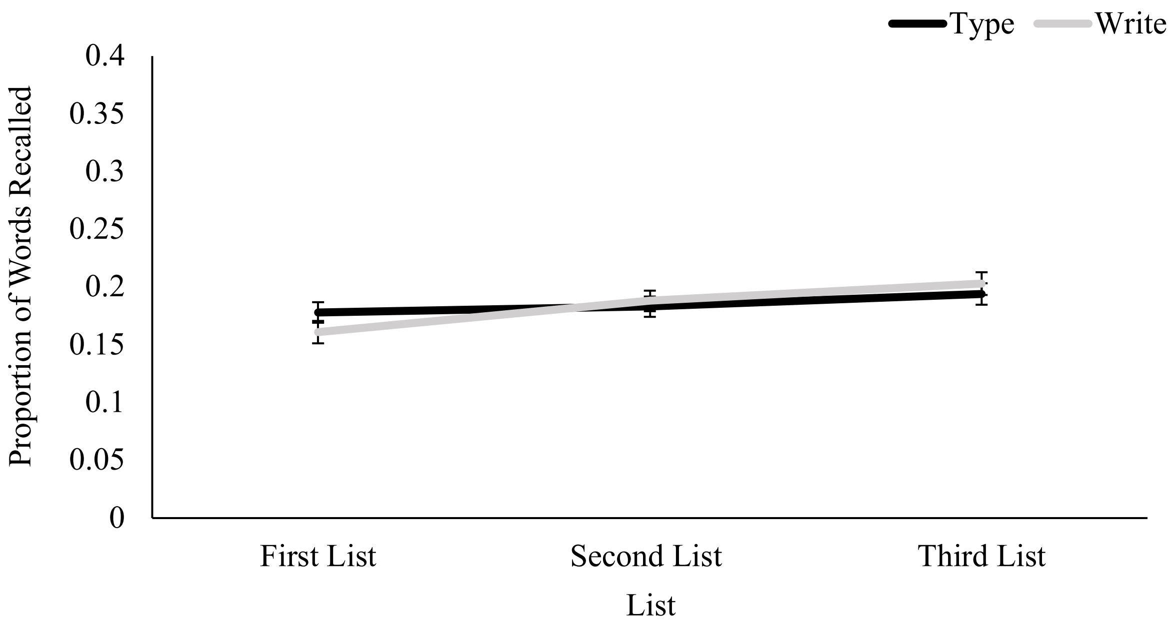
Note. Mean reaction times as a function of list and offloading condition in Experiment 1. Error bars represent one standard error of the mean.

Free Recall Performance

In order to examine whether there was a difference in free recall performance, a 2 (Offloading Condition: Typing, Writing) x 3 (List) mixed ANOVA was performed on the free recall scores. Results revealed that there was a main effect of list, $F(2, 244) = 8.66$, $p < .001$, $\eta_p^2 = .066$ (see Figure 3). However, there was not a main effect of offloading condition $F(1, 122) = .010$, $p = .920$, $\eta_p^2 < .001$ or significant interaction, $F(2, 244) = 2.12$, $p = .123$, $\eta_p^2 = .017$. Post hoc analyses using the Bonferroni correction revealed that participants' free recall performance was lower on the first recall test ($M = .17$, $SE = .01$) than the third recall test ($M = .20$, $SE = .01$), $t(122) = 4.16$, $p < .001$, $d = .37$. However, there was no significant difference between any other comparisons, ts ≤ 2.25, ps $\geq .075$, ds $\leq .20$.

Figure 3

Free Recall Performance for Experiment 1



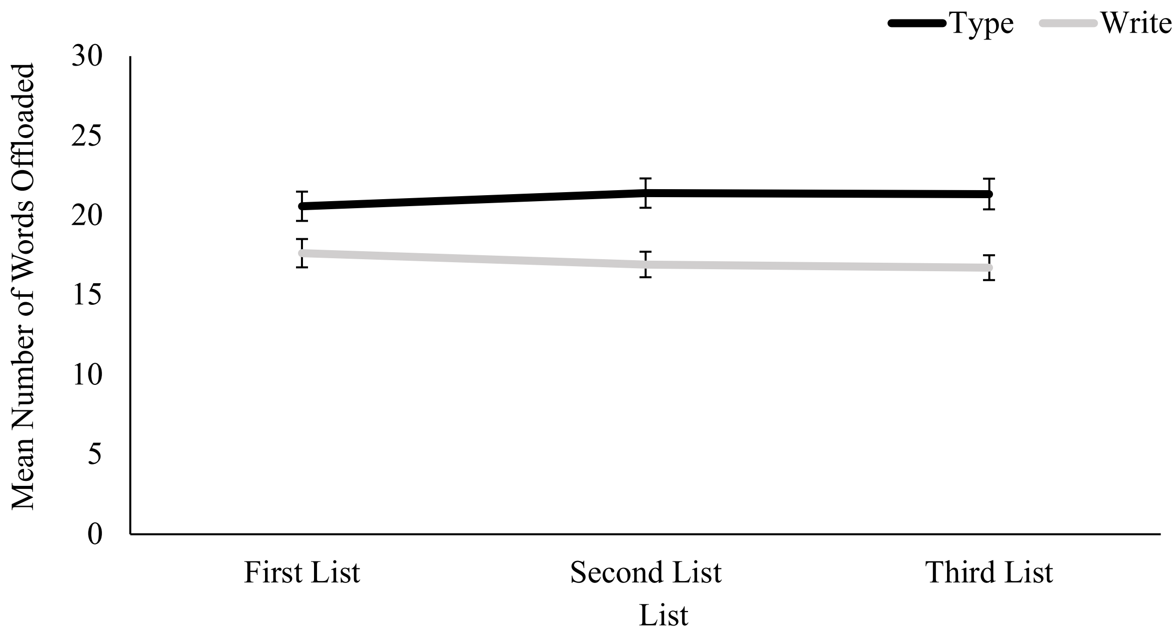
Note. Mean proportion of words recalled on each list separated by offloading condition in Experiment 1. Error bars represent one standard error of the mean.

Number of Offloaded Words

A 2 (Offloading Condition: Typing, Writing) x 3 (List) mixed ANOVA using the Greenhouse-Geisser correction was performed on the number of words offloaded (see Figure 4). The results revealed a main effect of condition, $F(1, 122) = 11.68$, $p < .001$, $\eta_p^2 = .087$, but no main effect of list, $F(1.65, 201.25) = .04$, $p = .933$, $\eta_p^2 < .001$, or interaction, $F(1.65, 201.25) = 2.24$, $p = .119$, $\eta_p^2 = .018$. Post hoc analyses using the Bonferroni correction revealed that participants in the typing condition ($M = 21.34$, $SE = .83$) offloaded more words than in the writing condition ($M = 17.32$, $SE = .83$), $t(122) = 3.42$, $p < .001$, $d = .31$.

Figure 4

Offloading behavior for Experiment 1



Note. Mean number of offloaded words on each list as a function of offloading condition from Experiment 1. Error bars represent one standard error of the mean.

Working Memory Capacity

Working memory capacity was operationalized through the short version of the operation span task (Oswald et al., 2015). Specifically, the absolute scoring method was used, which is the sum of letters in each perfectly recalled set. To illustrate, participants were shown two sets of four letters, two sets of five letters, and two sets of six letters, so a perfect score would be 30 if all the letters were recalled in each set, in order.

Importantly, there was no difference in working memory capacity between the typing condition and the writing condition, $t(122) = .41$, $p = .679$, $d = .08$. I ran exploratory correlations and found that free recall performance was positively correlated to working memory capacity for both the writing condition, $r = .262$, $p = .053$, and the typing condition, $r = .256$, $p = .034$. In other words, as working memory capacity increased participants performance on the free recall also improved. Working memory capacity was not significantly correlated to the number of offloaded words for either condition, *r*s ≤ .077, *p*s ≥ .533.

Discussion

Overall, Experiment 1 did not support the hypotheses, such that there was no difference in free recall performance. This finding supports previous research which suggests that note-taking modalities are not associated with any significant differences in test performance (e.g., Beck, 2015; Mangen et al., 2015; Morehead et al., 2019a; Urry et al., 2021). With no differences in performance, it follows that there were also no differences in cognitive load between the modalities, as measured by the reaction times. Therefore, there was no evidence to indicate that one of the offloading modalities induced more cognitive load than the other modality as predicted, and found in previous research (e.g., Bouriga & Olive, 2021; Ruan et al., 2015). Finally, the last note-worthy pattern of results was that the typing condition offloaded more words than the writing condition. This finding is not surprising as typing is faster than writing (Brown, 1988) and many studies have found that individuals who type have a higher quantity of notes (e.g., Bui et al., 2013; Mueller & Oppenheimer, 2014). Even though the typing condition did offload more words, this behavior did not lead to significant performance differences between the two conditions. Therefore, the benefit of taking more notes did not translate to better performance on an immediate free recall test.

The primary purpose of Experiment 1 was to investigate how the offloading modalities affected cognitive load. However, there was no observed difference in cognitive load between the modalities, so Experiment 2 will investigate whether the difficulty of the material influences cognitive load and performance in this learning task.

Experiment 2

Experiment 2 was designed to understand how the difficulty of the learning material may influence performance and cognitive load within each modality. An important factor within the cognitive load theory is that the material being learned may influence an individual's cognitive load (e.g., Sweller & Chandler, 1994). For example, one way a learner's cognitive load is influenced is by the complexity of the learning material, which is inherent based on the characteristics of the to-be-learned material (e.g., De Jong, 2010). By using material that differs in difficulty, the current study will examine whether the difficulty of the material may influence cognitive load and if this is the case, if this added load influences the effectiveness of an offloading modality. For example, individuals may adjust their note-taking strategies based on the cognitive load present including classroom variables, instructional design, and presented material. While students may make these adjustments to manage their cognitive load, there may be downstream consequences as shown by their memory performance.

In the current experiment, participants studied three different word lists of differing difficulty. Specifically, participants studied a categorized word list, which was the easiest list of materials to learn, as previous research has found that information that can be organized or *chunked* is beneficial for learning (Lu et al., 2021; Mandler, 1967; Miller, 1956; Thalmann et al., 2019). Additionally, a normed Italian word list was used as the difficult word list, because the words were unfamiliar to participants. The last studied list was taken from Experiment 1, which was the assortment of English words, used as a medium difficulty. I predicted that the difficulty level of the material would influence free recall performance such that participants would have the highest recall for the easy list and the lowest recall in the difficult list. Additionally, I also predicted that the difficulty of the words would influence cognitive load such that there would be the highest cognitive load for the difficult list and the lowest cognitive load for the easy list. Finally, based on the findings of Experiment 1, I hypothesized that there would be differences in performance and cognitive load between the writing and typing condition, but only for the difficult word list because the offloading modality may only influence performance when the cognitive load is high.

Method

Participants

An a priori power analysis for Experiment 2 using G*Power (Faul et al., 2009) was completed prior to any data collection for a 2 (Offloading modality) x 3 (List) mixed ANOVA with an alpha error of .05, and power of .90 and a medium effect size (d = .50). This power analysis revealed that a total 138 participants were required: 69 participants in each between-subjects group. However, due to outside factors affecting data collection and pre-set exclusion criteria, I did not reach the goal number of participants. Specifically, 12 participants reported taking a similar study or taking a study with similar materials, 23 participants chose not to utilize offloading, 18 participants did not respond to the preset criteria of tones, and 1 participant reported being very familiar with Italian, which was used for the difficult word list. Therefore, a total of seventy-three TCU undergraduate students participated in exchange for partial course credit or extra credit for their psychology course. The sample consisted of primarily females (55 females, 18 males, 2 did not report) who were college-aged (M_{age} = 20 years). Eighty-three percent of participants identified as White, 7% identified as Black, 3% identified as Asian or Pacific Islander, and the remaining 7% identified as other. Of those participants, 33 were randomly assigned to the typing condition and 40 participants were assigned to the writing condition. This experiment was approved by the TCU Institutional Review Board (IRB) and all participants gave written consent to participate.

Design

The dual-task methodology was used to understand participants' learning and cognitive load, similar to Experiment 1. A 2 (Offloading Modality: Write, Type) x 3 (List Difficulty: Easy, Medium, Difficult) mixed design was used for Experiment 2. Each participant was randomly assigned to either the typing or the writing condition. All participants experienced all levels of list difficulty. The goal of Experiment 2 was to understand if participants' learning and cognitive load differed between the offloading modalities and difficulty of the material. The dependent variable for the learning task was the proportion of words recalled on the recall test. Cognitive load was measured by the average reaction time to an auditory probe during the secondary task.

Materials

The stimuli included 90 nouns that ranged in length from four to six letters (*M* = 5.08 letters, *SD* = .15) and the English words had an average frequency of 8.29 (*SD* = .55), as measured by the log-transformed Hyperspace Analogue to Language (HAL) scale (Balota et al., 2007). The words were taken to comprise three lists, each list of a differing learning difficulty. One list was 30 words taken from Experiment 1. This list consisted of English words and will be referred to as the medium list. Another list was made up of 30 words from three distinct categories (vegetables, articles of clothing, and birds), 10 words belonging to each category, taken from DeSoto and Roediger (2014). This list of words was considered a comparatively easy list. Finally, the other list was made up of Italian words, taken from Iacullo and Marucci (2016), which was the difficult list, as participants had little to no prior experience with Italian words.

Procedure

The procedure of Experiment 2 followed the procedure of Experiment 1. Participants were welcomed into the lab, gave written consent, and were seated in front of a computer. After participants filled out a demographic questionnaire, they read instructions and completed the operation span task. Next, a trained researcher came into the room and helped participants set up the foot pedal and headphones for the learning task. The researcher stayed in the room for the duration of the experiment. After participants read the instructions for the task and then completed a baseline measurement of their reaction time to the tone. Following, all participants took the learning task, which utilized the dual-task methodology (i.e., a primary and secondary task; see Figure 1). After the study trial in the learning task, participants completed a free recall test. All participants completed the learning task three times, once for each word list. The order of the word lists studied was randomized for each participant. Finally, participants answered final questions about their experience with the task and were debriefed.

Results

In the following section, participants' self-report beliefs of the difficulty of the lists are reported, as a manipulation check. Then, the reaction times are discussed, followed by their free recall performance, and then their offloading behavior. Exploratory analyses on working memory capacity are also presented.

Manipulation Check

In a post-experimental question, participants were asked to report which lists they believed to be the easiest and most difficult to learn. Results revealed that as intended, majority of participants believed that the Italian word list was the most difficult and the categorized word list was the easiest (see Table 1). Therefore, it appears that the difficulty of the word lists was manipulated successfully as shown by the self-report answers.

Table 1

Self-reported word list difficulty

	Categorized English	Assortment of English	Italian	Same
1. Which word list do you believe was the easiest to learn?	83.56%	9.59%	0%	6.85%
2. Which word list do you believe was the hardest to learn?	4.11%	8.22%	78.08%	9.59%

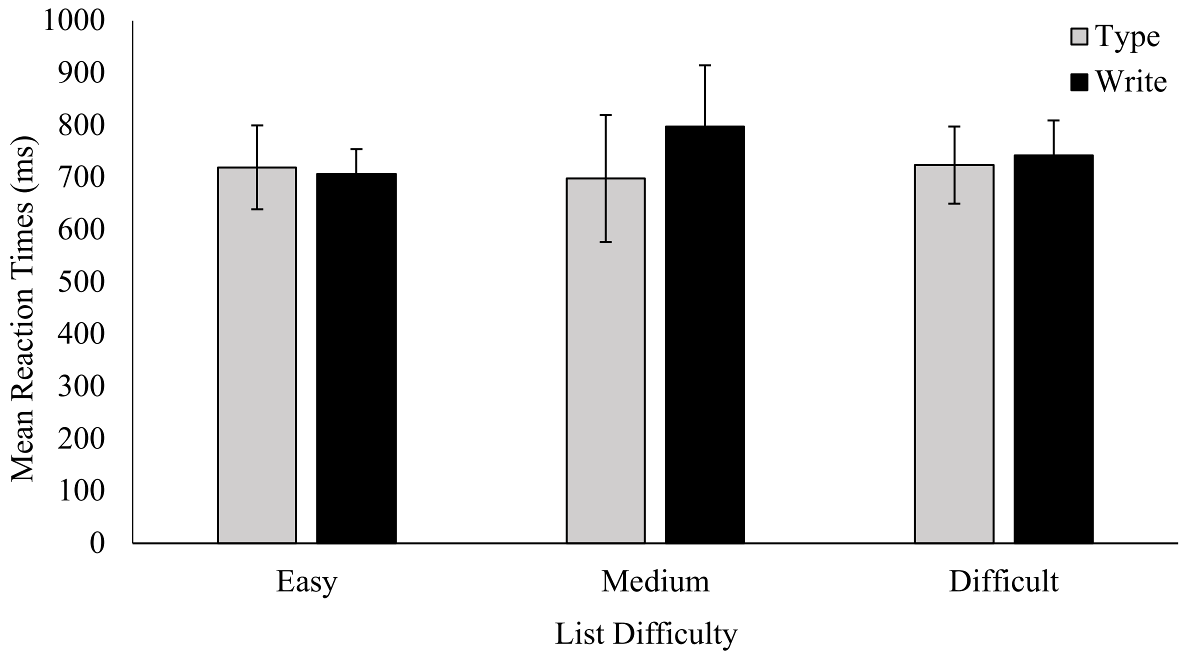
Reaction Times

Following procedures from Experiment 1, baseline measures were not subtracted from list reaction times. Importantly, there was no difference between baseline reaction times between the two offloading conditions, $t(71) = 1.89$, $p = .063$, $d = .44$.

A 2 (Offloading Condition: Typing, Writing) x 3 (List: Easy, Medium, Difficult) mixed ANOVA was performed on reaction times to the tone, with the former factor being manipulated between-subjects and the latter within-subjects. The results revealed no main effect of list, $F(2, 142) = .25$, $p = .782$, $\eta_p^2 = .003$, no main effect of condition, $F(1, 71) = .21$, $p = .646$, $\eta_p^2 = .003$, and no significant interaction, $F(1, 142) = .68$, $p = .509$, $\eta_p^2 = .009$ (see Figure 5).

Figure 5

Reaction Times for Experiment 2



Note. Mean reaction times as a function of list and offloading condition in Experiment 2. Error bars represent one standard error of the mean.

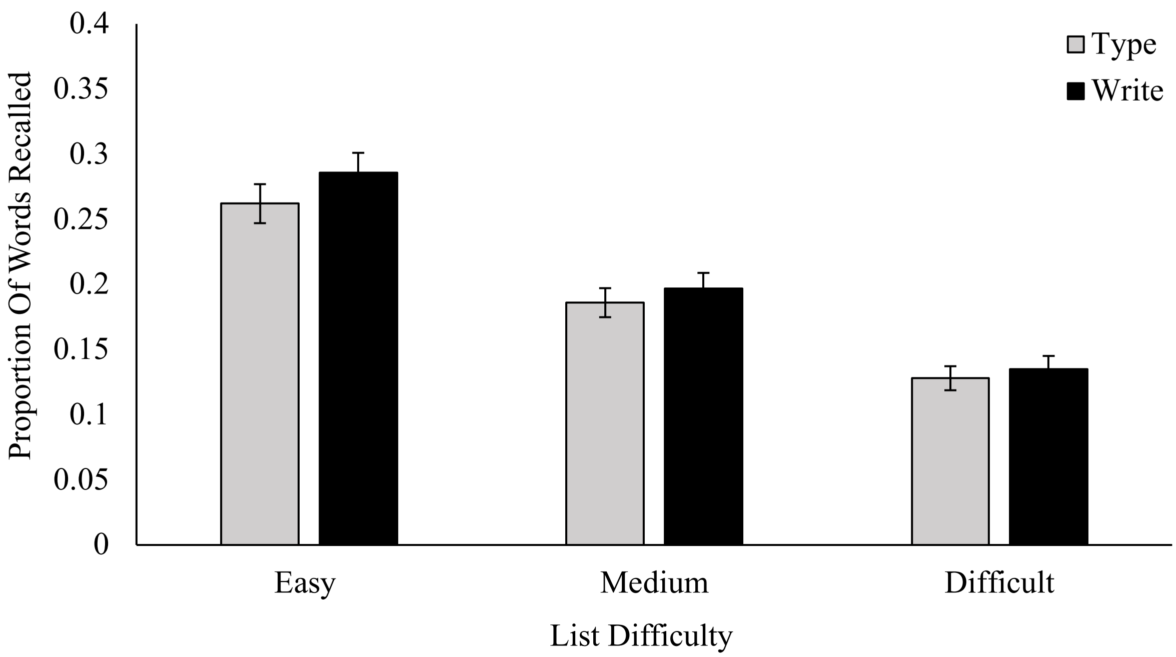
Free Recall Performance

In order to examine whether there was any difference in free recall performance, a 2 (Offloading Condition: Typing, Writing) x 3 (List: Easy, Medium, Difficult) mixed ANOVA using the Greenhouse-Geisser correction was performed on the free recall scores, with the former being between-subjects. Results revealed that there was a main effect of list, $F(1.83, 129.85) = 101.23$, $p < .001$, $\eta_p^2 = .588$ (see Figure 6). However, there was not a main effect of offloading condition, $F(1, 71) = 1.15$, $p = .287$, $\eta_p^2 = .016$ or significant interaction, $F(1.83, 129.85) = .42$, $p = .640$, $\eta_p^2 = .006$. Post hoc analyses using the Bonferroni correct revealed that participants recalled more words on the easy list ($M = .28$, $SE = .01$), than the medium list ($M = .19$, $SE = .01$), $t(71) = 8.21$, $p < .001$, $d = .96$, or the difficult list ($M = .13$, $SE = .01$), $t(71) = 14.17$, $p < .001$, $d =$

1.66. Additionally, participants had higher recall performance on the medium list as compared to the difficult list, $t(71) = 5.96$, $p < .001$, $d = .70$.

Figure 6

Free Recall Performance for Experiment 2



Note. Mean proportion of words recalled on each list as a function of offloading condition in Experiment 2. Error bars represent one standard error of the mean.

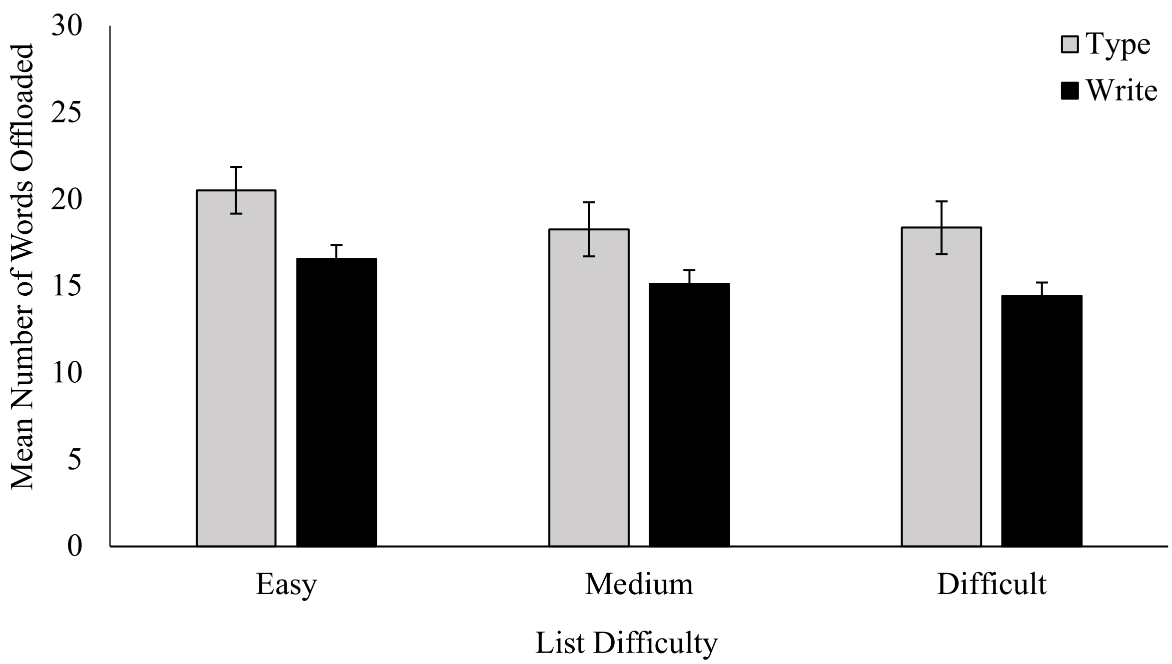
Number of Offloaded Words

A 2 (Offloading Condition: Typing, Writing) x 3 (List: Easy, Medium, Difficult) mixed ANOVA was performed on the number of words offloaded, with the latter being within subjects (see Figure 7). The results revealed a main effect of condition, $F(1, 71) = 6.21$, $p = .015$, $\eta_p^2 = .080$, a main effect of list, $F(2, 142) = 9.77$, $p < .001$, $\eta_p^2 = .121$, but no interaction, $F(2, 142) = .394$, $p = .675$, $\eta_p^2 = .006$. Post hoc analyses using the Bonferroni correction on the number of words offloaded between the offloading conditions revealed that the typing condition ($M = 18.88$, $SE = 1.04$) offloaded more words than the writing condition ($M = 15.22$, $SE = 1.04$), $t(71)$

= 2.49, *p* = .015, *d* = .29. Post hoc analyses on the number of offloaded words for the lists revealed that participants offloaded more words in the easy list (*M* = 18.37, *SE* = .79) as compared to the medium list (*M* = 16.54, *SE* = .79), *t*(71) = 3.51, *p* = .002, *d* = .41, and compared to the hard list (*M* = 16.23, *SE* = .79), *t*(71) = 4.09, *p* < .001, *d* = .48. There was no significant difference in the number of offloaded words between the medium and hard list, *t*(71) = .58, *p* = 1.00, *d* = .07.

Figure 7

Experiment 2



Note. Mean number of offloaded words on each list as a function of offloading condition from Experiment 2. Error bars represent one standard error of the mean.

Working Memory Capacity

As expected, there was no difference in working memory capacity between the typing and the writing conditions, *t*(70) = .25, *p* = .801. I ran exploratory correlations and found that unlike Experiment 1, free recall performance was not correlated to working memory capacity for the writing or the typing condition, *r*s ≤ .246, *p*s ≥ .130, but interestingly, working memory capacity was related to number of offloaded words in the typing condition, $r = .384$, $p = .027$, but not correlated in the writing condition, $r = .063$, $p = .705$.

Discussion

In sum, Experiment 2 had four main results of interest: recall performance did not differ between the modalities but did differ as a function of difficulty, cognitive load did not differ between the modalities or between the three different word lists, participants in the typing condition offloaded more words than the writing condition, and the difficulty of the word list influenced offloading behaviors. Therefore, these results did not support my hypothesis that differences in reaction times would be observed for the difficult word list, as differences in cognitive load were found in Bouriga and Olive (2021) between note-taking modalities. The findings of Experiment 2 largely replicated the findings from Experiment 1. Additionally, new to Experiment 2, the results did support my hypothesis that participants would recall more in the easy list as compared to the other two lists and recalled more in the medium list as compared to the difficult list, in line with other literature (e.g., Mandler, 1967). The difficulty of the word lists did not affect cognitive load, which contradicts the limited research that has manipulated difficulty (e.g., Bouriga & Olive, 2021; Van Gog et al., 2011). Finally, the word list difficulty did influence offloading behaviors such that more information was offloaded for the easy list as compared to the other lists. This may seem surprising at first, but may suggest that organized information benefits note-taking (e.g., Van Meter et al., 1994).

General Discussion

Since technology to aid cognition is becoming ubiquitous in the classroom and in work environments (e.g., Barak et al., 2006), it is important to understand how different tools used to record information may influence performance and offloading behaviors. The current set of experiments examined how note-taking modality may influence cognitive load, test performance, and note-taking behaviors in a memory task. Additionally, Experiment 2 investigated how the difficulty of the material may influence the variables of interest. From a cognitive load perspective, if one modality of offloading requires more cognitive capacity, learning may be negatively impacted, such that learning may be hampered when that modality of note-taking is used. Specifically, Bouriga and Olive (2021), found that typing notes was associated with higher cognitive load as compared to handwriting notes. Higher cognitive load may impact free recall performance, as too much load is detrimental for learning. Therefore, I predicted that typing would consume more cognitive resources as compared to writing, which would be reflected in higher reaction times to the tone and would result in lower recall scores.

Cognitive Load, Offloading, and Memory

Taking the results of Experiment 1 and 2 together, contrary to my hypotheses, participants' reaction times to the tone task did not differ between the writing and typing offloading modalities. One interpretation of this finding is that the modality individuals used to offload did not affect their cognitive load. To support that claim, the current studies also found that participants' free recall performance also did not differ between modalities. Thus, these results may suggest that the offloading modality may not have had a significant effect on how well the information is learned in the current paradigm. However, it is useful to understand how this finding fits into the previous research. In studies on note-taking outside of cognitive load theory, there is not a consistent answer regarding memory differences between modalities (e.g., Allen et al., 2020; Bui et al., 2013; Morehead et al., 2019a; Mueller & Oppenheimer, 2014; Urry et al., 2021). This current finding contradicts the limited previous research on cognitive load and note-taking modality performance that has provided evidence of learning benefits for those who write as compared to type (Bouriga & Olive, 2021; Ruan et al., 2015). Specifically, there are two relevant studies that have investigated how note-taking modality may influence cognitive load. However, these two studies revealed opposite findings in terms of modality and cognitive load. Ruan and colleagues (2015) found that participants *reported* higher cognitive load when writing, but Bouriga and Olive, (2021) using the dual task methodology as in the current study, found that cognitive load was lower when writing as compared to typing. Taking the findings from the previous two studies and the current work, the research has shown three different patterns of results (i.e., writing induces more cognitive load, less cognitive load, or no difference in cognitive load as compared to typing). Given the differences in previous findings, I suggest that modality should not be completely disregarded as a meaningful factor in note-taking, but the variables which influence these results should be considered. Specifically, I suggest below three potential explanations for why there was no difference between the modalities in cognitive load and performance in the current experiments (note that these explanations are not intended to be exhaustive).

One reason why the expected pattern of results was not found could be because the materials used were not appropriate for the cognitive load framework. In previous research that has utilized the dual-task methodology, the material that participants studied was often more complex than the current stimuli, such as text passages (Bouriga & Olive, 2021; Madrid et al., 2009), multi-step problems (Ayres, 2001; Renkl et al., 2003; Sweller, 1988), and multimedia learning (Brünken et al., 2002; Lin et al., 2016). No known research has investigated the dual-task methodology with word lists. More commonly, cognitive load theory often uses material which is more intrinsically complex (see Sweller et al., 2019). Cognitive load theory has found that materials with high interactivity, defined as the extent to which the elements of the learning material require simultaneous processing, is associated with more cognitive load than material low in interactivity (e.g., Schmeck et al., 2015; Sweller & Chandler, 1994). For example, Sweller (2011) states that chemical symbols (e.g., iron = Fe) are low in element interactivity because you can learn one element without knowing information about other symbols (e.g., one could learn iron without knowing the symbol for copper), so even though the learning may be challenging, it may be associated with low cognitive load. Alternatively, solving algebra problems may be associated with a higher cognitive load because the individual must learn how the different elements of the problem work in relation to each other. This simultaneous consideration of multiple facets of the problem (i.e., high interactivity) is predicted to increase load (Sweller, 2011). Information that is high in element interactivity can be reorganized into a schema, which is stored in long term memory (e.g., Artino, 2008; Sweller, 2011). When a schema is stored, the burden of working memory is reduced (Sweller & Chandler, 1994). In Experiment 2, all three lists were low in element interactivity as compared to previous materials used (e.g., Ayres, 2001; Madrid et al., 2009) and did not require schema development. Future research should investigate how note-taking modality may affect cognitive load with more complex and educationally relevant material.

Another possible reason that there was no difference between the cognitive load of the offloading modalities was because the task itself did not induce enough cognitive load. That is, these results may suggest that the modality of note-taking is only influential at high levels of cognitive load but not low levels, and the current study may not have reached high levels of load. The majority of the previous materials which investigated note-taking modalities used material similar to what might be presented in a lecture (e.g., Bui et al., 2013; Mueller & Oppenheimer, 2014; however, see Mangen et al., 2015; Smoker et al., 2009 for examples of simpler material). In the current experiment, more words were presented than participants would likely remember and participants experienced time pressure which may have increased cognitive load (e.g., Deck et al., 2021). However, the participants may have not been overloaded because, due to the setup of the task, they could have ignored any material that may have overloaded their memory system. Since the material was presented simultaneously, participants may have only processed some of the information (e.g., the top two rows of words, for example) instead of trying to learn all the information. Although this behavior may not have been ideal for participants to engage in given the goal of investigating load in the current studies, it suggests that individuals across the conditions may have engaged in effective self-regulation, by managing their learning to reduce their cognitive load (e.g., see de Bruin et al., 2020; de Bruin & Van Merriënboer, 2017 for overviews on cognitive load and self-regulation). That is, ignoring the information that is not relevant to one's goal could be adaptive for learners. Therefore, areas that may be fruitful for future research on cognitive load and modality include manipulating the presentation style (e.g., multimedia formats) or using realistic test conditions (e.g., longer study times; longer delays before tests) to extend the current findings to a variety of learning situations that are more likely to induce higher cognitive load.

Last, one possible explanation for why cognitive load may not have differed between the modalities is because of the typing fluency among the sample that participated. Since higher education is increasingly interested in incorporating technology into the classroom (e.g., King & Boyatt, 2015) and the number of students taking notes electronically has risen in recent years (e.g., Morehead et al., 2019b; Witherby & Tauber, 2019), the sample in the current work (i.e., undergraduate students in 2022) was likely very familiar with typing (see also Bui et al., 2013).

In a related study, researchers found that participants had higher quality and fluency in their notes when they wrote by hand, especially compared to participants who had low experience with typing (Kellogg & Mueller, 1993). As such, college students may have more experience with technology as compared to the average non-college-student individual, which lessens the cognitive load of typing. However, to draw this conclusion, future research would be needed that investigates how familiar and proficient college students are at typing, as the current studies did not address this possibility directly.

Additional Variables of Interest

The manipulation of list difficulty in Experiment 2 was successful, such that participants remembered the most words from the easy list and remembered the fewest words from the difficult list; self-reports about list difficulty supported this finding (see Table 1). However, the differing difficulty of the material did not affect cognitive load, such that there was no difference in reaction times to the tone task among the three different word lists, as discussed above. In Experiment 2, participants also took more notes when studying the easy list as compared to the medium and difficult lists. This result suggests that individuals' use of notes may be influenced by the material. Individuals may feel like when challenging information is presented, they should devote their attention to understanding the information and therefore decide to take less notes. In a related study, college students reported that strong organization during a lecture was one main factor that increased the ease and quality of their class notes (Van Meter et al., 1994). If individuals do take fewer notes when the material is organized and feels fluent, this behavior may have downstream consequences. For example, when they later review their notes, as is often the case when preparing for an exam, learners may not have as much information, or perhaps less of the important information, recorded. This behavior may consequently affect their performance. Future research should examine how the fluency and organization of the material may affect note-taking behaviors, as limited research has been done in this area (see Northern et al., 2022; Titsworth, 2001 for exceptions).

Another key finding from the current experiments was that participants' offloading behavior was influenced by the offloading tool used. Specifically, individuals recorded more information in the typing condition as compared to the writing condition. It is not surprising that individuals who type recorded more words because previous research has found that individuals can type information faster than they can write (e.g., Brown, 1988). However, it is interesting that even though participants in the typing condition on average recorded more words, taking more notes did not harm or benefit their performance as compared to those in the writing group. Some previous research suggests that taking more notes is beneficial for learning, even in the absence of review (e.g., Bui et al., 2013; Fisher & Harris, 1974). However, other research has found that the quantity of notes only matters when participants are given time to review their notes before being tested (e.g., Kiewra & Benton, 1988). In the current experiment, participants did not get to review or use their notes after taking them, thus suggesting that more notes may only be beneficial when notes have a storage function and are reviewed (e.g., see Di Vesta & Gray, 1972).

Finally, based on previous findings which suggest that working memory is an important factor in note-taking (e.g., Olive & Piolat, 2002), in the current experiments I explored how working memory capacity might correlate with free recall performance and offloading behavior. In Experiment 1, free recall performance was correlated with working memory capacity for both conditions, as measured by operation span; however, there was no such correlation among the variables in Experiment 2, inconsistent with prior research that found that working memory capacity is related to recall (e.g., Hambrick & Engle, 2002; Unsworth & Engle, 2007). There may have been no correlation in Experiment 2 because the effects of difficulty were more salient on recall performance. Prior research has found that task difficulty influences the relationship between performance and working memory capacity, such that the magnitude of the relationship is highest at average levels of difficulty (e.g., Turner & Engle, 1989). I also investigated how working memory capacity may correlate with offloading behaviors. Previous research has found conflicting findings in this regard, such that some studies suggest that working memory capacity correlates with note-taking (e.g., Bui et al., 2013; Kiewra & Benton, 1988), while other studies have not found this correlation (e.g., Peverly et al., 2007). Two recent cognitive offloading studies differed with respect to whether the quantity of offloaded material is related to working memory. Risko and Dunn (2015) found that participants with lower working memory capacity took more notes, but Morrison and Richmond (2020) failed to replicate this effect when using a similar paradigm. In Experiment 1, there was no correlation between working memory and offloading behavior. However, in Experiment 2, there was a relationship between working memory and offloading only for individuals who typed to take notes and not for the writing condition. These conflicting findings may suggest that note-taking and working memory may be related, but the strategy used while note-taking influences the relationship. For example, Bui and colleagues (2013) proposed that working memory capacity may be related to note-taking by the extent to which the note-taking strategy requires working memory and different note taking modalities may influence the strategy used for notes (see also Mueller & Oppenheimer, 2014). For example, taking organized notes may require more working memory capacity as compared to taking notes without any organziation. However, since I did not collect any information about the strategies individuals used to take notes, I cannot address this possibility specifically. Future research may investigate different how the material, transcription speed, and modality might influence the strategy of note-taking and how this may vary between offloading modalities.

Limitations and Future Directions

One limitation of the current study is the use of the tone for the secondary task. First, the baseline measurement which was taken without any learning material present was based on previous research that suggested taking this measure and subtracting it from average reaction times would remove the individual differences in response times (e.g., Bouriga & Olive, 2021; Brünken et al., 2002). The problem with the baseline measurements in the current studies is that the average reaction time was often higher than the average reaction time of the trials. Perhaps participants did not have enough practice with the tone prior to completing the task. This finding is worth noting because participants may have improved in their reaction times not because of the cognitive load, or lack thereof, but because they were gaining more experience with the tone task. For example, in Experiment 1, participants' reaction times decreased from the first list to the second list, even though the material did not differ in difficulty. To avoid this dilemma in future research, participants should practice the tone task to a particular criterion (e.g., respond to all the tones), to become proficient with the foot pedal so that the baseline measurements can be used.

Additionally, another limitation of the current experiment is that many participants (N = 47 participants in Experiment 1, N = 23 in Experiment 2) chose not to take notes at all, which limited the sample size but is also an interesting consideration. In the experiments, participants were not forced to transcribe notes because I wanted to investigate how natural note-taking behaviors may affect cognitive load. If individuals would have been forced to take notes, their strategy, cognitive load, or performance may have been affected consequently. I gave participants the decision to offload but told them they could use these notes on a final test (e.g., similar to an open-note test). The open-note test in the current study never occurred, rather, it was used to encourage participants to take notes. One drawback to a laboratory-based approach is that participants did not have any intrinsic reason to care about their performance on a final test, as they would have in a real-world exam situation.

Previous research suggests that participants take notes as long as the perceived benefit outweighs the cost (Risko & Dunn, 2015; Risko et al., 2014); the costs may have outweighed the benefits in the current studies. Other research suggests that individuals will take notes not solely for their utility, but also based on their beliefs about notes and their own internal memory (e.g., Gilbert et al., 2020; Sachdeva & Gilbert, 2020; Weis & Wiese, 2019). Some participants may have believed they would have higher performance without taking notes, calling into question whether individuals have beliefs about whether the process of recording notes may benefit performance (see Di Vesta & Gray, 1972), especially in a memory task that uses a short delay (e.g., 5 s) between each study session and recall test. Participants may also have chosen not to take notes because of the effort involved in recording notes. Previous research suggests that effort – both the internal cognitive effort required in the task (e.g., Gilbert et al., 2020) and the effort required by the tool to use it (e.g., Risko et al., 2014) – influences individuals' decisions about offloading Across the two experiments, participants who were randomly assigned to the writing condition ($N = 45$ across both experiments) chose more often *not* to take notes as compared to the typing condition ($N = 25$ across both experiments). This difference may suggest that individuals have more negative pre-existing beliefs about writing (e.g., it is more effortful) as compared to typing (see also Ruan et al., 2015). Future work should investigate how advances in technology influence individuals beliefs about the utility of different note-taking modalities.

Conclusion

In two experiments, I examined recall performance, cognitive load, and offloading behaviors between note-taking modalities by using the dual-task methodology. Overall, the current experiments suggest that there were no differences in memory performance or cognitive load when individuals use typing or writing to offload. Additionally, Experiment 2 revealed that participants' performance and offloading behavior was affected by the difficulty of the material, but their cognitive load was not influenced by the difficulty of the material. The current work contributes to the current literature that suggests that note-taking modality may not reliably influence performance outcomes (e.g., Beck, 2015; Morehead et al., 2019a; Urry et al., 2021) or may not influence performance under the circumstances used in the current paradigm (e.g., immediate recall test; simple material).

Considering the broader, more practical implications of these findings for students and teachers, it would be unwise at this time to suggest that students should adjust how they take notes to only use a specific modality, as the current results did not favor one modality over the other in terms of performance. That is, making suggestions for education at this time does not seem appropriate until research can pinpoint the factors that affect performance-related outcomes. Students may choose one modality over the other because of certain benefits; for example, typing on a computer may be advantageous because the student can quickly insert diagrams and go back to organize their notes. Alternatively, handwritten notes may allow for quick sketches that would not be as convenient to execute when using a laptop. Without thorough consideration and investigation into the variables that may contribute to learning and memory, it seems premature to recommend one offloading modality for complete adaptation. A potential benefit to typing was that individuals in the typing group took more notes without any detrimental or beneficial effects on memory; while this behavior was not beneficial for an immediate test, it could be valuable when individuals are given the opportunity to review their notes (e.g., Fisher & Harris, 1974) or when taking an open-note test. However, future research is needed to fully understand the circumstances that affect an offloading modality's effectiveness. Cognitive load theory may be a useful framework for note-taking modality research, especially with more complex or educationally relevant materials, and warrants future research. In sum, the current work did not find evidence that the note-taking modality had significant influence on performance or cognitive load, but by continuing research in this area, we can explore how external tools may be optimally utilized to benefit our internal memory system.

References

Aguilar-Roca, N. M., Williams, A. E., & O'Dowd, D. K. (2012). The impact of laptop-free zones on student performance and attitudes in large lectures. *Computers & Education*, 59(4), 1300–1308. https://doi.org/10.1016/j.compedu.2012.05.002

Aiken, E. G., Thomas, G. S., & Shennum, W. A. (1975). Memory for a lecture: effects of notes, lecture rate, and informational density. *Journal of Educational Psychology*, *67*(3), 439. https://doi.org/10.1037/h0076613

Allen, M., LeFebvre, L., LeFebvre, L., & Bourhis, J. (2020). Is the Pencil Mightier than the Keyboard? A Meta-Analysis Comparing the Method of Notetaking Outcomes. *Southern Communication Journal*, 85(3), 143–154. https://doi.org/10.1080/1041794X.2020.1764613

Aragón-Mendizábal, E., Delgado-Casas, C., Navarro-Guzmán, J. I., Menacho-Jiménez, I., & Romero-Oliva, M. F. (2016). A Comparative Study of Handwriting and Computer Typing in Note-taking by University Students. *Media Education Research Journal*, 24(2). https://doi.org/10.3916/C48-2016-10

Artino, A. R. (2008). Cognitive Load Theory and the Role of Learner Experience: An Abbreviated Review for Educational Practitioners. *AACE Review*, 16(4), 425–439. https://www.learntechlib.org/primary/p/25229/

Ayres, P. L. (2001). Systematic Mathematical Errors and Cognitive Load. *Contemporary Educational Psychology*, 26(2), 227–248. https://doi.org/10.1006/ceps.2000.1051

Baddeley, A. D. (1990). The development of the concept of working memory: Implications and contributions of neuropsychology. In Neuropsychological impairments of short-term memory (pp. 54–73). Cambridge University Press. https://doi.org/10.1017/CBO9780511665547

Baddeley, A. D. (1992). Working memory. *Science*, 255(5044), 556-559. doi: 10.1126/science.1736359

Baddeley, A. D. (2007). Working Memory, Thought, and Action. OUP Oxford.

Baddeley, A. D., & Hitch, G. (2001). Working memory in perspective. Psychology Press.

Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2009). Working memory and binding in sentence recall. *Journal of Memory and Language*, 61(3), 438–456. https://doi.org/10.1016/j.jml.2009.05.004

Balota, D. A., Yap, M. J., Hutchison, K. A., Cortese, M. J., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods*, 39(3), 445–459. https://doi.org/10.3758/BF03193014

Barak, M., Lipson, A., & Lerman, S. (2006). Wireless Laptops as Means for Promoting Active Learning in Large Lecture Halls. *Journal of Research on Technology in Education*, 38(3), 245–263. https://doi.org/10.1080/15391523.2006.10782459

Beck, K. M. (2015). Note Taking Effectiveness in the Modern Classroom. *The Compass*, 1(1). https://scholarworks.arcadia.edu/thecompass/vol1/iss1/9

Bouriga, S., & Olive, T. (2021). Is typewriting more resources-demanding than handwriting in undergraduate students? *Reading and Writing*, 34(9), 2227–2255. https://doi.org/10.1007/s11145-021-10137-6

Bretzing, B. H., & Kulhavy, R. W. (1981). Note-taking and passage style. *Journal of Educational Psychology*, 73(2), 242–250. https://doi.org/10.1037/0022-0663.73.2.242

Brown, C. M. L. (1988). Comparison of typing and handwriting in “two-finger typists”. In Proceedings of the Human Factors Society Annual Meeting, 32(5), 381-385. Los Angeles, CA: SAGE Publications.

Brünken, R., Plass, J. L., & Leutner, D. (2003). Direct Measurement of Cognitive Load in Multimedia Learning. *Educational Psychologist*, 38(1), 53–61. https://doi.org/10.1207/S15326985EP3801_7

Brünken, R., Steinbacher, S., Plass, J. L., & Leutner, D. (2002). Assessment of cognitive load in multimedia learning using dual-task methodology. *Experimental Psychology*, 49(2), 109–119. https://doi.org/10.1027/1618-3169.49.2.109

Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, 105(2), 299. https://doi.org/10.1037/a0030367

Carter, J. F., & Van Matre, N. H. (1975). Note taking versus note having. *Journal of Educational Psychology*, 67(6), 900–904. https://doi.org/10.1037/0022-0663.67.6.900

Chandler, P., & Sweller, J. (1991). Cognitive Load Theory and the Format of Instruction. *Cognition and Instruction*, 8(4), 293–332. https://doi.org/10.1207/s1532690xci0804_2

Chandler, P., & Sweller, J. (1996). Cognitive Load While Learning to Use a Computer Program. *Applied Cognitive Psychology*, 10(2), 151–170. https://doi.org/10.1002/(SICI)1099-0720(199604)10:2<151::AID-ACP380>3.0.CO;2-U

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, 24(1), 87–114. https://doi.org/10.1017/S0140525X01003922

de Bruin, A. B. H., Roelle, J., Carpenter, S. K., & Baars, M. (2020). Synthesizing Cognitive Load and Self-regulation Theory: A Theoretical Framework and Research Agenda. *Educational Psychology Review*, 32(4), 903–915. https://doi.org/10.1007/s10648-020-09576-4

de Bruin, A. B. H., & Van Merriënboer, J. J. G. (2017). Bridging Cognitive Load and Self-Regulated Learning Research: A complementary approach to contemporary issues in educational research. *Learning and Instruction*, 51, 1–9. https://doi.org/10.1016/j.learninstruc.2017.06.001

Deck, C., Jahedi, S., & Sheremeta, R. (2021). On the consistency of cognitive load. *European Economic Review*, 134, 103695. https://doi.org/10.1016/j.euroecorev.2021.103695

De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. Instructional science, 38(2), 105-134. https://doi.org/10.1007/s11251-009-9110-0

DeLeeuw, K. E., & Mayer, R. E. (2008). A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. *Journal of Educational Psychology*, 100(1), 223–234. https://doi.org/10.1037/0022-0663.100.1.223

DeSoto, K. A., & Roediger, H. L. (2014). Positive and Negative Correlations Between Confidence and Accuracy for the Same Events in Recognition of Categorized Lists. *Psychological Science*, 25(3), 781–788. https://doi.org/10.1177/0956797613516149

Di Vesta, F. J., & Gray, G. S. (1972). Listening and note taking. *Journal of Educational Psychology*, 63(1), 8–14. https://doi.org/10.1037/h0032243

Engle, R. W. (2002). Working memory capacity as executive attention. *Current directions in psychological science*, 11(1), 19-23. https://doi.org/10.1111/1467-8721.00160

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Fiorella, L., & Mayer, R. E. (2017). Spontaneous spatial strategy use in learning from scientific text. *Contemporary Educational Psychology*, 49, 66–79. https://doi.org/10.1016/j.cedpsych.2017.01.002

Fisher, J. L., & Harris, M. B. (1974). Effect of note-taking preference and type of notes taken on memory. *Psychological Reports*, 35(1), 384-386. https://doi.org/10.2466/pr0.1974.35.1.384

Frangou, S. M., Ruokamo, H., Parviainen, T., & Wikgren, J. (2018). Can you put your finger on it? The effects of writing modality on Finnish students' recollection. *Writing Systems Research*, 10(2), 82–94. https://doi.org/10.1080/17586801.2018.1536015

Frangou, S. M., Wikgren, J., Sintonen, S., Kairaluoma, L., & Vasari, P. (2019). The effect of writing modality on recollection in children and adolescents. *Research in Learning Technology*. https://doi.org/10.25304/rlt.v27.2239

Fried, C. B. (2008). In-class laptop use and its effects on student learning. *Computers & Education*, 50(3), 906–914. https://doi.org/10.1016/j.compedu.2006.09.006

Friedman, M. C. (2014). Notes on note-taking: Review of research and insights for students and instructors. *Harvard Initiative for Learning and Teaching*, 1-34.

Gilbert, S. J. (2015). Strategic offloading of delayed intentions into the external environment. *Quarterly Journal of Experimental Psychology*, 68(5), 971–992. https://doi.org/10.1080/17470218.2014.972963

Gilbert, S. J., Bird, A., Carpenter, J. M., Fleming, S. M., Sachdeva, C., & Tsai, P. C. (2020). Optimal use of reminders: Metacognition, effort, and cognitive offloading. *Journal of Experimental Psychology: General*, 149(3), 501–517. https://doi.org/10.1037/xge0000652

Gulek, J. C., & Demirtas, H. (2005). Learning with technology: The impact of laptop use on student achievement. *The journal of technology, learning and assessment*, *3*(2). https://ejournals.bc.edu/index.php/jtla/article/view/1655

Hambrick, D. Z., & Engle, R. W. (2002). Effects of domain knowledge, working memory capacity, and age on cognitive performance: An investigation of the knowledge-is-power hypothesis. Cognitive psychology, 44(4), 339-387.

Hargis, M. B., Castel, A. D., & Bjork, R. A. (under review). That's important, I'll save it: Effects of information importance on offloading and remembering.

Hartley, J., & Marshall, S. (1974). On notes and note-taking. *Higher Education Quarterly*, *28*(2), 225-235. https://doi.org/10.1111/j.1468-2273.1974.tb00467.x

Horbury, S. R., & Edmonds, C. J. (2021). Taking Class Notes by Hand Compared to Typing: Effects on Children's Recall and Understanding. *Journal of Research in Childhood Education*, 35(1), 55–67. https://doi.org/10.1080/02568543.2020.1781307

Iacullo, V. M., & Marucci, F. S. (2016). Normative data for Italian Deese/Roediger–McDermott lists. *Behavior Research Methods*, 48(1), 381–389. https://doi.org/10.3758/s13428-015-0582-3

Jansen, R. S., Lakens, D., & IJsselsteijn, W. A. (2017). An integrative review of the cognitive costs and benefits of note-taking. *Educational Research Review*, 22, 223–233. https://doi.org/10.1016/j.edurev.2017.10.001

Kay, R., & Lauricella, S. (2011). Exploring the Benefits and Challenges of Using Laptop Computers in Higher Education Classrooms: A Formative Analysis. *Canadian Journal of Learning and Technology*, 37(1). https://www.learntechlib.org/p/42756/

Kellogg, R. T. (1987). Effects of topic knowledge on the allocation of processing time and cognitive effort to writing processes. *Memory & Cognition*, 15(3), 256–266. https://doi.org/10.3758/BF03197724

Kellogg, R. T. (2008). Training writing skills: A cognitive developmental perspective. *Journal of Writing Research*, 1(1), 1–26. https://doi.org/10.17239/jowr-2008.01.01.1

Kellogg, R. T., & Mueller, S. (1993). Performance amplification and process restructuring in computer-based writing. *International Journal of Man-Machine Studies*, 39(1), 33–49. https://doi.org/10.1006/imms.1993.1052

Kiewra, K. A., & Benton, S. L. (1988). The relationship between information-processing ability and notetaking. *Contemporary Educational Psychology*, 13(1), 33–44. https://doi.org/10.1016/0361-476X(88)90004-5

King, E., & Boyatt, R. (2015). Exploring factors that influence adoption of e-learning within higher education. *British Journal of Educational Technology*, 46(6), 1272–1280. https://doi.org/10.1111/bjet.12195

Kobayashi, K. (2005). What limits the encoding effect of note-taking? A meta-analytic examination. Contemporary Educational Psychology, 30(2), 242-262. https://doi.org/10.1016/j.cedpsych.2004.10.001

Lansman, M., & Hunt, E. (1982). Individual differences in secondary task performance. *Memory & Cognition*, 10(1), 10–24. https://doi.org/10.3758/BF03197621

Lin, J. J. H., Lee, Y. H., Wang, D. Y., & Lin, S. S. J. (2016). Reading Subtitles and Taking Enotes While Learning Scientific Materials in a Multimedia Environment: Cognitive Load Perspectives on EFL Students. *Journal of Educational Technology & Society*, 19(4), 47–58. https://www.jstor.org/stable/jeductechsoci.19.4.47

Lin, L., & Bigenho, C. (2011). Note-Taking and Memory in Different Media Environments. *Computers in the Schools*, 28(3), 200–216. https://doi.org/10.1080/07380569.2011.594989

Lu, X., Kelly, M. O., & Risko, E. F. (2021). The gist of it: offloading memory does not reduce the benefit of list categorisation. *Memory*, 1-16. https://doi.org/10.1080/09658211.2021.1989465

Luo, L., Kiewra, K. A., Flanigan, A. E., & Peteranetz, M. S. (2018). Laptop versus longhand note taking: Effects on lecture notes and achievement. *Instructional Science*, 46(6), 947–971. https://doi.org/10.1007/s11251-018-9458-0

Madrid, R. I., Van Oostendorp, H., & Melguizo, M. C. P. (2009). The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behavior*, 25(1), 66–75. https://doi.org/10.1016/j.chb.2008.06.005

Mandler, G. (1967). Organization and Memory. Psychology of Learning and Motivation, (1) 327–372. *Academic Press*. https://doi.org/10.1016/S0079-7421(08)60516-2

Mangen, A., Anda, L. G., Oxborough, G. H., & Brřnnick, K. (2015). Handwriting versus keyboard writing: effect on word recall. *Journal of writing research*, 7(2), 227-247. https://doi.org/10.17239/jowr-2015.07.02.1

Marcus, N., Cooper, M., & Sweller, J. (1996). Understanding instructions. Journal of *Educational Psychology*, 88(1), 49–63. https://doi.org/10.1037/0022-0663.88.1.49

Martin, S. (2014). Measuring cognitive load and cognition: metrics for technology-enhanced learning. *Educational Research and Evaluation*, *20*(7-8), 592-621. https://doi.org/10.1080/13803611.2014.997140

Maxwell, N. G. (2007). From Facebook to Folsom Prison Blues: How Banning Laptops in the Classroom Made Me a Better Law School Teacher. *Richmond Journal of Law & Technology*, 14, 1.

May, K. E., & Elder, A. D. (2018). Efficient, helpful, or distracting? A literature review of media multitasking in relation to academic performance. *International Journal of Educational Technology in Higher Education*, 15(1), 13. https://doi.org/10.1186/s41239-018-0096-z

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

Morehead, K., Dunlosky, J., & Rawson, K. A. (2019a). How Much Mightier Is the Pen than the Keyboard for Note-Taking? A Replication and Extension of Mueller and Oppenheimer (2014). *Educational Psychology Review*, 31(3), 753–780. https://doi.org/10.1007/s10648-019-09468-2

Morehead, K., Dunlosky, J., Rawson, K. A., Blasiman, R., & Hollis, R. B. (2019b). Note-taking habits of 21st century college students: implications for student learning, memory, and achievement. *Memory*, *27*(6), 807-819. https://doi.org/10.1080/09658211.2019.1569694

Morrison, A. B., & Richmond, L. L. (2020). Offloading items from memory: Individual differences in cognitive offloading in a short-term memory task. *Cognitive Research: Principles and Implications*, 5(1), 1. https://doi.org/10.1186/s41235-019-0201-4

Mueller, P. A., & Oppenheimer, D. M. (2014). The Pen Is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note Taking. *Psychological Science*, 25(6), 1159–1168. https://doi.org/10.1177/0956797614524581

Northern, P. E., Tauber, S. K., St. Hilaire, K. J., & Carpenter, S. K. (2022). Application of a two-phase model of note quality to explore the impact of instructor fluency on students' note-taking. *Journal of Applied Research in Memory and Cognition*. Advance online publication. https://doi.org/10.1037/mac0000032

Oberauer, K. (2019). Working memory and attention—A conceptual analysis and review. *Journal of Cognition*, 2(1).

Olive, T., & Piolat, A. (2002). Suppressing visual feedback in written composition: Effects on processing demands and coordination of the writing processes. *International Journal of psychology*, 37(4), 209-218. https://doi.org/10.1080/00207590244000089

Oswald, F. L., McAbee, S. T., Redick, T. S., & Hambrick, D. Z. (2015). The development of a short domain-general measure of working memory capacity. *Behavior Research Methods*, 47(4), 1343–1355. https://doi.org/10.3758/s13428-014-0543-2

Park, B., & Brünken, R. (2015). The Rhythm Method: A New Method for Measuring Cognitive Load—An Experimental Dual-Task Study. *Applied Cognitive Psychology*, 29(2), 232–243. https://doi.org/10.1002/acp.3100

Peper, R. J., & Mayer, R. E. (1978). Note taking as a generative activity. *Journal of Educational Psychology*, 70(4), 514–522. https://doi.org/10.1037/0022-0663.70.4.514

Peverly, S. T. (2006). The Importance of Handwriting Speed in Adult Writing. *Developmental Neuropsychology*, 29(1), 197–216. https://doi.org/10.1207/s15326942dn2901_10

Peverly, S. T., Ramaswamy, V., Brown, C., Sumowski, J., Alidoost, M., & Garner, J. (2007). What predicts skill in lecture note taking? *Journal of Educational Psychology, 99*(1), 167–180. https://doi.org/10.1037/0022-0663.99.1.167

Piolat, A., Olive, T., & Kellogg, R. T. (2005). Cognitive effort during note taking. *Applied Cognitive Psychology*, 19(3), 291–312. https://doi.org/10.1002/acp.1086

Piolat, A., Olive, T., Roussey, J. Y., Thunin, O., & Ziegler, J. C. (1999). SCRIPTKELL: A tool for measuring cognitive effort and time processing in writing and other complex cognitive activities. *Behavior Research Methods, Instruments, & Computers*, 31(1), 113–121. https://doi.org/10.3758/BF03207701

Plass, J. L., Moreno, R., & Brünken, R. (2010). Cognitive Load Theory. Cambridge University Press.

Posner, M. I. (1982). Cumulative development of attentional theory. *American Psychologist*, 37(2), 168–179. https://doi.org/10.1037/0003-066X.37.2.168

Renkl, A., Gruber, H., Weber, S., Lerche, T., & Schweizer, K. (2003). Cognitive load during learning from worked-out examples. *Zeitschrift Fur Padagogische Psychologie*, 17(2), 93–101. https://pred.uni-regensburg.de/id/eprint/38985/

Risko, E. F., & Dunn, T. L. (2015). Storing information in-the-world: Metacognition and cognitive offloading in a short-term memory task. *Consciousness and Cognition*, 36, 61–74. https://doi.org/10.1016/j.concog.2015.05.014

Risko, E. F., & Gilbert, S. J. (2016). Cognitive Offloading. *Cognitive Sciences*, 20(9), 676–688. https://doi.org/10.1016/j.tics.2016.07.002

Risko, E. F., Medimorec, S., Chisholm, J., & Kingstone, A. (2014). Rotating With Rotated Text: A Natural Behavior Approach to Investigating Cognitive Offloading. *Cognitive Science*, 38(3), 537–564. https://doi.org/10.1111/cogs.12087

Ruan, L., Xiong, Z., Jiang, L., & Zhou, X. (2015). Comparison between digital and paper note-taking based on NASA-TLX 2015 IEEE, *International Conference on Progress in Informatics and Computing*, 221–225. https://doi.org/10.1109/PIC.2015.7489841

Sachdeva, C., & Gilbert, S. J. (2020). Excessive use of reminders: Metacognition and effort-minimisation in cognitive offloading. *Consciousness and Cognition*, 85, 103024. https://doi.org/10.1016/j.concog.2020.103024

Sana, F., Weston, T., & Cepeda, N. J. (2013). Laptop multitasking hinders classroom learning for both users and nearby peers. *Computers & Education*, 62, 24–31. https://doi.org/10.1016/j.compedu.2012.10.003

Schmeck, A., Opfermann, M., van Gog, T., Paas, F., & Leutner, D. (2015). Measuring cognitive load with subjective rating scales during problem solving: Differences between immediate and delayed ratings. *Instructional Science*, 43(1), 93–114. https://doi.org/10.1007/s11251-014-9328-3

Schönpflug, W. (1986). The trade-off between internal and external information storage. *Journal of Memory and Language*, 25(6), 657–675. https://doi.org/10.1016/0749-596X(86)90042-2

Schoor, C., Bannert, M., & Brünken, R. (2012). Role of dual task design when measuring cognitive load during multimedia learning. *Educational Technology Research and Development*, 60(5), 753–768. https://doi.org/10.1007/s11423-012-9251-8

Smoker, T. J., Murphy, C. E., & Rockwell, A. K. (2009). Comparing Memory for Handwriting versus Typing. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 53(22), 1744–1747. https://doi.org/10.1177/154193120905302218

Storm, B. C., & Stone, S. M. (2015). Saving-Enhanced Memory: The Benefits of Saving on the Learning and Remembering of New Information. *Psychological Science*, 26(2), 182–188. https://doi.org/10.1177/0956797614559285

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. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, 4(4), 295–312. https://doi.org/10.1016/0959-4752(94)90003-5

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. *The Cambridge handbook of multimedia learning*, 3(2), 19-30.

Sweller, J. (2011). Cognitive load theory. *Psychology of learning and motivation*, 55, 37-76. Academic Press. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Sweller, J., & Chandler, P. (1994). Why Some Material Is Difficult to Learn. *Cognition and Instruction*, 12(3), 185–233. https://doi.org/10.1207/s1532690xci1203_1

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General*, 119(2), 176–192. https://doi.org/10.1037/0096-3445.119.2.176

Sweller, J., Van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. *Educational Psychology Review*, 31(2), 261–292. https://doi.org/10.1007/s10648-019-09465-5

Thalmann, M., Souza, A. S., & Oberauer, K. (2019). How does chunking help working memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(1), 37–55. https://doi.org/10.1037/xlm0000578

Titsworth, B. S. (2001). The effects of teacher immediacy, use of organizational lecture cues, and students' notetaking on cognitive learning. *Communication education*, 50(4), 283-297. https://doi.org/10.1080/03634520109379256

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent?. *Journal of memory and language*, 28(2), 127-154.https://doi.org/10.1016/0749-596X(89)90040-5

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*(1), 104–132. https://doi.org/10.1037/0033-295X.114.1.104

Urry, H. L., Crittle, C. S., Floerke, V. A., Leonard, M. Z., Perry, C. S., Akdilek, N., Albert, E. R., Block, A. J., Bollinger, C. A., Bowers, E. M., Brody, R. S., Burk, K. C., Burnstein, A., Chan, A. K., Chan, P. C., Chang, L. J., Chen, E., Chiarawongse, C. P., Chin, G., …

Zarrow, J. E. (2021). Don't Ditch the Laptop Just Yet: A Direct Replication of Mueller and Oppenheimer's (2014) Study 1 Plus Mini Meta-Analyses Across Similar Studies. *Psychological Science*, 32(3), 326–339. https://doi.org/10.1177/0956797620965541

Van Gog, T., Kester, L., & Paas, F. (2011). Effects of concurrent monitoring on cognitive load and performance as a function of task complexity. Applied cognitive psychology, 25(4), 584-587. https://doi.org/10.1002/acp.1726

Van Matre, N. H., & Carter, J. F. (1975). The Effects of Note-Taking and Review on Retention of Information Presented by Lecture. https://eric.ed.gov/?id=ED103910

Van Meter, P., Yokoi, L., & Pressley, M. (1994). College students' theory of note-taking derived from their perceptions of note-taking. Journal of Educational Psychology, 86(3), 323.

Weis, P. P., & Wiese, E. (2019). Using Tools to Help Us Think: Actual but Also Believed Reliability Modulates Cognitive Offloading. *Human Factors*, 61(2), 243–254. https://doi.org/10.1177/0018720818797553

Witherby, A. E., & Tauber, S. K. (2019). The Current Status of Students' Note-Taking: Why and How Do Students Take Notes? *Journal of Applied Research in Memory and Cognition*, 8(2), 139–153. https://doi.org/10.1016/j.jarmac.2019.04.002

Yamamoto, K. (2007). Banning Laptops in the Classroom: Is it Worth the Hassles? *Journal of Legal Education*, 57(4), 477–520. https://www.jstor.org/stable/42894041

VITA

Cami Leigh Ciesielski was born on September 15, 1996, in Littleton, Colorado. She graduated from Front Range Christian School in 2015. After graduation, she went to Colorado State University in Fort Collins where she earned a Bachelor of Science in Human Development and Family Studies. She graduated in 2019, magna cum laude and became the first in her family with an undergraduate degree. In the fall of 2020, she began to pursue a Ph.D. in Experimental Psychology at Texas Christian University, working under Mary Hargis and researching cognitive psychology.

ABSTRACT

THE EFFECT OF NOTE-TAKING MODALITY ON OFFLOADING AND MEMORY UNDER COGNITIVE LOAD

by Cami Leigh Ciesielski, B.S., 2019

Department of Psychology

Texas Christian University

Thesis Advisor: Dr. Mary Hargis, Assistant Professor of Psychology

The current experiments examined how an offloading modality may influence cognitive load and performance in a memory task. Based on previous research, it was hypothesized that participants would have lower performance and higher cognitive load (i.e., reaction times) when typing as compared to writing when offloading the material. In Experiment 1, using the dual-task methodology, participants either wrote or typed the words to offload them while studying and concurrently responding to a tone. After each study trial, participants took a recall test. There was no difference in test performance or reaction times between participants who wrote or typed, suggesting that the offloading modality did not significantly impact cognitive load. In Experiment 2, again using the dual-task method, the difficulty of the studied material was manipulated; results largely mirrored the findings of Experiment 1. Additionally, the difficulty of the material influenced offloading behavior and performance, but did not influence cognitive load.