EXPLORING HOW NOTE-TAKING IMPACTS LEARNING

COGNITIVE OFFLOADING AND NOTE-TAKING: IDENTIFYING THE GAPS BETWEEN APPLIED RESEARCH AND INCLUSIVE LEARNING DESIGN

By: IRINA GHILIC B.Sc. (Hons.)

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy

McMaster University DOCTOR OF PHILOSOPHY (2022)

Hamilton, Ontario (Psychology, Neuroscience & Behaviour)

TITLE: Cognitive Offloading and Note-Taking: Identifying the Gaps Between Applied Research and Inclusive Learning Design

AUTHOR: Irina Ghilic, H.B.Sc. (McMaster University)

SUPERVISOR: Dr. Sandra Monteiro

NUMBER OF PAGES: xvi, 206

LAY ABSTRACT

Imagine a world without technology or external resources to express your thoughts: no “to-do” lists, calendar reminders, sketches, or notes. Since our memory capacities are limited, we often maintain a record of information “in the world”, as opposed to only using our limited memory stores. This form of mental delegation is known as “cognitive offloading”. One way we offload information for future access is through note-taking. In an educational setting, note-taking influences our ability to learn and review information. *How* we take notes, and their effects on learning, have been debated in the literature. This thesis explores the impact of cognitive offloading and note-taking on learning, and demonstrates the importance of exploring individual differences (e.g., memory capacity and note-taking preference) in applied educational research. Throughout this thesis, we prompt our audience to frame note-taking and cognitive research takeaways through an inclusive educational lens.

ABSTRACT

Note-taking is ubiquitous. Whether we write down a grocery list, type our intentions for the day, or record a voice note for a friend, we often use notes to externalize our thoughts. We “delegate” this information to “in the world” extensions of our cognition, thus lightening our cognitive loads. The current thesis investigates the effects of note-taking as a form of cognitive offloading in an applied research setting. The note-taking literature is fragmented regarding practical note-taking recommendations for educators. The current thesis advances our knowledge and understanding of the crossover between cognitive offloading, note-taking, and individual differences. The laboratory research presented in this thesis uses novel materials that mimic the classroom environment, with future goals of translating this research into the actual classroom. Chapter 2 explores note-taking from a cognitive offloading perspective and demonstrates how differences in note-taking quantity affect recall. Chapter 3 showcases how differences in learning between note-taking modalities are seen sporadically and only when they intersect with the type of test. Chapter 4 investigates the importance of individual differences (e.g., working memory capacity) when exploring cognitive offloading and note-taking, and demonstrates how surface findings are not generalizable once we investigate underlying individual differences. While our research started as a way to understand how we offload information via note-taking and its effects on learning, we hope our findings and general discussion encourage the reader to explore the

generalizability of applied cognitive research. Note-taking is a complex process, and our future work aims to investigate how learners differ and how we might disseminate research in education to be inclusive and diverse.

ACKNOWLEDGMENTS

I have no hook for you today. No catchy title, no intriguing start. As I write this section last, I am at a loss for words, with no shortage of tears. Graduate school, in my experience, is not a linear journey. It is riddled with obstacles, poor mental health, long hours, low pay, and the quintessential guilt when you try to relax instead of “working on your thesis”. My academic journey was atypical (and not always viewed favourably); I followed my own path and could not have imagined a more satisfying outcome. Now it is time to thank the friends I made along this trek, who dabbed my forehead and offered me their shoulders—without them, I would not be writing these words today.

To my unwavering supervisor: Dr. Sandra Monteiro. You came in during the hardest period of this journey and nurtured back to life my confidence, motivation, and passion for why I pursued this degree in the first place. Your thoughtful feedback and active steps in getting me to this stage have reinstated some faith in academia I had lost along the way. Thank you for being so incredibly dependable, caring, and present.

To my supportive and encouraging committee: Dr. Joe Kim and Dr. Sean Park. A dichotomy in our time together, from Joe witnessing (and always retelling) some of my most embarrassing undergraduate moments, to Sean joining us during my final few months. Your passion for education has inspired my journey and urged me to reflect on the reason why we pursue knowledge in

this field. Thank you for walking me to the finish line and continually inspiring me through your innovative philosophies.

To my academic pillars, my partners in research, work, and friendship: Dr. Amy Pachai and Dr. Lisa Lorentz. I have started thanking you in different languages since the phrase “thank you” loses its impact once uttered hundreds of times. You held me up when I was down and whispered encouragement when I had none. Your confidence in me did not falter, which means so much when your own belief starts to tremble. Thank you for being the most supportive cheerleaders a person could hope for!

To my industrious and bright undergraduate colleagues: Ashley Avarino, Marina Sadik, Meagan DeJesus, Raiyan Chowdhury, Sehar Arfeen, Taha Arshad, Victoria Rozycki, and all my other students whose work is not represented in this thesis. You allowed me the honour to mentor you, joined me in this research, and shared much of your knowledge in return! I hope you will indulge me in being incredibly proud of your post-undergrad lives and the energy you share with the world. Thank you for your support, laughter, and kindness—my journey would have been colourless without you.

To my first-floor friends and caffeine fiends: Brendan Stanley and Dr. Hanae Davis. Your caring nature nurtured my soul and offered me much solace through coffee runs, conference adventures, and fun times outside of school. As the backbones of your respective labs, you offered me numerous examples of traits and skills I greatly admire and try to practice. Thank you for your care,

intelligence, and for being the unofficial lab photographers (although I am not sure how grateful I *should* be for that last one…).

To my mentors, colleagues, and friends: Dr. David Shore and Dr. Michelle Cadieux. Your ability to banter while interleaving academic discourse taught me to step outside my comfort zone. David, you encouraged me to take in new challenges and transform them into something greater, so I loved taking your 10% odds of completing this thesis and turning them into 100%. Michelle, we did not fulfill our post-graduate dream of adjacent offices, but as I look outside my window and see your house while typing this, I think we did well. Thank you both for your mentorship, friendship, and long-standing academic relationship, and I look forward to future conversations, lunches, and conferences. David, don't forget your bet: you owe Michelle a beer, since I sure as heck finished my thesis.

To my PNB department supporting staff and faculty (and too many friends to name): Ann Hollingshead, Milica Pavlica, Nancy Riddell, Sally Presutti, Wendy Selbie; Dr. Bruce Milliken, Hasan Siddiqui, and Dr. Paul Andrews. I cannot imagine an academic life without our main office supporting staff, and Bruce's earlier contributions to my committee. Hasan and Paul, I have your encouragement and kind words always echoing in my ears. Thank you all for shaping my path and pointing me in the right direction anytime I felt lost.

To my understanding and loving parents: Dan and Daniela Popescu. I wouldn't be here without your major life disruption of immigrating 17 years ago. You made many sacrifices along the way, and we missed much time together throughout my grad school years. I cannot wait to spend happy, lazy weekends with you. Thank you for all your love—I can only hope to have made you proud. Vă iubesc mult de tot!

To my rock and cutie: Dan Szymczak. My partner, best friend, and fur papa. Tears spring anew when I think about your support and the years we collectively held 7 part-time jobs within an academic year to make ends meet and sustain our household. I am so proud of us for still living life even as grad students: finding our home, getting married, moving onto full-time jobs, and welcoming two wonderful doggies (love you, Clara and Remy!). Thank you for your unconditional support, my love. You're up next!

To everyone listed and unlisted who has offered me kindness and encouragement along the way: THANK YOU! You might not even realize your impact and how a kind word on a bad day can keep someone going. Thank you all for being the heroes of my journey!

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

DECLARATION OF ACADEMIC ACHIEVEMENT

The *General Introduction* to this thesis was written and conceptualized by Irina Ghilic, with edits from her supervisor, Dr. Sandra Monteiro, and committee member, Dr. Sean Park.

The methods used in *Chapter 2* (empirical chapter) were conceptualized by Irina Ghilic, with input and feedback from Dr. Amy Pachai and Dr. David Shore. The experimental programming for Chapter 2 was coded by Dr. Amy Pachai, with edits by Irina Ghilic. Data collection was primarily completed by Irina Ghilic and Meagan DeJesus. Data analysis was completed by Irina Ghilic and Dr. Lisa Lorentz. Most of the writing for this manuscript was completed by Irina Ghilic, with part of the introduction drafted by Dr. Amy Pachai, initial drafts of the methods completed by Meaghan DeJesus, and initial draft results completed by Dr. Lisa Lorentz. Chapter 2 received editing feedback from Dr. Amy Pachai, Dr. Lisa Lorentz, Dr. Sandra Monteiro, and Dr. Sean Park.

The methods used in *Chapter 3* (empirical chapter) were conceptualized by Irina Ghilic, with input from Dr. Joseph Kim and Dr. David Shore. All experimental programming for Chapter 3 experiments was coded by Irina Ghilic. Data collection was completed by Ashley Avarino, Meagan DeJesus, Raiyan Chowdhury, Sehar Arfeen, Taha Arshad, Victoria Rozycki, and Irina Ghilic. Data analysis was completed by Irina Ghilic. Most of the writing for this manuscript was completed by Irina Ghilic, with initial drafts of the methods amalgamated from those who completed the data collection. Chapter 3 received editing feedback from Dr. Lisa Lorentz and Dr. Sandra Monteiro.

The methods used in *Chapter 4* (empirical chapter) were conceptualized by Irina Ghilic, with input from Dr. David Shore. All experimental programming for Chapter 4 experiments was coded by Irina Ghilic. Data collection was primarily completed by Irina Ghilic, Ashley Avarino, Taha Arshad, and Victoria Rozicky. Data analysis was completed by Irina Ghilic and Dr. Lisa Lorentz. Most of the writing for this manuscript was completed by Irina Ghilic, with part of the introduction drafted by Taha Arshad and Ashley Avarino, and initial draft results completed by Dr. Lisa Lorentz. Chapter 4 received editing feedback from Dr. Amy Pachai, Dr. Lisa Lorentz, and Dr. Sandra Monteiro.

The *General Discussion* of this thesis was written and conceptualized by Irina Ghilic, with edits from Dr. Amy Pachai and Dr. Sandra Monteiro.

CHAPTER 1

GENERAL INTRODUCTION: WHY AND HOW WE OFFLOAD COGNITION

Quick: what is 7 times 8? Whether you immediately thought “56!” or had an “I need to think about this” moment, there was a time when multiplication tables were a way of life. Your elementary school teacher might have quizzed you relentlessly on those tables. Did you ever think: “why do I have to memorize these?” Well, you are not alone. Elementary school was the prime time to memorize facts. Having those facts at your fingertips and retaining as much information as possible was essential to your teachers. However, we often externalize our thoughts, as our limited memory capacity and cognitive loads render us unable to store everything inside our minds. There are a few ways to express these externalizations, such as using our bodies (by gesturing or moving our heads), with tools we can maneuver in our surroundings, or with external memory systems (such as the internet or other people). In cognitive research, these externalizations are known as “cognitive offloading” (Risko et al., 2014). The colloquial meaning of “offloading” makes us think of this process as permanently alleviating a burden. This colloquialism can imply a relatively simplistic view of the rich mechanics involved in cognitive externalizations. Throughout our body of applied cognitive research in education, we further conceptualize the goal of offloading as “mental delegation”—an intentional and purposeful extension of our cognition beyond the confines of our brain. While we prefer to use the term “mental delegation” to introduce our audience to this body of work, we will use the term "cognitive offloading" as we review and refer to the offloading literature throughout this thesis.

When we take on too much work, we often hear from colleagues how we should 'delegate more'. "It is better to perform at 100% on fewer tasks than at 70% on more projects", my boss once told me. If it is beneficial to delegate tasks in our work and daily lives, we should extend the same courtesy to our cognitive processes. Like in real life, there are levels to cognitive delegating, and a leader who is in charge of delegation. One plausible mental delegation leader is a process generally referred to as *metacognitive control* (Risko & Dunn, 2015). When we perform a task, we are constantly assessing our performance on the task—we are engaging in ***metacognitive monitoring***. The assessment results (e.g., the need to spend more time on a task) are communicated to ***metacognitive control processes***, which regulate behaviour based on the assessment (Risko & Dunn, 2015, p. 62). Current theories propose that metacognitive control regulates our cognition's externalization (or delegation) (see Dunn & Risko, 2016, for an explanation of the model on metacognitive control and cognitive offloading). Delegating can help relieve low-complexity cognitive burdens without necessarily enhancing performance, or it can help us learn from externalizations, by manipulating them (e.g., annotating diagrams and modifying notes) (Scaife & Rogers, 1996). There are, however, drawbacks to delegating our cognitive processes, such as highlighting text while studying, underlining (Dunlosky et al., 2013), or copying and pasting content (Bauer &

Koedinger, 2006) (techniques known to have a low utility when it comes to learning and remembering information) (Dunlosky et al., 2013). Lines can blur between what we know “inside our head” and the intended learning objectives. We can become overconfident, and our performance can suffer when we are on our own, such as taking a test without our study materials.

A popular tool that supports delegation is technology, specifically personal devices like smartphones and laptops. As the opportunity to delegate intensifies, we must understand “when” and “how” we can use this form of mental delegation to our advantage. We are living in a world of “free information”. We get a quick answer from the Internet if we have a question. I can say a magic phrase anywhere in my house (i.e., “Hey, Google!”), ask a question, and get an answer almost instantly! Thus, the way we view our memories, sensory experience, and cognition needs restructuring. Whatever is “inside the head” does not provide the whole meaning of the word *cognition*. Delegating, at its various levels of complexity, is a coupling of “inside the head” cognition with “in the world” knowledge. This coupling can give our brains a great advantage and help us become more intelligent problem solvers, as we will explain in future sections.

To understand the importance of cognitive offloading, especially through an educational lens, we will expand the following topics throughout this introduction: definitions within the field of cognitive offloading (please see Appendix A for an expanded table of definitions); how we offload cognition; when and why we offload, and the role of metacognition; the pros and cons of offloading; the role of cognitive offloading in education; and the scope of the current thesis.

1. The various ways to offload cognition.

Any externalization of our thoughts could be viewed as cognitive offloading (Eliseev & Marsh, 2021). Imagine an architect designing a project. They could go to their client and describe the mental imagery of the design OR take that imagery and lay it out in a visual format. Visualizing thought is a basic form of cognitive offloading (Clark & Chalmers, 1998; Tversky, 2011, 2015). To make the analogy explicit, they could offload the task of describing the intended design in words to an image they created: a picture is worth a thousand words, after all. Not only does the translation of thought onto paper help us communicate our ideas more clearly, but it also creates an artifact that can be used repeatedly, saves time, and allows us to modify the ideas in a malleable environment (Tversky, 2015). For the architect in our example, sketching is a valuable tool. Although diagrams are prime examples of cognitive offloading, sketches are raw representations of the thought process. They promote discoveries, allowing their creators to see multiple patterns and possibilities, which would not be possible if ideas only resided in their minds (Tversky, 2015).

Cognitive offloading goes beyond the mere externalization of thoughts onto paper. Offloading is "the use of physical action to alter the information processing requirements of a task to reduce cognitive demand" (Risko & Gilbert, 2016, p. 676). Another definition describes offloading as "the trading-off of internal processing (e.g., internal normalization processes) for external processing (e.g., tilting your head when reading vertical text)" (Risko et al., 2014, p. 540). Offloading can also be found under ***epistemic action**,* defined as "physical actions that make mental computation easier, faster, or more reliable; they are external actions that an agent performs to change his or her computational state" (Kirsh & Maglio, 1994, p. 513).

Next time you are in a bookstore, try to notice people looking for a book—you will often see them engaging in head-tilting behaviour; how else would they read those rotated book titles? People tilt their heads to ***normalize*** the orientation of the writing. This action is a form of cognitive offloading called ***external normalization*** (Risko & Gilbert, 2016, p. 677). If you chose not to tilt your head and mentally rotate the title, you would engage in a mental transformation known as ***internal normalization*** (Risko & Gilbert, 2016, p. 677). Using gestures can also help us offload cognitive burdens by delegating processes such as mental rotation to our hands (Risko & Gilbert, 2016). Have you ever heard the phrase "talking with your hands"? We often use gestures to express thoughts we cannot verbally explain or help us exemplify those thoughts. When describing elements such as size and shape, gestures can be faster and better at externalizing thoughts than verbal descriptions. Talking with our hands, or tilting our heads, are tools for externally normalizing strenuous cognitive processes.

As you think about using gestures and tilting your head to delegate cognitive load, stop for a second to think about tomorrow: what is on your agenda? Any meetings to attend, work to complete, errands to run? You have already engaged in cognitive offloading if you must check your phone calendar or a to-do list to answer those questions. Memory is vital to our existence. Whether we use it to remember daily intentions or to access our knowledge, memory is a process we delegate frequently.

"Our ability to remember delayed intentions is termed ***prospective memory***" (Risko & Gilbert, 2016, p. 678). Using a Google calendar, or making a grocery list on your kitchen notepad, helps you offload prospective memory to an external source. We often do not realize how important it is to honour delayed intentions. Patients with acquired brain injuries or amnesia often lose their jobs and friends over the inability to keep up with daily intentions. Delegating intentions to external tools, such as calendars and smartphones, compensate for prospective memory deficits (McDonald et al., 2011; Svoboda & Richards, 2009). The process of delegating memory becomes more elaborate as the memory process complexity increases. If you are struggling to remember a concept you learned at a public lecture, you may talk to a colleague who attended the same lecture, who is more knowledgeable in the field and would be able to provide you with the missing details. Many examples of such memory partnerships are known as ***transactive memory systems (TMS)*** (Peltokorpi, 2008; Sutton et al., 2010; Wegner, 1995). "People typically develop a group or ***transactive memory***: a combination of memory stores held directly by individuals, which they can access because they know someone who knows that information. Like linked computers, people in dyads or groups form a transactive memory system" (Sparrow et al., 2011, p. 776); the system as a whole knows more than any one individual (Risko & Gilbert, 2016, p. 682). With recent technological advancements, we are in a prime position to delegate memory processes by adopting the Internet as a transactive memory partner. The implications of such a partnership are two-fold; while a TMS can free some cognitive burden, allowing us to perform higher-level mental operations, it can also blur the distinction between our knowledge and the TMS partner's knowledge. Understanding "when" and "why" we offload cognition is crucial to adopting various forms of mental delegation to our advantage.

2. The "when" and "why" of offloading: Metacognition takes the wheel.

If people were given the opportunity to offload, would they seize it 100% of the time? Based on the literature, the short answer is "no". Intons–Peterson and Fournier (1986) tested participants on using external versus internal memory aids (such as note-taking and mental maps, respectively) to recall future or past scenarios. Participants also had to rate memory aids on dependability, ease of use, accuracy, and preference for each aid. For general situations, participants preferred external aids for future scenarios, but internal aids for past scenarios. Students, however, also preferred external aids for past remembering. One reason for choosing external ***memory aids*** (defined as "devices or strategies that are deliberately used to enhance memory", Intons–Peterson & Fournier, 1986, p. 267) was their dependability. Participants rated them as more accurate than their fallible internal memory aids. However, external memory aids are only reliable when they are easily retrievable.

Consider a scenario in which external memory aids, such as the Internet, are integral to our daily lives. How would that influence our propensity to offload and our cognition in general? Sparrow et al. (2011) gave participants a modified Stroop task (naming the literal word, as opposed to the meaning of the word), with words related to the Internet versus sports companies, after participants received either hard or easy trivia questions. Not knowing the answers to the trivia questions primed the need to "search" the internet for an answer, as shown by the slower reaction times to Internet-related words in the Stroop task. Searching the Internet for an answer increases the probability of future searches (Storm et al., 2017). In the first experiment phase, participants were asked eight difficult trivia questions. They either had the Internet to help them out, or they had to rely on their memories to answer. The second phase allowed *all* participants to answer eight easy trivia questions using the Internet. Although the second set of questions was easy, participants in the initial Internet condition were more likely to use the Internet than those in the memory condition. Internet-condition participants were also faster at choosing to use the Internet before attempting an answer themselves than memory-condition participants (Storm et al., 2017). Thus, using the Internet as an information source enabled future use of the Internet as a memory aid.

Let us imagine a different scenario in which our Internet, computers, or printers are slow. Does our cognitive offloading behaviour stay the same? ***Hard constraints*** "dictate what behaviours are possible when performing a task" (Patrick et al., 2015, p. 776). How we tackle the task, including the strategy chosen, describes flexible ***soft constraints***. The soft constraints vary when participants are given hard constraints, such as high versus low access-cost environments. Examples of high access-cost environments include: introducing a grey mask over desired information (Gray & Fu, 2004; Patrick et al., 2015), a high number of operations to print information (Schönpflug, 1986), and challenging recording of notes (Cary & Carlson, 2001). Even though "in the world" knowledge is still accessible, participants choose to use their own cognitive resources when the cost or reliability of using external delegation strategies outweighs the cost of using their mental resources (Cary & Carlson, 2001; Gray & Fu, 2004; Patrick et al., 2015; Schönpflug, 1986; Storm & Stone, 2015). Participants thus show flexibility in their offloading choices, depending on task-execution effort, constraints, or reliability.

The most plausible driver of cognitive offloading behaviour is one of the components of metacognition: metacognitive control. Metacognitive control regulates learning activities, like deciding to stop studying a concept, or changing study strategies (Rivers et al., 2020, p. 550). Subjective assessments of performance accuracy, effort, and judgments of ability, when compared to objective performance, task demands, and offloading rates, yield metacognitive control as the deciding factor in using internal or external processes (Dunn & Risko, 2016; Gilbert, 2015; Hegarty & Steinhoff, 1997; Risko & Dunn, 2015). When given a choice, participants prefer to offload and rely on external processes to maximize their *accuracy*. Wanting to minimize *effort*, however, leads to an increased reliance on internal processes (Dunn & Risko, 2016). Participants may even choose to offload something as simple as 2 letters if the effort of recording those letters is minimal. Thus, aside from task execution constraints and demands, or preference for maximizing accuracy and minimizing effort, personal metacognitive confidence in the ability to perform a task also drives the decision to offload cognition (Gilbert, 2015; Hegarty & Steinhoff, 1997). When we do decide to offload cognition, we benefit most when we interact with cognitive externalizations. Low-complexity cognitive offloading does not always improve performance (as seen in Dunn & Risko, 2016; Risko et al., 2014), but high-complexity externalizations go beyond the simple notion of relieving the mental burden.

3. Internalizing externalizations: The pros and cons of cognitive offloading.

Can you imagine the following geometric shape: it is three-dimensional and has twelve identical pentagonal faces, with three faces meeting in each of the 20 vertices? What if I gave you the dimension of an edge and asked you to calculate surface area and volume—all without writing anything down? A high-complexity level of cognitive offloading allows us to interact with externalizations, enrich them, and internalize the new knowledge (i.e., like a feedback loop). When mental delegation reaches this level of complexity, we are not using the world as external storage or a simple placeholder for mental representations. We begin to use the world for "external computation" (Kirsh, 2010; Nestojko et al., 2013). When we think with offloaded external representations, like the icosahedron shape I asked you about at the beginning of this paragraph (also known as a 20-sided die), we couple "inside the head" cognition with "in the world" knowledge.

Engaging in offloading with our bodies can help solve ***spatial visualization problems***, defined as the "ability to mentally manipulate, rotate, twist, or invert objects without reference to one's self" (Chu & Kita, 2011, p. 102). In three-dimensional mental rotation or folding paper tasks, participants used more gestures in difficult spatial visualization problems than in easy ones. Gestures also improved performance compared to the no-gesture condition, even in subsequent trials where gestures were not allowed (Chu & Kita, 2011). When solving mental rotation tasks in consecutive trials, participants start with gestures akin to holding the object in their hands. As participants become familiar with the task, they switch to an open-palm approach, the hand becoming the object. Over more trials, participants use even fewer gestures (Chu & Kita, 2008). The externalization of cognition via gestures becomes internalized; this form of cognitive offloading plays an active role in creating strong mental representations (Alač & Hutchins, 2004), decreasing offloading over time.

Not all gestures perform the complex role of enriching our mental representations by internalizing externalizations. Some gestures simply "lighten the load" by externalizing mental processes (Goldin-Meadow et al., 2001; Goldinmeadow & Wagner, 2005). After being asked to encode a word list, participants had to explain how they solved some math problems, with only half of the participants being allowed to gesture. Both children and adults remembered significantly more items when they were allowed to gesture (Goldin-Meadow et al., 2001). Similarly, when counting arrays of identical elements and typographic symbols on a computer screen, participants allowed to point at the screen were more likely to report correct totals (Carlson et al., 2007). However, counting gestures might go beyond lightening the load, by helping individuals bind elements within the task. For example, active gestures help children keep track of counted objects. Children made significantly more coordination errors when a puppet counted by pointing to the objects than when they counted. By actively pointing to the objects, children were not only reciting numbers but also 'tagging' each of the objects with a number. Gestures can act as an external placeholder for intermediate mental representations (thus lightening cognitive load) and a binding link between external elements and internal representations (Alibali & DiRusso, 1999; Carlson et al., 2007). There are multiple ways in which we can externalize our mental representations and link them to internal representations beyond the use of our physical bodies. Instead of using our hands to gesture, we can interact with physical or virtual objects to link our representations, such as sketching or note-taking. The theory behind physical representations and offloading directly extends to more complex activities, like learning.

Expanding the boundaries of our mental processes by relying on external resources challenges the somewhat rigid conceptualization of “memory” and “cognition”. The Internet has become the ideal transactive memory partner: we trust it to encode, store, and produce information. Even better, it is almost instant (Ward, 2013; Wegner & Ward, 2013). Transactive memory systems (TMS) have many benefits: a group can recall more information than any individual within the group (Harris et al., 2014; Hollingshead & Brandon, 2003). However, for a TMS to be successful, group members must be cognizant of other members’ expertise. A TMS will fail without proper communication among group members. The downside of using a TMS to store information is group member availability. There is no such issue when using the Internet if you have access and connectivity. The difference between asking a colleague for knowledge versus asking the Internet is the attribution of knowledge: when your colleague gives you an answer after you tracked them down with the specific question, the knowledge “owner” is indisputable. This line can become blurred when we constantly search for answers online. Participants who searched for information online, followed by a self-assessed ability to explain question answers in *unrelated* domains, proclaimed higher knowledge of the unrelated domains than participants who did not use the Internet (Fisher et al., 2015). Access to the Internet also decreases individuals’ willingness to volunteer answers to general knowledge questions.

Participants in the Internet-access condition produced fewer answers overall (i.e., they responded “I don’t know” before searching the Internet for answers), but when they did offer an answer, they had greater accuracy than no Internet-access participants, showing a higher level of metacognitive monitoring and control of their knowledge (Ferguson et al., 2015). Access to the Internet can alter our experience of what we know versus “in the world” knowledge. However, it can also allow our metacognitive drivers to err on the side of caution. As long as we know its pitfalls, we can use cognitive offloading to expand our cognitive capacities and enrich our educational experiences.

4. When cognitive offloading can make us better learners.

Humans are information hoarders; we store more information than we need, such as files on our computers or photographs on our phones. However, the act of ‘saving’ information can benefit us in the long run. Storm and Stone (2015) instructed participants to study and save some files (File A) for subsequent restudy, or close other files without saving them. After either saving or not saving, participants were given a new file to study (File B), which they were later tested on. Participants recalled a significantly higher number of words from File B when they saved File A. When the experiment made the saving process unreliable, participants in the unreliable condition recalled the same number of words from File B as when they saved or did not save File A. Henkel (2014) found similar results for participants’ memory of photographed objects. There was no memory advantage for the saved photos (as there was no advantage for File

A words); in fact, there was an overall memory deficit for the photographed objects. When participants were asked only to take photos of specific parts of objects, their subsequent memory accuracy was not impaired. ***Proactive interference*** "occurs when the ability to remember recently learned information is impaired by previously learned information" (Eskritt & Ma, 2014, p. 242). Being able to save files and photographs reliably, or take notes during tasks, provides participants with a performance boost on subsequent tasks, by reducing the effects of proactive interference (Cary & Carlson, 2001; Eskritt & Ma, 2014; Hegarty & Steinhoff, 1997). For example, if educators were to provide asynchronous materials, like handouts, web modules, or special course packs, learners would rely on those supporting materials and avoid over-burdening their cognitive load by trying to record and recall everything the educator was presenting. In this case, interference would be minimized, making cognitive space for learners to engage with and be more attentive to their present task: listening to the content and forming mental connections between topics.

Taking notes or using our fingers to keep track when counting exemplifies the concept of ***embedded cognition***, "which emphasizes an ongoing "online" interaction with the environment" (Pouw et al., 2014, p. 53). ***Embodied cognition*** "primarily focuses on how the body shapes disembedded or "off-line" cognition" (Pouw et al., 2014, p. 59). Learning by operating external ***manipulatives*** (small objects used to guide learning) represents an internalization, or embodied aspect, of our embedded cognition. Children learn fraction concepts, problem-solving, and arithmetic by gesturing, using tiles or pie wedges, and small objects (Guthrie et al., 2015; Martin & Schwartz, 2005; Novack et al., 2014). They internalize the initial external representations and can transfer their learning to novel, more abstract environments. Educators must be cautious, however, of making the externalized environments overly engineered. A certain level of abstraction, either with external manipulatives or gestures, enhances children's transfer of knowledge to novel scenarios (Guthrie et al., 2015; Novack et al., 2014).

5. Scope of the Present Thesis

The work presented in this thesis applies the principles of cognitive offloading literature to an educational paradigm. This thesis investigates note-taking as a form of offloading and explores the effect of various note-taking scenarios on lecture comprehension. While note-taking is a ubiquitous practice in our day-to-day lives, it is a complex, higher-order cognitive process when it takes place in an educational environment. The practice and science of note-taking are still a topic of contention in academia (Florence & Samananda, 2015), due to opposing views on the use of technology, its relation to distraction in the classroom, and accessibility concerns. While some are against using technology in the classroom because it leads to distraction, others support using learning technologies, from an accessibility and inclusivity perspective. This thesis hopes to identify the gaps between applied research and the learner's experience, such as which research findings are applicable outside of a laboratory environment, what experimental conditions lead to differences in learning across a variety of conditions, and whether these studies' results are valid when considering individual differences between participants. We hope to explore these gaps by conducting laboratory studies on offloading notes, different note-taking modalities, and individual differences that might affect note-taking outcomes. The research presented in this thesis took place in the laboratory, and our next steps are to extend its reach by conducting real-classroom studies informed by the cognitive offloading and critical disability literature on education inclusivity, as our interests lie with the practical applications of research in diverse educational settings.

In Chapter 2, we approached note-taking from a cognitive offloading perspective, by extending Storm and Stone's (2015) methodology to include note-taking as a method of studying word lists, re-designed their "hands-on" experimental setup to an experiment delivered via PsychoPy, and investigated a cognitive offloading approach with online lecture content and multiple-choice tests. From a methodological perspective, we wanted to test whether the "stakes" of the experimental method need to be as obvious to the participant, or if we could observe the effects of cognitive offloading with a less blatant manipulation, in the interest of reducing experimenter-introduced variability, saving experimental manipulation time and effort, and improving the randomization of experimental conditions. We delivered the experiment in PsychPy, allowing for more randomization: 1. Our word lists were randomly generated by pulling without replacement from a bank of words, and 2. The "save" and "no" save blocks were randomized within a participant's experimental session. By adding the note-taking condition, we wanted to see if note-taking acted as an extra opportunity to offload, or if taking notes was not enough to trigger an offloading response (in which case, only saving information for later use would enable learners to "forget" about the information and make more mental space for the upcoming information).

Chapter 3 extended the investigation into the role of note-taking in learning by comparing various note-taking conditions and two key note-taking modalities: handwriting versus typing notes. We examined whether one note-taking modality led to better learning when testing with real-classroom materials and whether various note-taking conditions (summarizing, transcribing, type of lecture slides, providing context before or after a lecture) modulated any potential note-taking effects. To assess the effects of note-taking on learning, we examined multiple-choice quiz scores at a "depth of processing" level, by looking at any potential interactions between the type of questions (factual or application) and the experimental manipulations.

Chapter 4 aimed to connect cognitive offloading and note-taking modalities, by exploring whether the expectation of studying one's notes affects learning, in handwritten and typed notes, immediately after a lecture or with a delay. We wanted to continue exploring the effects of note-taking "below the surface", by including individual differences and correlating participants' working memory capacity scores to their test performance, note-taking modality, and whether the note-taking modality assigned by the experimenter matched their regular note-taking habits.

This thesis explores the intersectionality between note-taking, applied cognitive research, and inclusive design by investigating individual differences and reflecting on the critical disability literature. It extrapolates principles of cognitive offloading and individual differences using materials and methodologies inspired by blended-classroom structures, and it encourages researchers, educators, learning designers, and learners to use what we glean from research and translate those teachings into practical learning experience design applications.

6. Conclusion

Cognitive offloading comes in many forms. We gesture, tilt our heads, take notes, set calendar reminders, and search the Internet for answers. We either offload to lighten the cognitive load or to manipulate and learn from offloaded information. Our metacognition drives offloading decisions, which can sometimes lead to enhanced learning. Research on calculator use has ruled in favour of children using them to offload computations, without affecting (and sometimes even enhancing) operational, computational, and problem-solving skills (Ellington, 2003; Hembree et al., 1986). Developing a ***number sense***, "by learning math facts along with a deep understanding of numbers and the ways they relate to each other" (Boaler, 2015, p. 2), and discouraging memorization or fast regurgitation of facts, leads to improved learning of mathematics.

So the next time someone asks you “quick: what is 7 times 8?”, and you do not have the memorized answer, do not worry. Simply think about that for a minute or use a calculator (odds are, you *do* always have a calculator in your pocket). Instead of thinking of cognitive offloading as the ‘unloading’ of a mental burden, we can reconceptualize it as extending cognition beyond the confines of our brains, and intentionally delegating it to an external resource. Viewing cognitive offloading as a companion tool for our cognition can liberate our learning process, increase educational inclusivity and accessibility, and help us become more savvy learners.

References

Alač, M., & Hutchins, E. (2004). I See What You Are Saying: Action as Cognition in fMRI Brain Mapping Practice. *Journal of Cognition and Culture*, *4*(3–4), 629–661. https://doi.org/10.1163/1568537042484977

Alibali, M. W., & DiRusso, A. A. (1999). The function of gesture in learning to count: More than keeping track. *Cognitive Development*, *14*(1), 37–56. https://doi.org/10.1016/S0885-2014(99)80017-3

Bauer, A., & Koedinger, K. (2006). Pasting and Encoding: Note-Taking in Online Courses. *Sixth IEEE International Conference on Advanced Learning Technologies (ICALT'06)*, 789–793. https://doi.org/10.1109/ICALT.2006.1652559

Boaler, J. Williams, C., & Confer, A. (2015). *Fluency Without Fear: Research Evidence on the Best Ways to Learn Math Facts*. *Reflections*, *40*(2), 7–12. Retrieved from https://www.cusd200.org/cms/lib/IL01001538/Centricity/Domain/1018/FluencyWithoutFear-2015.pdf

Carlson, R. A., Avraamides, M. N., Cary, M., & Strasberg, S. (2007). What do the hands externalize in simple arithmetic? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(4), 747–756. https://doi.org/10.1037/0278-7393.33.4.747

Cary, M., & Carlson, R. A. (2001). Distributing working memory resources during problem solving. *Journal of Experimental Psychology: Learning, Memory,* *and Cognition, 27*(3), 836–848. https://doi.org/10.1037/0278-7393.27.3.836

Chu, M., & Kita, S. (2008). Spontaneous gestures during mental rotation tasks: Insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General*, *137*(4), 706–723. https://doi.org/10.1037/a0013157

Chu, M., & Kita, S. (2011). The nature of gestures' beneficial role in spatial problem solving. *Journal of Experimental Psychology: General*, *140*(1), 102–116. https://doi.org/10.1037/a0021790

Clark, A. & Chalmers, D. (1998). The extended mind. *Analysis, 58*(1), 7–19. https://doi.org/10.1093/analys/58.1.7

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning With Effective Learning Techniques: Promising Directions From Cognitive and Educational Psychology. *Psychological Science in the Public Interest*, *14*(1), 4–58. https://doi.org/10.1177/1529100612453266

Dunn, T. L., & Risko, E. F. (2016). Toward a Metacognitive Account of Cognitive Offloading. *Cognitive Science*, *40*(5), 1080–1127. https://doi.org/10.1111/cogs.12273

Eliseev, E. D., & Marsh, E. J. (2021). Externalizing autobiographical memories in the digital age. *Trends in Cognitive Sciences*, *25*(12), 1072–1081. https://doi.org/10.1016/j.tics.2021.08.005

Ellington, A. J. (2003). A Meta-Analysis of the Effects of Calculators on Students' Achievement and Attitude Levels in Precollege Mathematics Classes. *Journal for Research in Mathematics Education*, *34*(5), 433–463. https://doi.org/10.2307/30034795

Eskritt, M., & Ma, S. (2014). Intentional forgetting: Note-taking as a naturalistic example. *Memory & Cognition*, *42*(2), 237–246. https://doi.org/10.3758/s13421-013-0362-1

Ferguson, A. M., McLean, D., & Risko, E. F. (2015). Answers at your fingertips: Access to the Internet influences willingness to answer questions. *Consciousness and Cognition*, *37*, 91–102. https://doi.org/10.1016/j.concog.2015.08.008

Fisher, M., Goddu, M. K., & Keil, F. C. (2015). Searching for explanations: How the Internet inflates estimates of internal knowledge. *Journal of Experimental Psychology: General*, *144*(3), 674–687. https://doi.org/10.1037/xge0000070

Florence, L., & Samananda, L. (2015). Comparison on perception of teaching aids among medical versus dental students. *National Journal of Physiology, Pharmacy and Pharmacology*, *5*(4), 303–305. https://doi.org/10.5455/njppp.2015.5.0207201540

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

Goldin-Meadow, S., Nusbaum, H., Kelly, S. D., & Wagner, S. (2001). Explaining Math: Gesturing Lightens the Load. *Psychological Science*, *12*(6), 516–522. https://doi.org/10.1111/1467-9280.00395

Goldinmeadow, S., & Wagner, S. (2005). How our hands help us learn. *Trends in Cognitive Sciences*, *9*(5), 234–241. https://doi.org/10.1016/j.tics.2005.03.006

Gray, W. D., & Fu, W.-T. (2004). Soft constraints in interactive behavior: The case of ignoring perfect knowledge in-the-world for imperfect knowledge in-the-head. *Cognitive Science*, *28*(3), 359–382. https://doi.org/10.1207/s15516709cog2803_3

Guthrie, L. G., Vallée-Tourangeau, F., Vallée-Tourangeau, G., & Howard, C. (2015). Learning and interactivity in solving a transformation problem. *Memory & Cognition*, *43*(5), 723–735. https://doi.org/10.3758/s13421-015-0504-8

Harris, C. B., Barnier, A. J., Sutton, J., & Keil, P. G. (2014). Couples as socially distributed cognitive systems: Remembering in everyday social and material contexts. *Memory Studies*, *7*(3), 285–297. https://doi.org/10.1177/1750698014530619

Hegarty, M., & Steinhoff, K. (1997). Individual differences in use of diagrams as external memory in mechanical reasoning. *Learning and Individual Differences*, *9*(1), 19–42. https://doi.org/10.1016/S1041-6080(97)90018-2

Hembree, R., & Dessart, D. J. (1986). Effects of hand-held calculators in precollege mathematics education: A meta-analysis. Journal for research in mathematics education, 17(2), 83–99. https://doi.org/10.5951/jresematheduc.17.2.0083

Henkel, L. A. (2014). Point-and-Shoot Memories: The Influence of Taking Photos on Memory for a Museum Tour. *Psychological Science*, *25*(2), 396–402. https://doi.org/10.1177/0956797613504438

Hollingshead, A. B., & Brandon, D. P. (2003). Potential Benefits of Communication in Transactive Memory Systems. *Human Communication Research*, *29*(4), 607–615. https://doi.org/10.1111/j.1468-2958.2003.tb00859.x

Intons-Peterson, M. J., & Fournier, J. (1986). External and internal memory aids: When and how often do we use them?. *Journal of Experimental Psychology: General, 115*(3), 267–280. https://doi.org/10.1037/0096-3445.115.3.267

Kirsh, D. (2010). Thinking with external representations. *AI & SOCIETY*, *25*(4), 441–454. https://doi.org/10.1007/s00146-010-0272-8

Kirsh, D., & Maglio, P. (1994). On Distinguishing Epistemic from Pragmatic Action. *Cognitive Science*, *18*(4), 513–549. https://doi.org/10.1207/s15516709cog1804_1

Martin, T., & Schwartz, D. L. (2005). Physically Distributed Learning: Adapting and Reinterpreting Physical Environments in the Development of Fraction Concepts. *Cognitive Science*, *29*(4), 587–625.

https://doi.org/10.1207/s15516709cog0000_15

McDonald, A., Haslam, C., Yates, P., Gurr, B., Leeder, G., & Sayers, A. (2011). Google Calendar: A new memory aid to compensate for prospective memory deficits following acquired brain injury. *Neuropsychological Rehabilitation*, *21*(6), 784–807. https://doi.org/10.1080/09602011.2011.598405

Nestojko, J. F., Finley, J. R., & Roediger, H. L. (2013). Extending Cognition to External Agents. *Psychological Inquiry*, *24*(4), 321–325. https://doi.org/10.1080/1047840X.2013.844056

Novack, M. A., Congdon, E. L., Hemani-Lopez, N., & Goldin-Meadow, S. (2014). From Action to Abstraction: Using the Hands to Learn Math. *Psychological Science*, *25*(4), 903–910. https://doi.org/10.1177/0956797613518351

Patrick, J., Morgan, P. L., Smy, V., Tiley, L., Seeby, H., Patrick, T., & Evans, J. (2015). The influence of training and experience on memory strategy. *Memory & Cognition*, *43*(5), 775–787. https://doi.org/10.3758/s13421-014-0501-3

Peltokorpi, V. (2008). Transactive Memory Systems. *Review of General Psychology*, *12*(4), 378–394. https://doi.org/10.1037/1089-2680.12.4.378

Pouw, W. T. J. L., van Gog, T., & Paas, F. (2014). An Embedded and Embodied Cognition Review of Instructional Manipulatives. *Educational Psychology Review*, *26*(1), 51–72. https://doi.org/10.1007/s10648-014-9255-5

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. *Trends in 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

Rivers, M. L., Dunlosky, J., & Persky, A. M. (2020). Measuring metacognitive knowledge, monitoring, and control in the pharmacy classroom and experiential settings. *American Journal of Pharmaceutical Education, 84*(5), 549–560. https://doi.org/10.5688/ajpe7730

Scaife, M., & Rogers, Y. (1996). External cognition: How do graphical representations work? *International Journal of Human-Computer Studies*, *45*(2), 185–213. https://doi.org/10.1006/ijhc.1996.0048

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

Sparrow, B., Liu, J., & Wegner, D. M. (2011). Google Effects on Memory: Cognitive Consequences of Having Information at Our Fingertips. *Science*, *333*(6043), 776–778. https://doi.org/10.1126/science.1207745

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

Storm, B. C., Stone, S. M., & Benjamin, A. S. (2017). Using the Internet to access information inflates future use of the Internet to access other information. *Memory*, *25*(6), 717–723. https://doi.org/10.1080/09658211.2016.1210171

Sutton, J., Harris, C. B., Keil, P. G., & Barnier, A. J. (2010). The psychology of memory, extended cognition, and socially distributed remembering. *Phenomenology and the Cognitive Sciences*, *9*(4), 521–560. https://doi.org/10.1007/s11097-010-9182-y

Svoboda, E., & Richards, B. (2009). Compensating for anterograde amnesia: A new training method that capitalizes on emerging smartphone technologies. *Journal of the International Neuropsychological Society*, *15*(4), 629–638. https://doi.org/10.1017/S1355617709090791

Tversky, B. (2011). Spatial thought, social thought. In T. W. Schubert & A. Maass (Eds.), *Spatial Dimensions of Social Thought* (pp. 17–38). DE GRUYTER. https://doi.org/10.1515/9783110254310.17

Tversky, B. (2015). The Cognitive Design of Tools of Thought. *Review of Philosophy and Psychology*, *6*(1), 99–116. https://doi.org/10.1007/s13164-014-0214-3

Ward, A. F. (2013). Supernormal: How the Internet Is Changing Our Memories and Our Minds. *Psychological Inquiry*, *24*(4), 341–348.

https://doi.org/10.1080/1047840X.2013.850148

Wegner, D. M. (1995). A Computer Network Model of Human Transactive Memory. *Social Cognition*, *13*(3), 319–339. https://doi.org/10.1521/soco.1995.13.3.319

Wegner, D. M., & Ward, A. F. (2013). How Google Is Changing Your Brain. *Scientific American*, *309*(6), 58–61. https://doi.org/10.1038/scientificamerican1213-58

Appendix A

Table 1

Defining the world of cognitive offloading

Term	Definition	Ref	Page #
Cognitive offloading	Cognitive offloading - the use of physical action to alter the information processing requirements of a task so as to reduce cognitive demand (see computational offloading; epistemic actions).	Risko & Gilbert, 2016	676
Cognitive offloading	The trading-off of internal processing (e.g., internal normalization processes) for external processing (e.g., head tilt) is referred to generally as cognitive offloading.	Risko et al., 2014	540
Deagentivization	Deagentivization of the motor strategy: the removal of agent from the representation of rotation.	Chu & Kita, 2008	722
Distributed cognition framework	Distributed cognition framework suggests that cognitive states and processes are sometimes distributed, such that neural and bodily resources couple in coordinated ways with material or social resources to accomplish cognitive tasks.	Harris et al., 2014	286
Embedded cognition	Embedded Cognition refers to the adaptive flexibility of cognitive processes during interaction with the environment. Examples: making notes during a conversation, using fingers to keep track of counting, asking another person to remind you of something, or using a tall building for navigating your way home. Embedded Cognition emphasizes an ongoing “on-line” interaction with the environment.	Pouw et al., 2014	53
Embodied cognition	Embodied cognition suggests that sensorimotor information made available during previous interactions is reused for internal cognitive processing. Embodied Cognition primarily focuses on how the body shapes disembedded or “off-line” cognition.	Pouw et al., 2014	59
Epistemic actions	Epistemic actions alter the world so as to aid and augment cognitive processes such as recognition and search.	Clark & Chalmers, 1998	8
Epistemic actions	Physical actions that make mental computation easier, faster, or more reliable; they are external actions that an agent performs to change his or her own computational state.	Kirsh & Maglio, 1994	513

External normalization	When individuals encounter a rotated stimulus (e.g., a tilted book) they often physically tilt their head to normalize its orientation.	Risko & Gilbert, 2016	677
External normalization	Bringing the stimulus closer to its canonical orientation via the physical movement of the body.	Dunn & Risko, 2015	3
Externalized thought examples	Diagrams, along with pictures, film, paintings in caves, notches in wood, incisions in stone, cuttings in bone, impressions in clay, illustrations in books, paintings on walls, and of course words and gestures	Tversky, 2011	500
Hard constraints	Hard constraints determine which microstrategies are possible.	Gray & Fu, 2004	1
Hard constraints	Hard constraints dictate what behaviours are or are not possible when performing a task.	Patrick et al., 2015	776
Intention offloading	The process of setting up external reminders for delayed intentions.	Gilbert, 2015	257
Intentional forgetting	Intentional forgetting is the deliberate elimination or suppression of certain information that was once processed for potential future retrieval.	Eskritt & Ma, 2014	237
Internal normalization	Internal normalization is an internal transformation (in this case mental rotation) that aligns a representation of a stimulus with a representation stored in memory.	Risko & Gilbert, 2016	677
Manipulatives	Manipulatives are small objects, such as pie wedges, frequently used in early mathematics instruction.	Martin & Schwartz, 2005	591
Memory aids	Devices or strategies that are deliberately used to enhance memory.	Intons–Peterson & Fournier, 1986	267
Metacognition: Metacognitive monitoring and control	Metacognition is thought to involve metacognitive monitoring, which involves an individual's subjective assessment of their cognitive processing, and metacognitive control, which involves actions taken to regulate cognition.	Risko & Dunn, 2015	62
Number sense	Number sense includes learning of math facts along with deep understanding of numbers and the ways they relate to each other.	Boaler, 2015	2
Pragmatic actions	Actions performed to bring one physically closer to a goal.	Kirsh & Maglio, 1994	515

Proactive interference	Proactive interference occurs when the ability to remember recently learned information is impaired by previously learned information.	Eskritt & Ma, 2014	242
Prospective memory	Our ability to remember delayed intentions is termed prospective memory. Prospective memory delegates to-be-remembered material to the environment.	Risko & Gilbert, 2016	678
Prospective memory	Prospective memory has been defined as the process or skills required to support the fulfillment of an intention to perform a specific action in the future.	McDonald et al., 2011	785
Prospective memory	The ability to perform intended actions at specific times in the future is referred to as *prospective memory* and it is vital for everyday memory function, since it is implicated in most activities of daily living.	McDonald et al., 2011	785
Soft constraints	Soft constraints determine which of the possible microstrategies are most likely to be selected.	Gray & Fu, 2004	1
Soft constraints	Soft constraints are flexible and concern how the person tackles the task, including the strategy chosen.	Patrick et al., 2015	776
Spatial visualization	The ability to mentally manipulate, rotate, twist, or invert objects without reference to one's self.	Chu & Kita, 2011	102
Transactive memory system	Knowledge is distributed across two or more individuals such that the system as a whole knows more than any one individual.	Risko & Gilbert, 2016	682
Transactive memory system	People typically develop a group or *transactive memory*, a combination of memory stores held directly by individuals and the memory stores they can access because they know someone who knows that information. Like linked computers, people in dyads or groups form transactive memory systems.	Sparrow et al., 2011	776
Transactive memory system	A "transactive memory system" (TMS) is a set of individual memory systems in combination with the communication that takes place between individuals. A TMS is a socially coupled dynamical system with emergent properties, which in certain cases can be highly integrated and enduring, and exhibit high levels of continuous reciprocal causation.	Sutton et al., 2010	547

Note: Some terms will have more than one definition, since their representation is multi-faceted within the literature, and each one can add useful information to the overall term. Although most definitions were explained throughout the paper, the table contains all definitions, organized in alphabetical order.

CHAPTER 2

FORGET-ME-NOT: THE EFFECTS OF NOTE-TAKING ON COGNITIVE OFFLOADING AND LEARNING

Irina Ghilic, Amy A. Pachai, Lisa Lorentz, and David I. Shore

Abstract

Background: Our memory capacities are limited. We couple “inside the head” knowledge with “in the world” information to externalize our thoughts and reduce our cognitive load. Offloading information reduces the amount of interference we see between the information we are currently trying to encode, and past information we might try to remember. Note-taking is one way to offload our cognition, as it creates a record of information for future reviewing and learning. In the present work, we explored the saving-enhanced memory effect of cognitive offloading, in a reading and typing condition. We extended our paradigm to a more ecologically valid lab study, by including actual lecture and test materials.

Method: In Experiment 1, participants were exposed to the following sequence throughout 8 blocks: study List A (by either reading or typing it), study List B (by reading it), engage with a distractor task, get tested on List B, and the get tested on List A. Half the time, though, participants were prompted to “save” List A. If they saved it, they would get to re-study it before being tested on List A. In Experiment 2, we explored a similar experimental design, but with only one block, and using Lecture A and B instead of word lists.

Results: Saving List A information lead to higher recall of List B items in Experiment 1. For those who studied the initial List A by typing the words, the more words they typed, the better they recalled List A items for the “save” condition. In the “no save” List A condition, if they typed notes and had more time to study, the number of words they typed did not affect their performance. When they had less time to study, the more words they typed, the worse they performed on List A recall. In Experiment 2, we saw no benefits for Lecture B's performance when participants took notes on Lecture A.

Conclusions: The present work further substantiates the value of offloading in reducing proactive interference while also showing the importance of maintaining an accurate record of notes, with a caveat: if we’re short on time, the more we write, the more we offload, the less we recall. This deficit, however, is easily overcome by having access to the record of notes.

Keywords: Cognitive offloading, note-taking, proactive interference, individual differences, saving-enhanced learning.

Introduction

Our memory system is fallible. We forget so much information throughout our lives, from grocery list items to appointments; TV shows to classroom content. Some of the information we forget is no longer needed, such as old phone numbers or completed items on a to-do list. However, sometimes the forgotten information is still necessary. To deal with this information overload, we have a complex set of processes that prioritize relevant information, filter out information that was previously useful but now can be forgotten, and ignore information that does not need to be remembered in the first place.

These processes are not infallible, and our limited memory and cognitive capacities cannot always store everything inside our heads. As a result, we externalize our thoughts. We achieve these externalizations either through our bodies (e.g., when we gesture or move our heads), with tools we can manipulate in the real world (e.g., writing down a to-do list), or via memory-extending systems (e.g., other people or the Internet). In the cognition literature, such externalizations are known as cognitive offloading: “the trading-off of internal processing for external processing” (Risko et al., 2014, p. 540). Writing down information is one method of engaging in cognitive offloading, which encompasses any physical action that reduces a task's overall cognitive processing load (Risko & Gilbert, 2016). Writing down to-be-remembered information maintains a more complete and accurate record of information.

However, our memory system is still necessary to remember *where* the information is kept (see Risko & Gilbert, 2016, for a relevant review).

Cognitive offloading is an increasingly common process, given society's technological advances. Cognitive offloading is necessary for success in environments where cognitive load tends to be high, such as during a lecture. Note-taking creates an external record of the lecture content that we can reference to assist learning. It provides both benefits of external storage and improved encoding during the note-taking process (Kiewra, 1989).

Using external memory stores, such as notes, is an attractive option. However, it is essential to note that storing information externally can make our memory for that information more likely to fail (Henkel, 2014; Sparrow et al., 2011; Storm & Stone, 2015). Henkel (2014) found that if participants took photos of items in an art museum, they were less likely to remember details about those items and their locations on a later memory test. Because this information was stored in an external source, the memory system was no longer accountable for maintaining it, allowing it to be forgotten. This phenomenon is referred to as *directed forgetting*, where information is purposely forgotten or weakly encoded because it is unnecessary (see MacLeod, 1998 for a review). By forgetting unnecessary information, such as lecture content that has been captured via notes, our memory system makes room for new connections and essential information. Forgetting previously learned content reduces the likelihood of interference with new information. When it is more challenging to remember recently presented information because of information you have learned before is referred to as “proactive interference” (Eskritt & Ma, 2014). Being able to reliably save files, take photographs, or record notes during tasks provides participants with a performance boost on subsequent tasks by reducing the effects of proactive interference (Eskritt & Ma, 2014; Hegarty & Steinhoff, 1997). For example, when professors provide lecture slides, students do not have to worry about copying down the slides and what the lecturer says; interference is reduced, allowing students more cognitive resources to focus on listening to and understanding the lecture.

To explore how cognitive offloading might reduce proactive interference and encourage further offloading, Storm and Stone (2015) had participants learn and recall two PDFs containing lists of words. Participants first encoded List A from a PDF, but before being tested on this list, they were presented and tested on List B. The critical manipulation was whether or not participants were able to save List A (and restudy it after the List B test) before studying List B. When participants could save List A, this reduced the amount of proactive interference, subsequently improving List B's memory performance. This finding was in line with the hypothesis that cognitively offloading to-be-remembered words to a saved file allowed participants to engage in directed forgetting of the words, which reduced the degree to which List A proactively interfered with List B's memory.

Storm and Stone's (2015) study showcases the benefits of cognitive offloading: reduced proactive interference and better memory for "in the moment" information, with the ability to study "past" records information and thus "revive" the memory for "past" information—a win-win scenario. Although this experimental paradigm adds interesting contributions to cognitive research, its application in educational settings and learning design is harder to conceptualize. In a real classroom, instructors do not usually test students on later content before testing them on the earlier content. Student's performance on the earlier content would suffer unless they got a chance to study it before the test. In various ways, we can still use directed forgetting and reduce proactive interference in an actual course, as strategies to recall future information. Students engage in directed forgetting when they receive a test, quickly look over the test questions, identify which information they studied will be needed for the test, and "forget" the information that is not necessary to answer the question, thus "lightening" their cognitive loads (Posnansky, 1976). Practicing retrieval throughout a study sequence can also be used as feedback to discover which material is well-known and can be "put aside" mentally (i.e., offloaded and no longer subject to repetition, thus reducing proactive interference) (Szpunar et al., 2008), like List A in Storm and Stone (2015), and which material requires future focus, like List B in Storm and Stone (2015).

The current research aims to replicate the saving-enhanced memory effect seen by Storm and Stone (2015), while also investigating whether adding an active typing condition alters this effect. **In Experiment 1**, like in Storm & Stone (2015), participants either saved or did not save List A before moving on to List B. In addition, participants either typed List A, akin to taking notes or passively read List A. If note-taking produces a similar effect as reliably saving information, then note-taking may also be a cognitive offloading strategy that allows individuals to forget externally processed information to enhance the encoding of new information. Essentially, by “forgetting” the first list of words through note-taking, the memory of the first list would have less interference with the encoding of the second list. Thus, similar to saving the lists, note-taking could produce a memory-enhancing effect for List B compared to passive reading, while also reducing memory for List A, especially when not prompted to save List A. We also aim to explore potential individual differences effects in the typing condition: how might the individual differences in the quantity of the List A “notes” affect List A recall performance?

The experimental design of our studies deviates from the extensive procedural manipulation of Storm and Stone (2015), by using a PsychoPy-delivered experiment environment, as a time-saving modification and automatic ability to save the lists, as opposed to saving PDF files to a USB drive. This design allowed us to make quick modifications to the procedure if needed, it automatically randomized the lists of words and save/no save block order, and it did not require extensive involvement on the experimenter’s side, aside from initial instructions and debriefing of participants.

In **Experiment 2**, we explore a similar experimental design but use classroom-like lectures and quiz materials. This experiment serves as a more ecologically valid approach to exploring the effects of typing and saving notes for later study compared to not taking notes and having no available material to restudy—especially when a second lecture is involved. Will participants offload more Lecture A information and perform better on Lecture B when given the chance to take notes on Lecture A, and will studying those notes also provide a quiz performance advantage for Lecture A results?

Students are faced with multiple studying choices, given the competing demands of an entire course load (assuming they are taking a mix of lecture-based courses). A typical higher-education program exposes students to 4-5 unrelated courses, for a few months at a time. The lack of interconnectivity between courses can place higher demands on the student's cognitive load and attention resources. To maximize their study time and cognitive resources, students might choose to offload much of the information from Course A, for example, if they have a Course B quiz coming up first. Once the Course B quiz is over, they can review and study for Course A. While this "blocked" study strategy might be challenged by the "interleaving practice" literature (i.e., "implementing a schedule of practice that mixes different kinds of problems, or a schedule of study that mixes different kinds of material, within a single study session" (Dunlosky et al., 2013, p. 6), interleaving requires a lot of practice and time management discipline. For cognitively overburdened students, reducing proactive interference between their courses might be their best approach to successfully completing their course demands. Some educational settings have designed their programs to maximize students' full immersion in a single subject (please see Helfand, 2016, for a description of Quest University). This "blocked education" design aims to reduce attentional demands and lighten the learner's cognitive load, by allowing them to focus and master one subject at a time. However, while the "mix of disparate courses within a semester" model of higher education design prevails, students' performance will depend highly on their cognitive abilities and how they choose to focus on their studies.

EXPERIMENT 1

Experiment 1A Method

Participants

Participants were recruited for the experiment through McMaster's Psychology, Neuroscience & Behaviour online research participation system (SONA). The experimental procedures were approved by the McMaster Research Ethics Board (MREB) and all participants provided written consent before completing the experiment. Participants received partial credit for an Introductory Psychology course in exchange for their participation. Eighty-six McMaster University undergraduate students participated (mean age = 18.3). However, 5 participants' scores were discarded because they did not follow instructions and, thus, did not properly complete the experiment.

Design

The experiment was a 2 x 2 mixed design. One independent variable was whether participants could save or not save List A. This independent variable was measured within participants, so each participant experienced 4 save blocks and 4 no-save blocks. The other independent variable was the study condition. This was measured between participants, where some participants read List A and others typed List A. The dependent variable was the proportion of words correctly recalled for both List A and List B words.

Materials

The experiment was displayed using a 24-inch Mac computer and PsychoPy software. Participants were given disposable earplugs to wear during the experiment to attenuate environmental sounds. Word lists were created by randomly selecting eight words from a total pool of 128 words without replacement. All words were five-letter English nouns, with a frequency between the 60^{th} and 80^{th} percentiles according to the Brysbaert and New (2009) word frequency norms. These lists were randomly assigned to one of eight total blocks as either List A or List B.

Procedure

The computers were set up with the PsychoPy program running and open to the first instructional screen before participants entered the room. Participants began seated in front of a desktop computer in one of the university's computer labs. They were first given a standard consent form to read and sign. They were then asked to fill out a lab-standard brief questionnaire regarding their reading, hearing, and motor competency before being given general verbal instructions. The questionnaire results did not influence the experimental procedure unless the participant indicated major concerns in their motor ability to type or with their reading comprehension. In that case, participants had the choice to withdraw from the study (and still get the credit). We had no such cases in our experiments. The participants were told that they would be studying lists of words and would be asked to recall them. They were also told that for some lists of words, they would be given the opportunity to save the list so that it could be studied immediately before being tested on it. There were no external incentives for test performance.

After being given verbal instructions to begin, participants turned their attention to the computer screen in front of them. The first set of instructions explained that the experiment would consist of 8 blocks. Each block would contain two lists of words, List A and List B, which they would study in succession. Occasionally, they would be given the opportunity to save List A so that they may study it immediately before testing. Each participant's instructions also specified whether they would be studying List A by reading or typing it, depending on the condition they were placed in. They were not told that their method of studying was different from others. To differentiate between List A and List B, the former was presented and tested on the left side of the screen, while the latter was presented and tested on the right. As per Storm and Stone (2015), participants were told that they would study List A, but before being tested on this list, they would study and be tested on List B. Just prior to being tested on List B, participants were given a 30-second distractor task of arithmetic questions (i.e., three-digit addition) completed on the computer screen, to avoid potential mental repetition of the stimuli outside of the original presentation window.

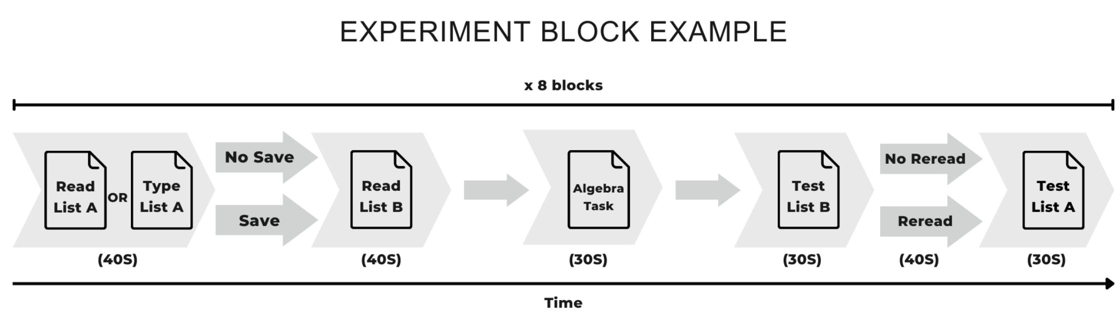
On half of the blocks, participants were given the ability to click a “save” button for List A and were, subsequently, able to re-study this list just prior to being tested on it. On the other half of the blocks, participants clicked a “next” button and were not given the opportunity to re-study.

Once participants finished reading the first set of instructions, they used the keyboard to move on to the next screen. Another instructional screen appeared, indicating that the first block would begin and to study List A by either reading or typing the words. The next screen displayed List A and gave participants 40 seconds (40s) to either read or type the list of words. After 40s, the list disappeared, and participants were either given the instruction to save the list or no instruction. Next, participants were given List B to read for 40s. Participants then engaged in a distractor task consisting of simple algebraic problems for 30s before moving on to the recall tests. First, they were asked to freely recall and type as many words as they could remember from List B in 30s. If the block were a “save” block, participants would then be given the opportunity to restudy List A for 40s. The list given was either the original list if the participant was in the “read” condition, or the list they had typed if they were in the “type” condition. If the block were a “no save” block, the participants would simply move on to the next recall test. Participants were then asked to freely recall and type as many words as they could remember from List A in 30s. Completing this recall test signaled the end of the first block.

The program would repeat the pattern (as shown in Figure 1) until participants had completed all 8 blocks of the experiment. Upon completing the final block, participants were given approximately 120s to freely recall and type as many words as they could remember from the entire experiment. This manipulation was exploratory in nature, and the results are beyond the scope of this paper. After indicating they had finished, the program would automatically close. Participants were then given a brief verbal debrief of the experiment and a debrief form explaining the nature of the study. The entire experiment was completed in approximately 45 minutes.

Figure 1

Experiment 1A Trial Sequence Example



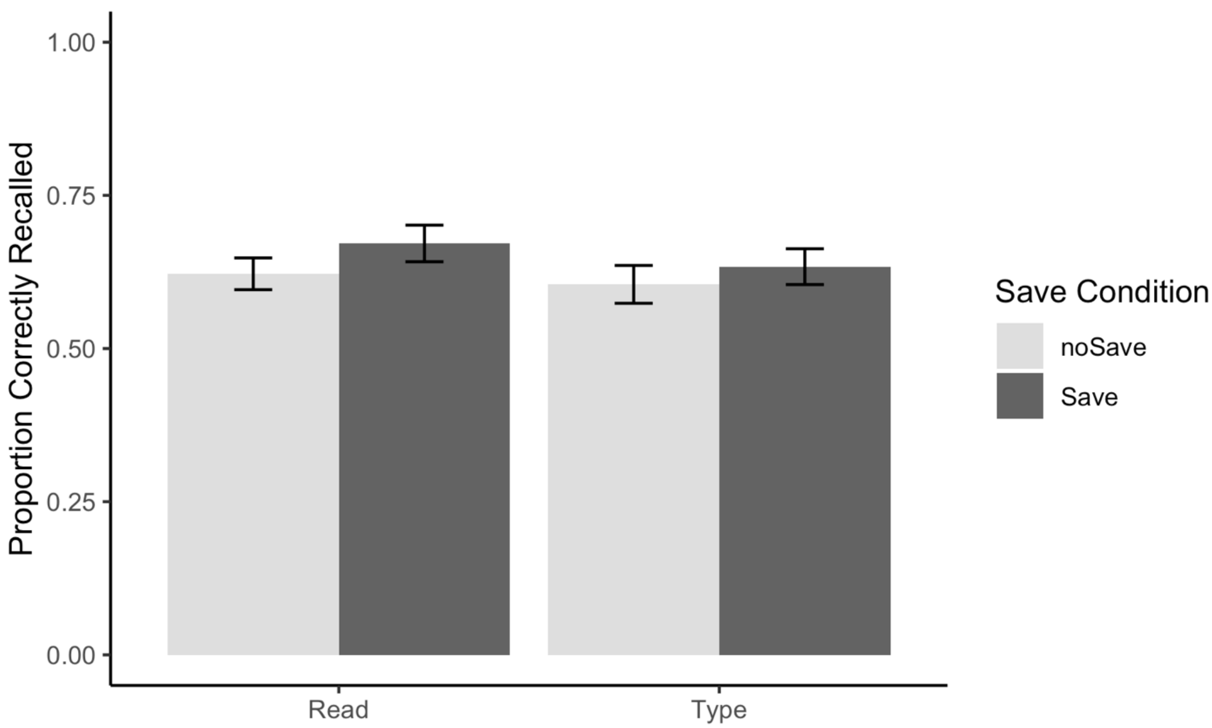
Note. Participants studied List A by either reading or typing. They were randomly either given a “save” or “no save” instruction, after which they read List B.

Following the study of both lists, participants completed a short algebra task. Then, participants were tested on their recall of List B. Participants either restudied List A if they had saved it or were not allowed to restudy before being tested on their recall of List A. Participants completed 8 of these blocks.

Experiment 1A Results

Figure 2

Experiment 1A, List B Proportion Correctly Recalled Words



Note. The average proportion of correctly recalled List B words collapsed across participants in Experiment 1A. Error bars represent ±*SEM*.

List B Recall. The average proportion of correctly recalled values was calculated for each participant as the total number of items correctly recalled across all List B recall tests divided by the total number of List B recall tests experienced across the experimental session (see Figure 2). The average proportion of correctly recalled values was submitted to a 2 x 2 mixed factor ANOVA that treated typing condition (read/type) as a between-participants factor, and the save condition (no save/save) as a within-participants factor.

List B recall performance was higher in the save condition (M=.653, SD=.188) than in the no save (M=.613, SD=.180) condition, $F(1,79)=4.09$, $p=.05$, $\eta_p^2=.049$. There was no effect of typing condition, $p=.460$, nor was there an interaction between typing and save condition, $p=.556$.

Testing for the potential effect of reliability of save condition. Storm and Stone (2015) demonstrated that the reliability of the save feature affected the influence saving had on performance. More specifically, the authors found that saving only led to better performance when saving reliably resulted in access to the saved list (i.e., the result was not found under conditions where files could be "corrupted" and participants consequently did not have access to their saved lists in some blocks).

The reliability of the save condition was not explicitly manipulated in the present work, so it is possible that there were differences between participants in the way that the save condition was experienced. All participants experienced an equal number of save and no save blocks, which were randomly dispersed throughout the experimental session, but some participants experienced the no save condition first, while others experienced the save condition first. Although participants were told they would sometimes be able to save their lists, participants who experienced the no save condition first may have felt “deceived” about the reliability of the save feature, which, based on the work by Storm and Stone (2015), would lead to a diminished effect of saving condition for these participants.

To test whether this was influencing List B results in the present work, we submitted the average proportion of correctly recalled List B results to a 2 x 2 x 2 mixed factor ANOVA that included the study condition and save condition experienced first (no save/save) as the between-participants factors, and save condition (no save/save) as a within-participants factor.

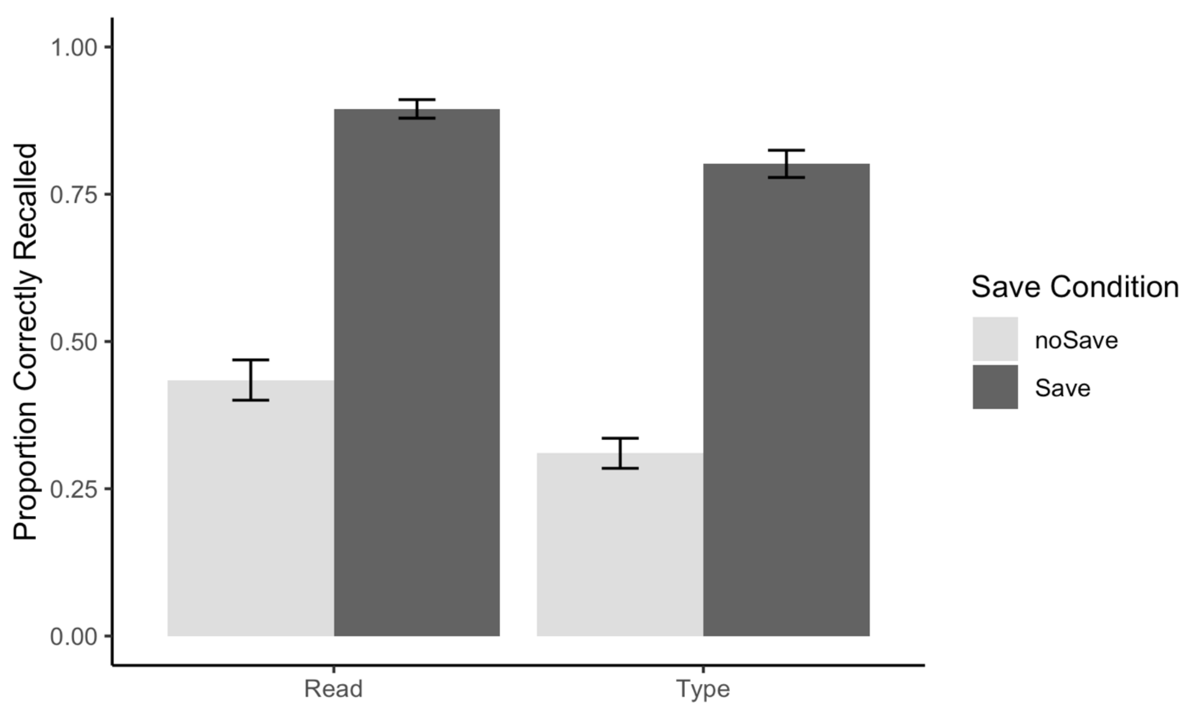
The effect of the saving condition experienced first was not significant, p=.985, nor were any of its interactions, all ps>.3.

Mini-Discussion of Experiment 1A, List B. For List B recall, we replicated Storm and Stone’s (2015) effects for the “save” condition: List B recall performance was higher in the save condition than in the no save condition. When participants were allowed to save the first list of words (List A) before they studied List B, they recalled more words from List B. The cognitive offloading and proactive interference literature can explain this result from a “cognitive load” perspective. If participants cannot save List A, they could be holding on to the information presented in List A while trying to study List B, thus creating interference with the new List B words, and burdening their mental load with up to 16 words, instead of 8. However, if participants get to save the first list of words, and we demonstrate that they can reliably re-study that list before their recall test, they can direct their focus on the second list of words (List B) and not feel as compelled to burden their cognitive load with the List A words because they will get to see those words again.

In looking at the List B results, there was no effect of typing condition, nor was there an interaction between the study and the save condition. In Experiment 1A, allowing participants 40s to “study” the eight List A words by either reading or typing them did not drive differences in their recall results for List B. Whether they read or typed the words in List A, their recall performance remained similar for List B. In this case, typing did not seem to promote offloading more than reading.

Figure 3

Experiment 1A, List A Proportion Correctly Recalled Words



Note. The average proportion of correctly recalled List A words collapsed across participants in Experiment 1A. Error bars represent ±*SEM*.

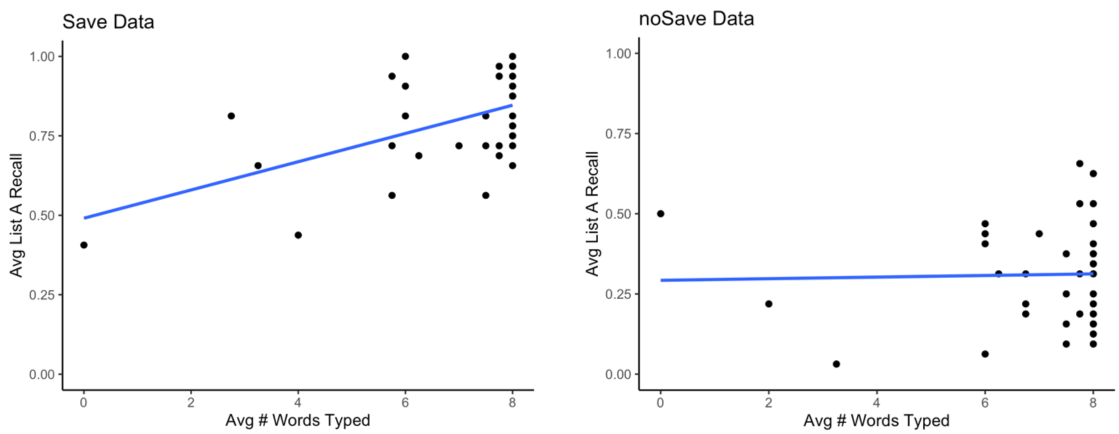
List A Recall. The average proportion of correctly recalled values was calculated for each participant in the same manner as for List B recall (see Figure 3), and the average proportion of correctly recalled values was submitted to a 2 x 2 mixed factor ANOVA with the same factors as for List B recall.

List A recall performance was significantly higher in the save (M=.849, SD=.133) than in the no save condition (M=.373, SD=.202), $F(1,81)=273.9$, $p<.001$, $\eta_p^2=.776$. Performance was also significantly higher in the read condition (M=.665, SD=.145) than in the type condition (M=.556, SD=.126), $F(1,79)=12.91$, $p<.001$, $\eta_p^2=.140$. There was no interaction between the study and save condition, $p=.435$.

Effect of the number of words typed. To further examine the effect of typing condition, we analyzed whether the number of List A words typed influenced List A recall (see Figure 4). Not surprisingly, in the save condition, the number of words typed was significantly and positively correlated with List A recall performance, *Pearson's* $r=.536$, $p>.001$, with an average of 6.99 words typed per block. The average number of words typed was not correlated with List A recall in the no save condition, $p=.737$, with an average of 7.09 words typed per block.

Figure 4

Experiment 1A, List A Average of Correctly Recalled Words x Typed Words Correlation



Note. Correlations between the average number of words typed and average List A recall for the save and no save conditions in Experiment 1A.

***Mini-Discussion of Experiment 1A, List A**.* Storm and Stone (2015) did not focus their discussion on List A recall results. We were very interested, however, to learn from List A results, especially with our added condition of study method: reading versus typing. How might participants perform on List A recall when they got to re-study the words they had typed, and how might typing List A affect recall in the “no save” condition?

Unsurprisingly, List A recall performance was significantly higher in the save than in the no-save condition. When participants got to save the lists earlier in the block, they were given the opportunity to study them again before being tested on them. Their performance nearly doubled, following the second exposure to the saved words and the close proximity between restudy and recall test.

Our main interests for List A results lie in the study condition differences: How might typing the words for List A, instead of reading them, affect recall performance? While the "read" condition presented participants with the same lists when they re-studied them, the "typed" condition List A restudy consisted only of those words that were typed by the participants. Typing word lists is prone to more individual differences between participants' approaches to studying than the "read" condition (e.g., speed of typing, eye-finger span—looking at the keyboard while typing—, reading comprehension) (Muñoz et al., 2006; Shaffer & Hardwick, 1969), and those differences affect the number of words participants type. Overall, performance was significantly higher in the read condition than in the type condition, regardless of whether participants saved or did not save List A. When we looked at the average number of words typed for the "no save" condition, typing more words as a way of studying List A did not influence List A performance. Since participants were given an ample amount of time (40s) to "study" the words, we hypothesize that those 40s were enough for participants to type and read the words, thus leading participants to similar outcomes in the "no save" condition, regardless of how many words they typed. Thus, when not given the opportunity to study the typed words and enough time in the "study" condition, participants' varying note-taking differences did not influence their testing outcome. There was no cost to the participants who focused on typing more words when presented with List A and were given enough time at study.

However, the average number of words typed in the “save” condition did make a difference in the participant’s performance. The quantity of notes participants had for their restudy period predicted performance: the more words they typed, the higher their recall scores. Since “saving” a list signals participants the ability to later study the list, it encourages offloading (whose effects we see in the List B recall results). True to the nature of taking notes during a class, participants only had available whatever they had written down for restudy, and the quantity of those notes positively predicted their performance, as seen in the literature as well (Peverly et al., 2007; Peverly & Wolf, 2019).

Overall, typing did not drive an offloading effect for List B, but individual differences in the quantity of the List A “notes” did affect List A recall performance. The more accurate the record when given a chance to study, the better the participants performed. When participants did not study their typed List A notes, the number of words typed did not make a difference in their performance. For List A performance, the “read” condition led to an overall increase in performance compared to the “type” condition. Given the amount of time to study the lists (40s), participants in the “read” condition anecdotally reported going over the list multiple times, whereas those who typed the list reported more of a focus on typing the list rather than re-reading the list until the time ran out.

Experiment 1B Method

Participants

Participants were recruited in the same way as in Experiment 1A. Sixty-five McMaster University undergraduate students participated (mean age = 19.3). However, one participant's scores were discarded because they did not follow instructions and did not properly complete the experiment.

Design

The main procedure, independent, and dependent variables remained the same as those in Experiment 1.

Materials

The materials were the same used in Experiment 1A. However, 4 additional word lists were used to create 2 practice blocks at the beginning of the experiment. Therefore, 2 new List A–List B pairs were added to the existing 8 from Experiment 1A.

Procedure

The procedure was identical to that used in Experiment 1A, with the following amendments: adding two practice blocks and reducing the study/restudy time. Due to the difficulty in following instructions experienced by some participants in Experiment 1A, participants were given 2 practice blocks following their initial instruction screen. These practice blocks were similar in format to the blocks used in Experiment 1A and consisted of one "save" block and one "no save" block. Participants were then told when the practice blocks were over and continued to complete the same 8 blocks used in Experiment 1A (Figure 5).

Each block used in this experiment followed the same pattern as Experiment 1A, with a modification to the amount of time participants were given to study the word lists. Participants were given only 20s to either read or type List A, depending on which condition they were initially placed in. Based on our initial study, 40s gave participants too much time with their task; we wanted to give them just enough time to complete the task, instead of allowing participants to engage with the trials differentially. For example, some participants anecdotally mentioned finishing the trial and just waiting, while others repeatedly studied the list. We piloted practice trials for both the read and the type condition, and 20s was sufficient time to complete the study task and minimize off-task behaviours. After being given either the “save” or “no save” instruction, participants were given 20s to study List B. From this point on, the distractor task and recall tests remained the same as Experiment 1. Once participants completed the 2 practice blocks and the 8 test blocks, they were given 120s to freely recall and type as many words as they could remember from the entire experiment. The program would then automatically end the experiment and participants were given both a verbal and written debrief regarding the nature of the study. The entire experiment was completed in approximately 50 minutes.

Figure 5

Experiment 1B Trial Sequence Example

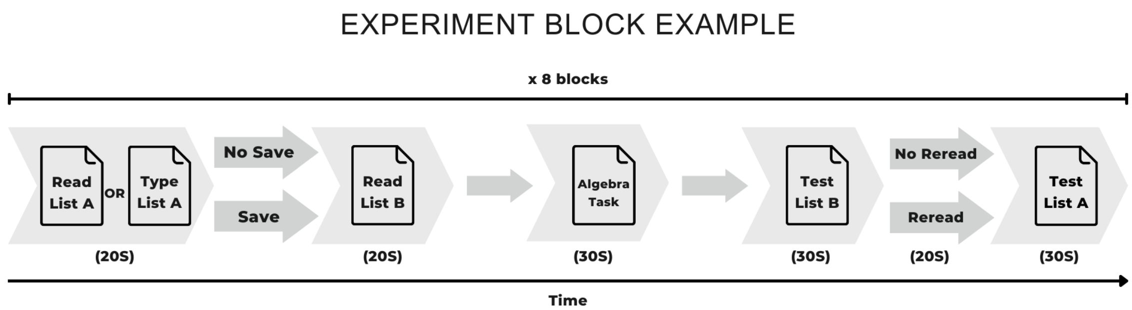
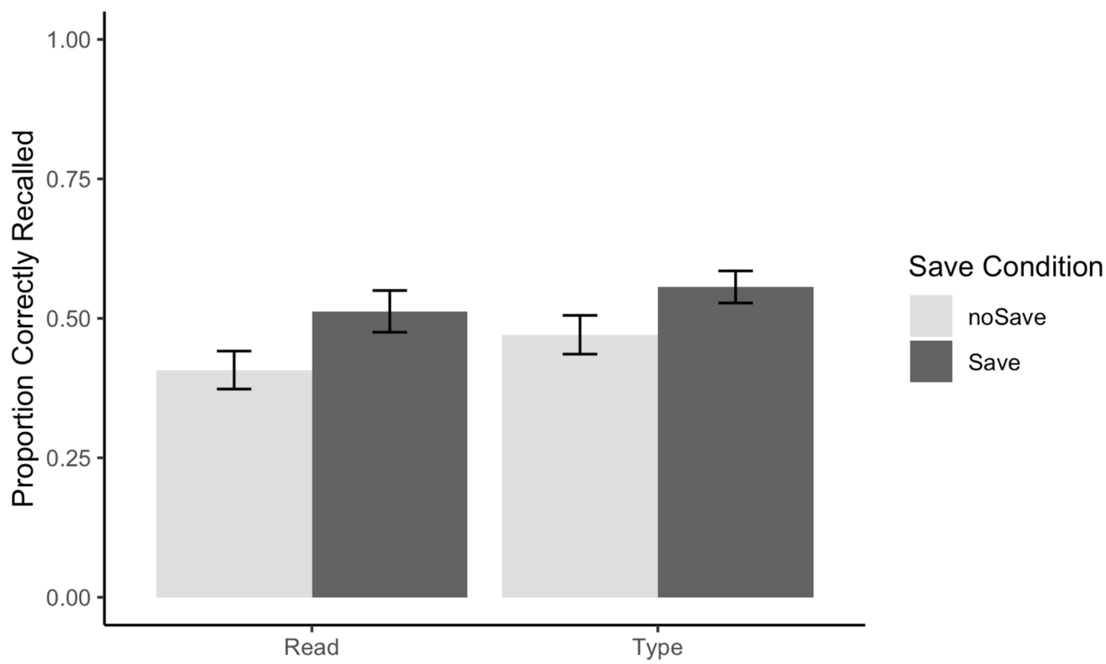


Figure 5. Participants studied List A by either reading or typing. They were randomly either given a “save” or “no save” instruction, after which they read List B. Following the study of both lists, participants completed a short algebra task. Then, participants were tested on their recall of List B. Participants either restudied List A if they had saved it or were not allowed to restudy before being tested on their recall of List A. Participants completed 8 of these blocks. Before the experimental blocks, participants received two practice blocks: one for each save/no save condition.

Experiment 1B Results

Figure 6

Experiment 1B, List B Proportion Correctly Recalled Words



Note. The average proportion of correctly recalled List B words collapsed across participants in Experiment 1B. Error bars represent ±*SEM*.

List B Recall. The average proportion of correctly recalled values was calculated in the same manner as for Experiment 1A, by calculating the total number of items correctly recalled across all List B recall tests divided by the total number of List B recall tests experienced across the experimental session (see Figure 6). These scores were then submitted to a 2 x 2 ANOVA that treated study condition (read/type) as a between-participants factor and save condition (no save/save) as a within-participants factor.

List B recall was significantly better in the save condition (M=.536, SD=.187) than in the no save condition (M= .441, SD=.198), $F(1,63)=10.88$, $p=.002$, $\eta_p^2=.147$. There was no effect of typing condition, $p=.213$, nor was there an interaction between study and save condition, $p=.655$.

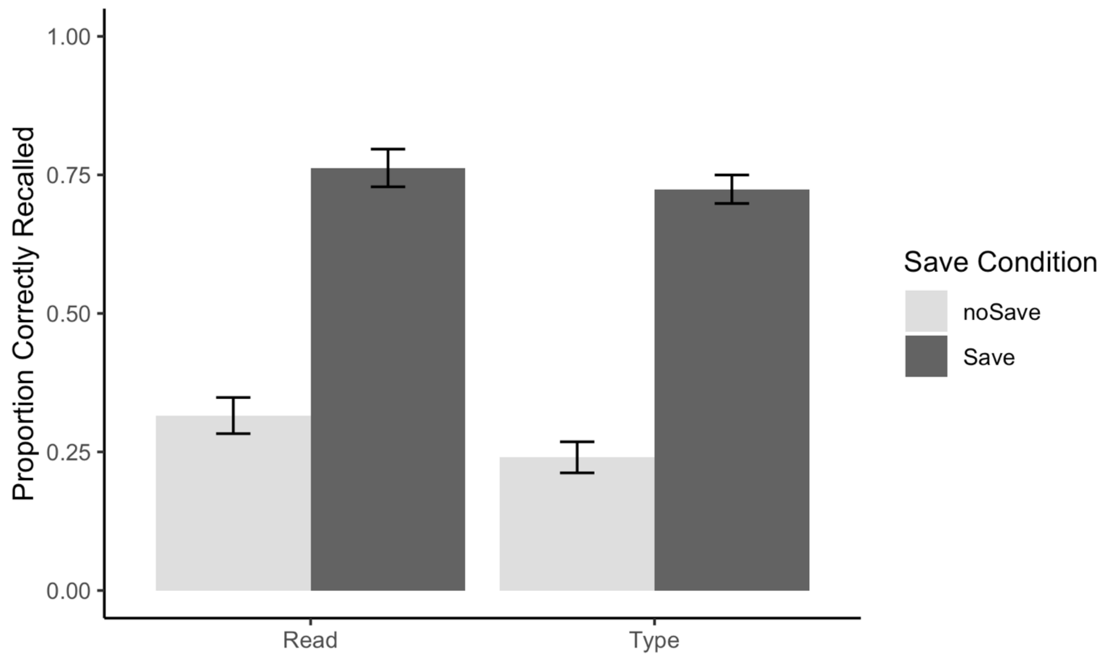
Testing for the potential effect of reliability of save condition. As in Experiment 1A, we examined whether the save condition that participants experienced first influenced performance on List B. We submitted average List B proportion correctly recalled performance to a 2 x 2 x 2 ANOVA that treated the study condition (read/type) and save condition experienced first (no save/save) as between-participants factors, and save condition (no save/save) as a within-participants factor. The main effect of save condition experienced first was not significant, $p=.871$, nor were any of its interactions, all *p*s>.1.

Mini-Discussion of Experiment 1B, List B. List B recall performance was higher in the save condition than in the no save condition. When participants were allowed to save the first list of words they had to study (List A), before they studied List B, they recalled more words from List B. In looking at the List B results, there was no effect of study condition (read vs. typed), nor was there an interaction between the study and save condition. In Experiment 1B, allowing participants 20 seconds to “study” the eight List A words by either reading or typing them did not drive differences in their recall results for List B. Whether they read or typed the words in List A, their recall performance remained similar for

List B. As in Experiment 1A, typing did not seem to promote offloading more than reading for List B.

Figure 7

Experiment 1B, List A Proportion Correctly Recalled Words



Note. The average proportion of correctly recalled List A words collapsed across participants in Experiment 1B. Error bars represent ±*SEM*.

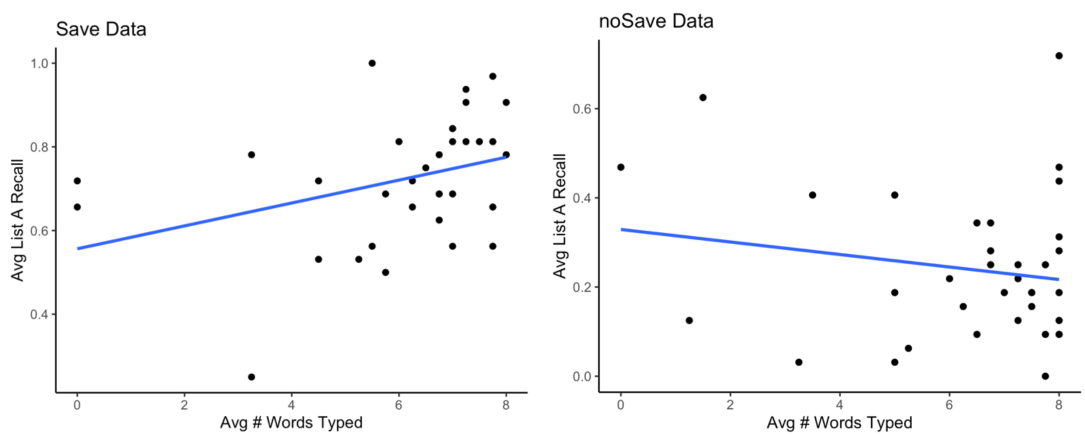
List A Recall. The average proportion of correctly recalled values was calculated for each participant in the same manner as for List B recall (see Figure 7), and the average proportion of correctly recalled values was submitted to a 2 x 2 mixed factor ANOVA with the same factors as for List B recall.

List A recall performance was significantly higher in the save (M=.742, SD=.169) than in the no save condition (M=.275, SD=.175), $F(1,63)=220.47$, *p*<.001, η_p^2=.778. There was no effect of typing condition, *p*=.130, nor was there an interaction between typing and save condition, *p*=370.

Effect of the number of words typed. Although the effect of typing condition was not significant, we examined whether the number of List A words typed influenced List A recall (see Figure 8). In the save condition, the number of words typed was significantly correlated with List A recall performance, *Pearson's r*=.353, *p*>.001, with an average of 6.13 words typed per block. The average number of words typed was negatively correlated with List A recall in the no save condition, *Pearson's r*=-.179, *p*=.035, with an average of 6.34 words typed per block.

Figure 8

Experiment 1B, List A Average of Correctly Recalled Words x Typed Words Correlation



Note. Correlations between the average number of words typed and average List A recall for the save and no save conditions in Experiment 1B.

Mini-Discussion of Experiment 1B, List A. As in Experiment 1A, List A recall performance was significantly higher in the save than in the no save condition. Interestingly, however, performance was no different between the read and type conditions, unlike Experiment 1A, which we will discuss shortly.

When looking at individual differences in the average number of words typed for the “no save” condition, the higher the number of typed List A words, the lower the performance for List A. In the current experiment, participants were given a shorter amount of time (20s, as opposed to 40s) to “study” the words, leading to a performance cost when typing more words; essentially, these participants typed more words, which appears to have left them with less time to encode the words. Thus, when not given the opportunity to study the typed words and not enough time in the “study” condition, participants’ varying note-taking abilities influenced their testing outcome. In Experiment 1B, with a shorter study time (20s vs. 40s), we see that there was indeed a cost to memory for List A words for participants who focused on typing more words (when using number of words typed as a proxy for focus on typing).

Like in Experiment 1A, the average number of words typed in the “save” condition made a difference in the participant’s performance. The quantity of notes participants had for their restudy period predicted performance: the more words they typed, the higher their recall scores.

Although typing did not drive a higher offloading effect for List B, the individual differences in the quantity of the List A “notes” affected List A recall performance. The more robust the list when given a chance to study, the better the participants performed. However, when participants were not given a chance to study their typed List A notes, the number of words typed made a difference in their performance: the more words typed, the lower their performance. In a "time-crunch" condition, typing more words could have acted as an undesirable difficulty, with typing more words resulting in more mindless transcription, increased offloading, less time to read through the words again, and potentially increased divided attention (Gaspelin et al., 2013).

For the overall List A performance, the "read" condition did not lead to an overall increase in performance compared to the "type" condition. With the reduced study time, participants in the "read" condition no longer had the advantage of repeatedly studying List A, thus levelling the playing field between the reading and typing tasks.

EXPERIMENT 2

Experiment 2 explores a similar experimental method to Experiment 1, but introduces more ecologically valid lecture-style materials and tests (although still adapted for the feasibility of testing in a lab environment). Participants in this experiment were instructed to retain information from Lectures A and B, before being tested on Lectures B and A, respectively. However, this experiment only had one "block", and the saving manipulation was only applied to participants who typed. As stated in the introduction, this experiment serves as an initial approach to exploring the effects of typing and saving one's lecture notes for later study, versus not taking notes and having no available material to restudy, especially when a second lecture is involved.

Experiment 2 Method

Participants

Participants were recruited for the experiment through McMaster's Psychology, Neuroscience & Behaviour online research participation system (SONA) and all experimental procedures were approved by MREB. Participants provided written informed consent and were given partial credit for an Introductory Psychology course in exchange for participating in the experiment. 66 McMaster University undergraduate students participated (average age of 18). However, 5 participants' scores were discarded because they did not follow instructions and did not properly complete the experiment.

Design

This study's independent variable was the study condition. This was measured between participants, where some participants passively listened to Lecture A and others took notes for Lecture A. The dependent variable was the proportion of correct scores for both Lecture A and Lecture B content. For our statistical design, we planned a 2 x 2 x 2 mixed factor ANOVA that treated the notes condition (notes/no notes) and lecture experienced first (Lecture Topic 1 first/Lecture Topic 2 first) as between-participants factors and question type (factual/application) as a within-participants factor.

Materials

The experiment was displayed using a 24-inch Mac computer, PsychoPy software, and MP4 video files. Participants were presented with two 5-minute long TedEd style recorded presentations. Topic 1 was on Social Anxiety, while Topic 2 was on Goal Setting. Participants then completed a simple algebra math distractor task. Two post-lecture quizzes were given to assess the knowledge of Topics 1 and 2 factual (7 multiple choice questions) and application (7 multiple choice questions). Please see Appendix A for sample quiz questions.

Procedure

The computers were set up with the PsychoPy program running and open to the first instructional screen before participants entered the room. The experimenter ensured that the participants' headphones were plugged in and the laptop's Wi-Fi was off. Participants began seated in front of a desktop computer in one of the university's computer labs. They were first given a standard consent form to read and sign. They were then asked to fill out a brief questionnaire regarding their reading, hearing, and motor competency before being given general verbal instructions.

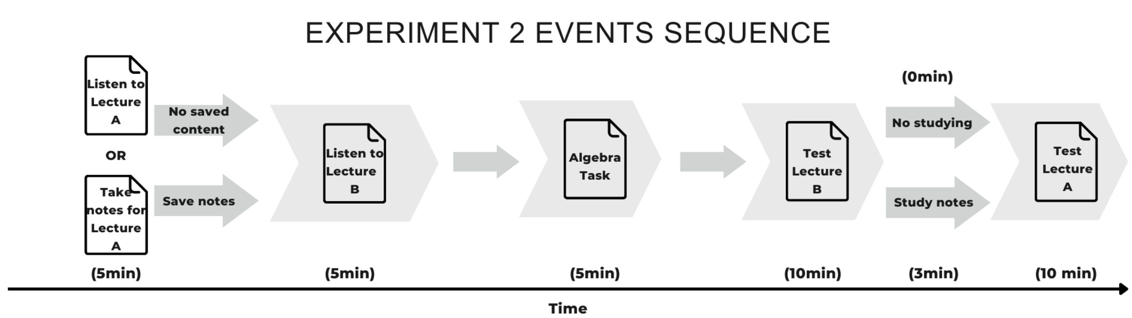
The participants were told they will be experiencing two lectures, which they would later be tested on. Participants were told that they will watch two lecture-style videos produced by undergraduate students, then complete a brief math distractor task just to get their mind off the lecture for a bit, to give themselves a break, and finally complete a quiz related to the content they watched in the two videos. Participants were instructed not to pause the videos, and each video was about 5-6 minutes long. Participants were asked to pay attention to the content and try to retain as much of the information as they could, as they will be tested on it. For the participants who took notes for Lecture A, they were asked to take notes as they would in a regular lecture on a laptop, and told that they would be allowed to study their notes before receiving the quiz. Participants were instructed to make sure to save their notes by clicking the 'file' tab followed by 'save'. We asked participants that no matter what they did, they should not unplug the laptop or it would turn off and take a long time for it to start up again. Then all participants were told that after the first video was complete, to press a button to notify the experimenter so they could return and set up the second video for them. The experimenter came back into the room once notified by the participant, to set up the second lecture. For the participants who took notes, the experimenter removed the laptop, as nobody took notes for Lecture B. Participants were told they would not need to take notes on the second lecture, but the laptop would be given back once it came time to study the notes.

Once Lectures A and B were complete, the participants were given math sheets and were allowed five minutes to complete them. Once they completed the algebra task, the experimenter set up PsychoPy and instructed participants to complete the quiz, which was separated into two sets of questions, one set for each lecture. They completed the quiz in reverse order, so the last lecture they watched was the one they were tested on first, similar to Experiment 1's format.

Once participants inputted an answer and pressed enter, they could not navigate back to it. After the first quiz was over, participants were presented with a screen that instructed them to call the experimenter. If they did not take notes for Lecture A, they were instructed to skip the instruction by pressing the spacebar to continue with the second quiz. If participants took notes for Lecture A, they were instructed to call the experimenter back into the room after the first quiz. The experimenter presented participants with their Lecture A notes and they were given 3 minutes to study the notes. Once the notes were taken away, participants continued with the second quiz (please see Figure 9 below for a visual representation of Experiment 2's events). When the quizzes were completed, participants were then given a verbal debrief of the experiment and a debrief form explaining the nature of the study. The entire experiment was completed in approximately 45 minutes.

Figure 9

Experiment 2 Experimental Sequence

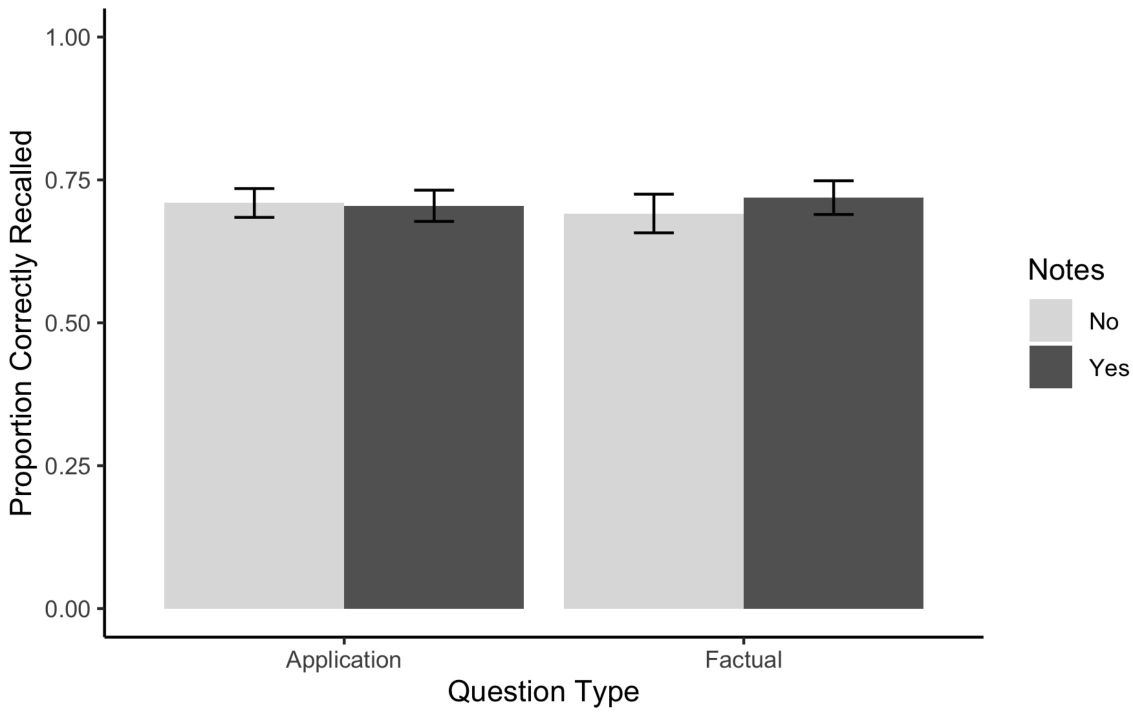


Note. The experimental sequence for Experiment 2.

Experiment 2 Results

Figure 10

Experiment 2 Lecture B Proportion Correctly Recalled Words: Notes versus Question Type



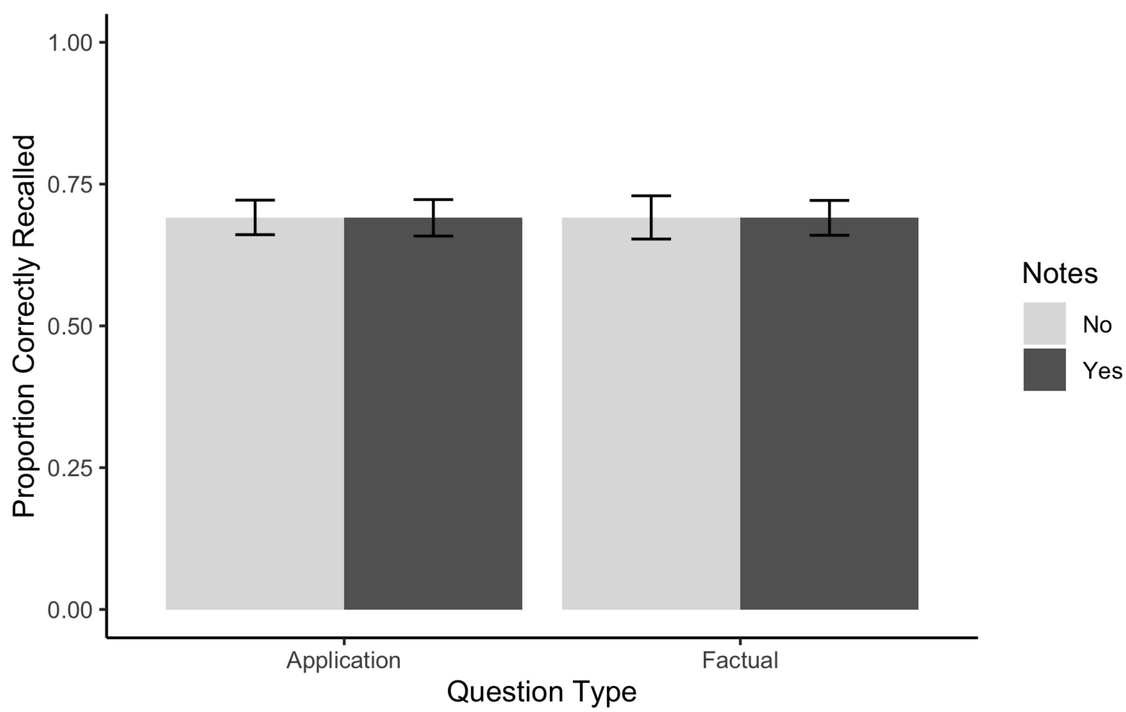
Note. Lecture B proportion correct values collapsed across participants in Experiment 2. Error bars represent ±*SEM*.

Lecture B Performance. The proportion of correct values was calculated for each participant separately for the recall and application style questions (Figure 10). These values were submitted to a 2 x 2 x 2 mixed factor ANOVA that treated the "notes" condition (no notes vs. notes for Lecture A) and lecture experienced first (Lecture Topic 1 first/Lecture Topic 2 first) as between-participants factors and question type (factual/application) as within-participants.

There were no effects of notes condition or question type, all *p*s>.2. However, there was a trend toward a main effect of which lecture topic was experienced first, $F(1,57)=2.86$, $p=.096$, $\eta_p^2=.048$, with better Lecture B performance for those participants who experienced topic 1 (Social Anxiety) first (M=.735, SD=.12; M=.676, SD=.13 for topic 2: Goal Setting first), meaning that performance was better when Lecture B was topic 2.

Figure 11

Experiment 2 Lecture A Proportion Correctly Recalled Words: Notes versus Question Type



Note. Lecture A proportion of correct values collapsed across participants in Experiment 2. Error bars represent ±*SEM*.

Lecture A Performance. Lecture A proportion correct values were treated the same as Lecture B values (Figure 11). There were no effects of notes condition or question type, all *p*s>.3. However, there was a main effect of which lecture was experienced first, $F(1,57)=5.92$, $p=.018$, $\eta_p^2=.094$, with better Lecture A performance for those participants who experienced topic 2 (Goal Setting) first (M=.731, SD=.13; M=.652, SD=.13 for topic 1 first), meaning that performance was better when Lecture A was topic 2.

Mini-Discussion of Experiment 2. In Experiments 1A and 1B, the effects of saving information during the first round of studying (i.e., List A) led to better performance on the second round of study materials (i.e., List B). When participants typed the information in the first round and saved it, the more information they had, the better their performance for the first round. When they did not save the typed notes and had ample time at study, the number of words they typed did not affect their round one performance, but under a time crunch at study, the more words they typed, the worse they performed.

Experiment 2 expanded this question to examine lecture-style materials and explored any benefits of typing and saving one's notes for later study, versus not taking notes and having no available material to restudy, especially when a second lecture was involved. From this initial study, we see no benefits for Lecture B when more information is offloaded during Lecture A. However, there are many elements to consider when taking an applied cognitive approach into the lab, with materials and procedures that try to mimic a “real-lecture” environment.

In our “save” condition, only those who took notes were able to review Lecture A content; those who just watched Lecture A were not given a complete set of notes for later study. Following Experiment 1A and 1B’s design, a future study should have a “save” and “no save” condition for both having just watched or taken notes for Lecture A. This comparison would parallel Experiment 1A and 1B’s procedure, in which those who read List A received the full list of words at study, as well as those who took notes/typed. This manipulation will further check if the quality/quantity of notes positively predicts performance, and if reviewing an educator’s notes yields similar benefits to taking one’s own notes (Fisher & Harris, 1973). Furthermore, the “save” and “no save” conditions should be applied to the typing condition: participants who typed their notes would be randomly assigned to restudying their notes later, versus not having a chance to see them again.

In Experiment 2, we see the same pattern of no effect of reading (in this case watching Lecture A) versus typing. However, because those who only passively watched the lecture did not get a “save” condition, we cannot examine the effect of offloading via saving for passive reading as was done in Experiments 1A and 1B. Experiment 2 also had one block of to-be-remembered information (due to the time-consuming nature of classroom lecture materials), and no within-participant condition of saving condition, further reducing the power of detecting cognitive offloading benefits.

Because Experiment 2 encouraged more complex note-taking than writing down verbatim words, mere word quantity in the notes cannot be used as a predictor for individual differences. Anecdotally, by looking at the participant's notes, the notes varied between some participants writing point-form phrases, to some participants writing semi-structured sentences (please see Appendix B for some sample notes for both topics). In future studies, a robust algorithm for analyzing notes would be needed to explore individual differences in note-taking abilities, and their relation to lecture comprehension (see these papers for an example of note-taking analysis: Bui et al., 2013; Flanigan & Titsworth, 2020; Peverly et al., 2007). For future research, either testing this paradigm in a real classroom where the intrinsic motivation to do well is high or introducing short answer recall questions (as opposed to the recognition-based multiple choice testing) and delayed testing, could prove successful at identifying differences in offloading when taking notes and subsequently studying them.

General Discussion

The current research aimed to explore factors related to the saving-enhanced memory effect seen in Storm and Stone (2015). By creating a more efficient paradigm that eliminated the need for external drives, we introduced manipulations to the study conditions, such as active typing.

Experiment 1A demonstrated Storm and Stone's (2015) effects of the "save" condition. When participants were allowed to save the first list of words they had to study (List A), before they studied the second list (List B), they recalled more words from the second list (List B). Looking at the List B results, there was no effect of typing condition. Whether participants studied List A by passively reading or typing it, their performance was similar for List B. While Storm and Stone (2015) did not focus their discussion on List A recall results, we were very interested in the learning outcomes for the first list of words. Unsurprisingly, when List A was saved (and subsequently restudied before the test), performance was much higher than in the "no save" condition.

Overall, while typing did not drive an offloading effect for List B, the individual differences in the quantity of the List A "notes" affected List A recall performance. The more accurate the record when given a chance to study, the better the participants performed. When participants did not study their typed List A notes, the number of words typed did not make a difference in their performance. This could suggest that in the time given to type List A, the action of typing the words did not lead to an increase in offloading than when participants read the words.

For the overall List A performance, the “read” condition did lead to an increase in performance compared to the “type” condition. Given the amount of time to study the lists (40s), participants in the “read” condition anecdotally reported going over the list multiple times, while those who typed the list reported more of a focus on typing the list and not re-reading the list until the time ran out.

For Experiment 1B, we decided to amend our methodology by making two main changes: provide participants with two practice blocks for them to experience the “save” and “no save” conditions, and only allow 20s for studying the lists. Through our experience and anecdotal evidence from our participants, 40s was a long time to study 8 words. We wanted to provide participants enough time to complete their assigned conditions, while reducing their option to “choose their own adventure” (i.e., even typing condition participants had a chance to read the words over multiple times), so to speak, when faced with too much time within a trial. Unnecessary trial time can introduce extra noise and variability, such as some participants reading over the lists multiple times, some only reading it once, while those who type having the choice of both typing and reading the list in the remaining time.

Although we were interested in seeing if typing promoted increased offloading of List A (regardless of the “save” or “no save” conditions), we did not find an effect of typing condition for List B. We also learned from Experiment 1B that while having a record of information is important, it only makes a positive difference when people are allowed to review the said record. A time crunch benefitted overall offloading, but it was not beneficial when trying to engage in note-taking and recalling information short-term. With a shorter study time, typing more words could have allowed for more offloading and, thus, lower memory for List A words, although not enough to identify an effect outside of the individual differences and to influence List B results.

We also infer from Experiment 1B that participants are likely monitoring cues of reliable offloading, such as how many words they typed. If they only managed to type a few words, even when given the opportunity to save the list, they might not benefit from the 'assurance' of offloading, since they have not fully offloaded the list. These participants would be prone to more interference (thus lowering List B performance), and might perform better on List A than those who typed more words (as seen in our Experiment 1B results). Writing down information is an externalization or extension of our cognition, but it might only be considered offloading, or mental delegation to an external memory source, when we have the opportunity and intention to access that source. Taking notes without looking back at their record could be a form of cognitive offloading, but not the type of offloading that would reduce proactive interference. The definitions and conceptualizations for offloading versus externalizing information merit further conversation within the literature on educational applications.

Experiment 2 examined whether participants would be swayed to offload information and perform better on a second lecture when given the chance to take notes on a first lecture, compared to participants who just watched the first lecture. From this initial study, we did not see any differences in quiz performance between those who just watched the lecture versus typed notes during the lecture (and later studied their notes). The inconsistent effect of cognitive offloading on performance, when content is similar to the classroom and tested in a lab environment, requires a closer look. We encourage future studies to consider a few factors in their investigation of cognitive offloading “in the classroom”. We would like to see a future study with a “save” and “no save” condition for both watching and typing for Lecture A. This manipulation will further check if the quality/quantity of notes positively predicts performance. Furthermore, the “save” and “no save” conditions should be applied to the typing condition: participants who typed their notes would be randomly assigned to restudying their notes later, versus not having a chance to see their notes again. Since we seldom get tested on later-presented material before being tested on earlier-presented content, future research could have participants study and get tested on List A/Lecture A, before studying and being tested on List B/Lecture B, both in a save/no save scenario, similar to the format of practicing retrieval while studying (Szpunar et al., 2008).

The research conducted here further validates the importance of offloading in proactive interference, while also looking at individual differences in external records of cognitive offloading, such as writing down notes. More broadly, the current research has interesting implications for the ecological validity of offloading research on short-term encoding and note-taking. For future research, either testing this paradigm in a real classroom, where the intrinsic motivation to perform well is high, or testing recall versus pure recognition, both with short-term and delayed testing, would help our goal: identifying the offloading benefits of taking notes, for guiding the creation of valuable instructional blueprints for both students and educators.

References

Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior research methods, 41*(4), 977–990. https://doi.org/10.3758/brm.41.4.977

Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, *105*(2), 299–309. https://doi.org/10.1037/a0030367

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning With Effective Learning Techniques: Promising Directions From Cognitive and Educational Psychology. *Psychological Science in the Public Interest*, *14*(1), 4–58. https://doi.org/10.1177/1529100612453266

Eskritt, M., & Ma, S. (2014). Intentional forgetting: Note-taking as a naturalistic example. *Memory & Cognition*, *42*(2), 237–246. https://doi.org/10.3758/s13421-013-0362-1

Fisher, J. L., & Harris, M. B. (1973). Effect of note taking and review on recall. *Journal of Educational Psychology*, *65*(3), 321–325. https://doi.org/10.1037/h0035640

Flanigan, A. E., & Titsworth, S. (2020). The impact of digital distraction on lecture note taking and student learning. *Instructional Science*, *48*(5), 495–524. https://doi.org/10.1007/s11251-020-09517-2

Gaspelin, N., Ruthruff, E., & Pashler, H. (2013). Divided attention: An undesirable difficulty in memory retention. *Memory & Cognition*, *41*(7), 978–988. https://doi.org/10.3758/s13421-013-0326-5

Hegarty, M., & Steinhoff, K. (1997). Individual differences in use of diagrams as external memory in mechanical reasoning. *Learning and Individual Differences*, *9*(1), 19–42. https://doi.org/10.1016/S1041-6080(97)90018-2

Helfand, D. (2016). Mucking About in the Mess: Research-based Education at Quest University Canada. *Council on Undergraduate Research Quarterly.,* *36*(3), 28–33. https://doi.org/10.18833/curq/36/3/4

Henkel, L. A. (2014). Point-and-Shoot Memories: The Influence of Taking Photos on Memory for a Museum Tour. *Psychological Science*, *25*(2), 396–402. https://doi.org/10.1177/0956797613504438

Kiewra, K. A. (1989). A review of note-taking: The encoding-storage paradigm and beyond. *Educational Psychology Review*, *1*(2), 147–172. https://doi.org/10.1007/BF01326640

MacLeod, C. M. (1998). Directed forgetting. In J. M. Golding & C. M. MacLeod (Eds.), Intentional forgetting: Interdisciplinary approaches (pp. 1–57). Lawrence Erlbaum Associates Publishers.

Muñoz, B., Magliano, J. P., Sheridan, R., & McNamara, D. S. (2006). Typing versus thinking aloud when reading: Implications for computer-based assessment and training tools. *Behavior Research Methods*, *38*(2), 211–217. https://doi.org/10.3758/BF03192771

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

Peverly, S. T., & Wolf, A. D. (2019). Note-taking. In J. Dunlosky & K. A. Rawson (Eds.), The Cambridge handbook of cognition and education (pp. 320–355). Cambridge University Press. https://doi.org/10.1017/9781108235631.014

Posnansky, C. J. (1976). Directed forgetting among third and seventh graders. *Contemporary Educational Psychology*, *1*(3), 247–256. https://doi.org/10.1016/0361-476X(76)90031-X

Risko, E. F., & Gilbert, S. J. (2016). Cognitive Offloading. *Trends in 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

Shaffer, L. H., & Hardwick, J. (1969). Reading and Typing. *Quarterly Journal of Experimental Psychology*, *21*(4), 381–383. https://doi.org/10.1080/14640746908400233

Sparrow, B., Liu, J., & Wegner, D. M. (2011). Google Effects on Memory: Cognitive Consequences of Having Information at Our Fingertips. *Science*, *333*(6043), 776–778. https://doi.org/10.1126/science.1207745

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

Szpunar, K. K., McDermott, K. B., & Roediger, H. L. (2008). Testing during study insulates against the buildup of proactive interference. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(6), 1392–1399. https://doi.org/10.1037/a0013082

Appendix A

Sample Quiz Questions

Topic 1: Social Anxiety

Factual Questions

Q: How would you describe a person who experiences shyness?

A. Inhibited in front of others, not social, awkward, quiet.
B. Socially awkward, trouble with eye contact, inhibited in front of others.*
C. Trouble with eye contact, needs help with conveying emotions, quiet.
D. Quiet, inhibited in front of others, not tense in front of strangers.

Q: How would you describe sociability?

A. One with the desire to want to spend time with other people, but to work individually.
B. One with the unwillingness to spend time with other people, and prefers to work individually.
C. One with the desire to want to spend time with other people, and work in groups.*
D. One with the unwillingness to spend time with other people, but prefers to work in groups.

Application Questions

Q: Which of the following circumstances is an example of social anxiety?

A. Barry does not like to race anymore because he is afraid of losing.

B. Allen finds is difficult to find a date because he feels he is not good enough.

C. Bruce has difficulty meeting new people because he feels like they will not like him*

D. Wayne does not go the gym anymore because he is afraid he will injure himself again.

Q: Why would you expect Cynthia, an individual who is a high shy, high sociable personality, to be more prone to social anxiety than Mark, who is an individual with a low shy, high sociable personality.

A. Cynthia and Mark both want to make new friends, but only Cynthia will find it highly daunting to make friends.*

B. Cynthia and Mark both do not want to make friends, and Cynthia will stay away from any social situation, unlike Mark.

C. Cynthia wants to find new friends, and finds it really daunting to be in social situations, while Mark, who doesn't care for making new friends, does not find it difficult to be in social situations if placed in them.

D. Cynthia does not want to make new friends, and completely avoids social situations, while Mark loves to make new friends and does not find it daunting to be in social situations.

Topic 2: Goal Setting

Factual Questions

Q: Which of the following are two main factors when setting goals?

A. The relevancy of the goal and the content of the goal.
B. How realistic the goal is, and how difficult the goal may be to achieve.
C. How specific the goal is, and how challenging it may be to achieve.*
D. The content of the goal, and how realistic it may be to achieve.

Q: In the wood harvesting study, what did the people in the quota group represent?

A. A difficult goal.
B. A specific goal.*
C. Collecting a specific amount of wood.
D. Doing your best.

Application Questions

Q: You want to be a better long distance runner. Which is the better goal to set: A) “Improve your 5km running time” or B) “Beat your previous record by 5 mins, by the end of the week”?

A. Goal B is better because it is more challenging.
B. Goal B is better because it is more specific and challenging.*
C. Goal A is better, it is as challenging, with less pressure on yourself.
D. Goal A is better because it is less difficult to achieve.

Q: Joe wants to become a doctor. What is NOT a good example of a goal he can set in order to achieve this goal?

A. Finish University with a 4.0 GPA.

B. Be a part of at least 6 extracurricular activities before graduating University.

C. Volunteer twice a week at a hospital.

D. Be involved in athletic activities or sports teams.*

Appendix B

Sample Typed Notes

Lecture A: Topic 1 (Social Anxiety)

"Social Anxiety

- meeting new people

- public speaking

Socially awkward

- tense, avoid eye contact

Sociable

- desire talking with others and interactions

High shy people exhibit most social anxiety

They touch hair, face and do not maintain eye contact

EEG highly fashionable, measure brain waves

Frontal Lobe responsible for emotions we feel

Left frontal lobe; joyful, happy (approach)

Right frontal lobe; fear, sadness (withdrawal)

Those who are low shy and low social

Have low activity overall, do not have desire to engage

Those who are high shy and high social

Have high activity overall, want to both approach and withdraw"

——

Social Anxiety is the anxiety of Meeting new people, public talking

Individual differences – personality factors

Shiness – socially awkward – feel tense, eye contact awkward

Social – work in groups, enjoy talking to others

Can be a mix of any

High shy /high social group – more likely to have social anxiety

Want to be in group but feel uncomfortable in groups

Experiment paired people with same social scores

Group of high shy/social – experienced signs of touching face, avoiding eye contact

How might SA appear /map on brain

Studies – EEG – Frontal lobe – emotions

Left -happiness anger – cause you to approach people

Right – fear sadness, aversion – withdrawl

Brain activity – unique patterns

Low shy, high social – high withdrawl

High s low social – active on right

Low/low – low activity overall

h/h – high on both hemispheres

conflict in personalities and physiologies cause social anxiety simply an emotion in the end - we are still in control, emotions do not control us, we

are able to control.

____

- Social anxiety

Why do we experience social anxiety?

- Shyness, personality (orthogonal factors – unrelated to each other)

o Can be both shy and have social anxiety

- shy and socialable spend less time talking, and give less eye contact (they tend to touch their hair…)

- frontal lobe is responsible for emotions

o L = approach

o R = withdraw (fear, sadness)

Top = high social

Bottom = low social

Left = low shy

Right = high shy

- conflict leads to social anxiety

Lecture A: Topic 2 (Goal Setting)

Presentation 1 (Goals):

Goal setting: source of motivation

A goal is what we strive to achieve (aim of actions)

o Content (specificity, difficulty)-challenging and specific goals lead to success

o Your goals should reflect you (what you want and can complete)

———

Misconceptions about goal setting

- just do it video, why is it so popular?
- It gives us a goal, to just do it
- Goal setting- gives us a goal to motivate ourselves
- How do we properly set a goal?
- A goal is what we strive to achieve it is the aim of our actions, the content is what that goal actually is, 2 main: specificity and difficulty
- Challenging goals leads to success
- Female typists performed better when given a goal
- The more challenging our goals are, the better our chances of succeeding
- Making a goal specific, specific direction, increases chances of success
- If we aren't specific we can get a failure instead of success. Do not say "just do your best" because what is our best?

- If a runner wanted to improve their running skills they should give themselves a goal as to how much they want to run
- Amount of wood collected by wood harvesting groups: one group was given a quota the other one did not. The ones that were given a quota harvested much more wood
- Goals should reflect you, only you know what goals are difficult for you, what goals are manageable to motivate you

____

MISCONCEPTIONS OF GOAL SETTING

“Just do it isn’t enough”

Gives us a goal – Just do it

Goal setting is a source of motivation

Goal =/ success

A goal is what we strive to achieve

Two main components of content:

Specificity

Difficulty

Challenging goals lead to success

Specific goals lead to success

DON’T “do your best”; Your goal should reflect you

CHAPTER 3

TO TYPE OR NOT TO TYPE: THE EFFECTS OF NOTE-TAKING MODALITY ON LECTURE COMPREHENSION

Irina Ghilic and David I. Shore

Abstract

Background: Note-taking is ubiquitous in higher education (and everyday life). *How* we take notes in an educational setting can influence the amount of information we learn. Some note-taking literature has debated the advantages of handwriting notes, while other studies showcase the benefits of typing information, especially from an accessibility perspective. In this paper, we explore a variety of note-taking parameters in our comparison of two main note-taking modalities: handwriting and typing. This research explores the effect of various note-taking factors on lecture comprehension.

Method: We measured two main variables throughout our 5 studies: note-taking modality (handwrite/type; between-participants), type of test question (factual/application), and their overall effects on lecture comprehension. Throughout the experiments, we varied other potentially modulating variables, such as note-taking instruction (summarize/transcribe), lecture slides (redundant text/complementary images), and content context (pre-lecture/post-lecture reading).

Results: Our two earlier experiments showed a marginally significant learning advantage to taking notes by hand, but only for application-type questions. We did not find that advantage in 3 out of our 5 studies, nor any other interactions between the tested variables.

Conclusions: Note-taking is a complex process that needs further investigation before researchers can make concrete recommendations to educational designers/developers. Note-taking modality on its own does not seem to be an influential factor in lecture comprehension. Instead, as researchers and educators, our future focus is exploring *how* students can improve their note-taking habits, and how to promote accessible note-taking in education.

Keywords: Note-taking, handwriting, typing, lecture parameters, test parameters, factual questions, application questions.

Introduction

Students and instructors believe note-taking benefits learning. Students use notes as study materials, to organize lecture content, and to enhance their exam performance (Dunkel & Davy, 1989). Over 95% of North American students take notes during class (Dunkel & Davy, 1989; Palmatier & Bennett, 1974), and 46% of students take notes on a laptop (Morehead et al., 2019). Although students report that note-taking sometimes interferes with their immediate understanding of the lecture (Dunkel & Davy, 1989), they also believe note-taking is important (Morehead et al., 2019) and that professors expect them to take notes during their lectures (Landrum, 2010). The current paper explores the topic of note-taking by asking the question: do different note-taking modalities modulate information encoding?

1. Note-Taking Theories: Encoding versus External Storage

The benefits of note-taking can be explained via two hypotheses: encoding and external storage.

The encoding hypothesis refers to improvements in the learning and storage of information due to note-taking (Rickards & Friedman, 1978). In contrast to just listening to lecture content, taking notes helps organize lecture information visually, sustains attention, allows students to elaborate and make connections between topics, and encourages summaries and generation of information (Kiewra, 1989). Peper and Richard (1978) investigated *how much* information is recalled as a result of note-taking and *what* is recalled. Most note-taking lab studies tap into how much information is retained by looking at overall recall through multiple-choice or open-ended questions, making it a matter of volume instead of idea units. But what if there is a difference between those who listen and those who take notes during lectures on the amount of *key information* they retain?

Generally, when students are asked to identify key/main points from a lecture, there are large differences between key points identified by students and those identified by teachers (Schellings & Hout-Wolters, 1995). However, Peper and Richard (1978) were interested in whether those who took notes encoded and retained a higher number of key ideas than those who just listened to the lecture and if note-takers could apply learned information to a broader context. Although overall scores between listeners and note-takers were not significantly different, various question types uncovered a different pattern of performance: participants who did not take notes performed better on near-transfer questions (i.e., on knowledge of content that was similar to the lecture), while participants who took notes performed better on far-transfer questions (i.e., on knowledge of content applied in a novel situation). While the benefits of note-taking on information encoding have been shown in the literature (Kiewra, 1989; Di Vesta & Gray, 1972; Peper & Mayer, 1978), to better understand the real-world impacts of note-taking we must also consider the influence of being able to review those notes (Fisher & Harris, 1973).

The external storage hypothesis refers to the benefits of reviewing notes (Rickards & Friedman, 1978). Students rarely study or review their notes within one lecture session unless they get time to review the information before an end-of-class quiz. Instead, we typically take notes for future reference—for example, meeting minutes, grocery lists, and lecture notes. To parse the benefits of notes as external storage of information, laboratory studies have compared the performance of participants who were allowed to review their notes and those who were not (Einstein et al., 1985). A meta-analysis comparing reviewed vs. not reviewed notes showcased increased learning effects when participants were allowed to review their notes (Kobayashi, 2006).

In an educational setting, students often review their notes when they study and prepare for a test (Dunkel & Davy, 1989). The process of studying involves goal-setting and information synthesis, which often include observable traces on the notes themselves, such as notebook markings or highlighting of text (Boekaerts et al., 1999). To achieve set study goals, students need good study materials. Because students review class notes as the main source of lecture information (Dunkel & Davy, 1989), it logically follows that the quality of their notes is essential to achieving successful learning outcomes.

2. The Effects of Note-Taking Quality on Encoding and External Storage

The quality of notes affects the encoding and reviewing of externally stored information (Einstein, Morris, & Smith, 1985; Peper & Richard, 1978). High-quality notes facilitate a broader connection between prior knowledge and current information; they provide a scaffold for encoding new information and promote an organizational structure for the to-be-remembered idea units. However, not all note-takers produce the quality of notes required to obtain this benefit. A host of differences affect note quality between note-takers, including differences in lecture style, lecture pace, a learner's background knowledge, and personal characteristics. Importantly, these differences affect how students choose to structure notes and consequently, the quality of their notes (Peverly et al., 2007, 2013, 2014; Peverly & Sumowski, 2012; Reddington et al., 2015).

Most test errors arise from inadequately reviewing accurate and complete lecture notes compared to failure to accurately record the material (Palkovitz & Lore, 1980). Similarly, students perform better on tests when instructors provide them with well-organized notes to review if they initially just listened to the lecture and did not take notes, compared to students who took rather brief or unorganized notes during the lecture. These findings accentuate the benefit of having a comprehensive external record of information rather than the process of personally recording them (Kiewra, 1985).

3. Impact of Note Structure on Note Quality: Summarizing versus Transcribing Notes

Notes can have two overarching structures: summarized or transcribed. Put simply, note-takers can choose to either write information in their own words or write down what the speaker is saying. The note-taker summarizes the message when the verbal message is written in the note-taker's voice, either through paraphrasing or condensing the information into keywords and newly generated idea units. When people summarize information in their notes, they write, on average, fewer words than the number of spoken words (Kiewra, 1987; Summers & Catarro, 2003). Summarizing leads to longer listening pauses, and a balanced ratio of time spent listening versus time spent writing. Note-takers who write down word for word what the speaker is saying are transcribing the information, and, thus, spend more time writing than listening. Their notes also have a higher overlap of spoken versus written idea units, and a similar word count to the spoken word count (Morehead, Dunlosky, & Rawson, 2019). The structure in which the notes are written (either summarized or transcribed) has differential effects on learning, which may be explained by the levels of processing framework proposed by Craik and Lockhart (1972).

Levels of encoding and note structure. Craik and Lockhart (1972) proposed that information can be encoded at multiple levels; this was a novel perspective compared to the multi-store information processing model at the time. According to their framework, the level of encoding depends on how much "work" a person has to do at the encoding stage. Items encoded through the elaboration of a word's meaning (e.g., "does the word "duck" represent an animate object?") are encoded more deeply and thus learned better than items not processed for meaning, at a shallow level (e.g., "does the word "duck" rhyme with "buck"?").

Importantly, the different note-taking structures result in different levels of encoding, with the generative nature (i.e., an activity that requires the production or reproduction of information) of summarized notes facilitating deeper learning than rote transcription (Peper & Richard, 1986). When people summarize information via notes, they tend to generate that information, which leads to deeper processing and increased encoding. Transcription, on the other hand, leads to decreased encoding; transcription promotes shallow processing during note-taking (Bui et al., 2013). Those who transcribe do not form connections between the new material and their prior knowledge, and they do not engage in generating the information themselves. Transcription only requires the capacity to process the speaker's words in working memory, just long enough for those words to be written down (Aben et al., 2012; Baddeley & Hitch, 1974; Cowan et al., 2012). The pace of transcription is fast, consequently discouraging listeners from processing the information at a deep level. Furthermore, transcribing through handwriting is a challenging task, due to the difference between the speed of writing and the speed of speech, and it leads to a decreased encoding of information.

Note-taking modality and note structure. Various note-taking modalities facilitate either summarized or transcribed notes. Due to the slower speed of handwriting than typing notes (Bui et al., 2013), handwriting encourages summarizing and the generation of information to keep up with incoming information. The cognitive effort associated with summarizing and generation leads to a deeper level of processing than transcribing (Bjork et al., 2011; Bui et al., 2013; Peverly et al., 2013; Piolat et al., 2005). Handwriting notes is an intense cyclical event: students must listen to what the lecturer is saying, summarize that information while still listening, outline the subsequent idea units, and repeat the cycle.

Typed notes facilitate transcription and shallow information processing. When typing notes, it is easy to fall into a mechanistic pattern of note-taking (i.e., verbatim note-taking without processing the information presented), which has been associated with shallow-level processing (Fried, 2008; Kiewra, 1985; Mueller & Oppenheimer, 2014; Slotte & Lonka, 1999; Van Meter et al., 1994). However, some authors disagree with the notion that typed note-taking is disadvantageous (Bui et al., 2013, p. 201; Fried, 2008), and this argument requires us to think beyond the encoding hypothesis to the external storage hypothesis of reviewing our notes. Because students type faster than they can write by hand, it is argued that increased note quantity via typing can benefit students (Carter & Matro, 1975; Kiewra & Benton, 1988; Slotte & Lonka, 1999), in contrast to how handwriting benefits students via deeper encoding.

The effects of lecture style on note structure and modality. Students choose how to take notes on a lecture-by-lecture basis (Morehead, Dunlosky, Rawson, et al., 2019; Witherby & Tauber, 2019). Factors such as slide content, lecture pace, familiarity with the content, and subject matter are cited in the decision-making process about which note style to use (Van Meter, Yokoi, &

Pressley, 1994; Witherby & Tauber, 2019). Over the years, lectures have shifted from the ‘blackboard’ way of teaching to increasing the use of multiple technologies during lectures (such as PowerPoint slides and Audience Response Systems). Students have adapted to these new lecture parameters by changing the modality in which they take notes (Morehead, Dunlosky, Rawson, et al., 2019).

The literature on the *benefits* of adapting note-taking habits to suit each learning setting is inconclusive and merits further investigation in a real classroom setting (Morehead, Dunlosky, Rawson, et al., 2019; Peverly et al., 2003; Peverly & Sumowski, 2012; Witherby & Tauber, 2019). “Ubiquitous computing”, a term coined by Brown and Petitto (2003), describes the state of most university and college campuses: most students have laptops, and wifi is readily available. Due to the ease of carrying one piece of equipment, as opposed to multiple notebooks, and the speed at which a person can type, many students now prefer to take their notes on a laptop. Some studies, however, advise students against using laptops: handwriting, for all of its cognitive advantages mentioned above, helps students learn more information than when they type (Mueller & Oppenheimer, 2014). On the flip side? Laptops address accessibility concerns, such as individual differences in working memory capacity (Bui et al., 2013), and various learning exceptionalities (Boyle, 2010a, 2010b; Hughes & Suritsky, 1994; Oefinger & Peverly, 2020). Some studies have failed to find a difference in learning between handwriting and typing notes (Morehead, Dunlosky, & Rawson, 2019), while other studies even show an increase in learning when typing notes (Bui et al., 2013).

4. The Present Study: Handwritten versus Typed notes.

The evidence from multiple studies comparing handwritten and typed notes has been inconclusive: it is unclear if one format is better. Yet, there are calls to ban laptops in the classroom (Bahr, 2022; Fried, 2008; Magdolen, 2022; May, 2014). Before committing to handwritten notes as the best approach to learning, we require clear evidence. There is an indisputable need to replicate findings in psychology (Maxwell et al., 2015), and the note-taking literature field is no exception. Prior research in this area lacks a systematic exploration of cognitive factors that modulate the encoding of handwritten and typed notes within authentic classroom contexts. In our current studies, we focused our efforts on two main questions: (1) Do handwritten notes lead to better encoding than typed notes in online lecture modules? and (2) Do lecture parameters (such as familiarity with material and content delivery) or note-taking instruction (to summarize or transcribe) modulate the encoding of handwritten and typed notes?

Our research focused on investigating the “handwriting leads to better encoding” argument (Mueller & Oppenheimer, 2014) while extending the ecological validity of note-taking studies using real-classroom materials in a laboratory setting. We also explored any potential differences between note-taking modalities by looking beyond overall test scores and breaking down lecture comprehension into “factual” or “applied” knowledge of lecture content.

We focused on the encoding argument of note-taking due to our broader interest in applying research findings in educational settings and the impact the literature on this topic has had on the practical use of technology in the classroom.

Methods

For all the experiments, we used Introductory Psychology (Level 1) online lectures as the experiment's lecture content, and their duration ranged from 8 to 25 minutes. Since most of our university's first-year Science courses are delivered through a blended-learning approach (online, asynchronous content paired with in-person lecture components) (Sana et al., 2011), with multiple-choice tests as the main method of testing, we maintained the same format for all of the following studies, to increase the ecological validity of our studies. All experiments tested learning as a result of encoding information during the lecture. None of the participants reviewed or studied their notes since the main debate in the literature and in the popular media stems from the battle between handwritten and typed notes, and focuses on the encoding aspects of the two note-taking modalities.

EXPERIMENT 1

Rationale

The present study explored whether note-taking modality (handwritten or typed) affected information encoding within an online lecture format. Given our review of the note-taking literature, we expected that taking lecture notes by hand, compared to typing, would promote deeper information processing and subsequently improve test performance. If participants who handwrote notes do, in fact, achieve higher test scores, handwritten notes may be optimal for facilitating deep encoding even within an online lecture environment. In contrast, if typed notes result in higher test scores, the benefit of the ability to take more notes may override the cost of transcription and shallow-level processing. Additionally, the note-taking modality might not differentially impact comprehension in an online lecture format. It is possible that students can learn the same amount of information using either modality, in which case we would find no difference in comprehension scores.

Method

Participants. Participants were recruited through the undergraduate experiment participant pool at McMaster University. Methods were approved by the McMaster Research Ethics Board and all participants provided written consent. Participants were compensated with course credit for their participation. Data from 52 participants were collected (38 females, 13 males, and 1 unidentified). Their mean age was 17.7 years, with a standard deviation of 4.7. Each participant completed the experiment within an hour.

Apparatus. Participants viewed the module on a 70-inch projector screen. Participants who were in the typed condition (T) typed their notes on a 23.5-inch iMac Desktop using an individual Google Doc. Those who were in the handwritten condition (HW) used lined paper and a pen. The results were analyzed using IBM's SPSS and R.

Stimuli. The online lecture on hunger and satiety was taken from the Introductory Psychology course at McMaster University. The module was 12-minutes long. Upon completion, participants were given a post-lecture comprehension test containing 10 factual and 10 application-based multiple-choice questions.

Design and Procedure. This mixed-measures experiment had a between-participants manipulation of note-taking modality, in which participants were randomly assigned to a condition as they entered the experiment room and a within-participants condition of test question type. Participants in the T condition were seated in front of an iMac desktop computer, approximately 45 centimetres away from the screen. Participants in the HW condition sat at desks without a computer. All participants were seated in the same room during the experiment session regardless of their condition. Participants were run in groups of 10 or fewer (minimum of 2) where approximately half were assigned to the T condition and half to the HW condition. Participants were given typed instruction packages respective to their condition. The instruction packages included instructions for their condition, a signed consent form, a handedness questionnaire, and a demographic questionnaire (indicating age, sex, and visual acuity). Participants were instructed to take notes (according to their assigned condition) as they normally would in a lecture (i.e., take notes in preparation for a final test). After completing and signing the forms in the package, the module was played while participants took notes. Once the module and the note-taking were complete, participants in the T condition were asked to log off the computer, while those in the HW condition were asked to flip over their notes. Participants were immediately given a test comprising 10 factual and 10 application multiple choice questions, each correct answer worth 1 point out of a total of 20 maximum points. After the experiment, participants were given a structured debrief and awarded their credit.

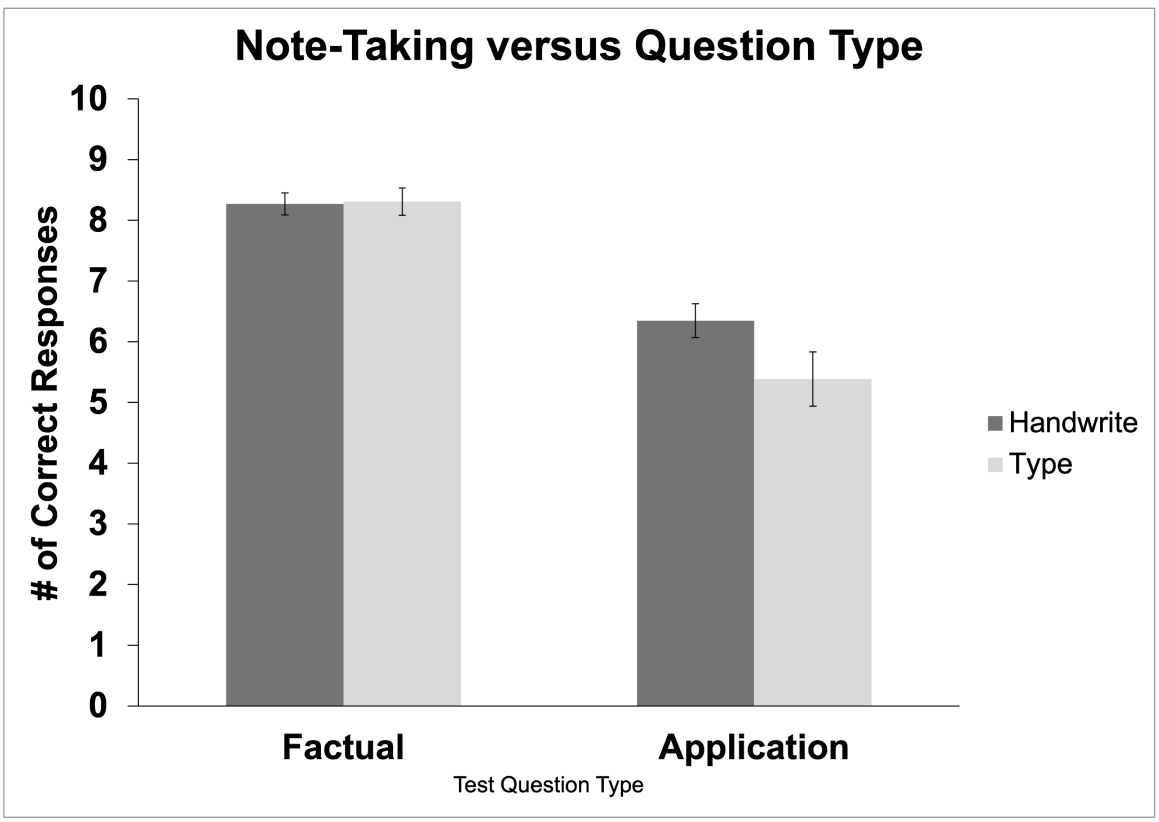
Results

Experiment 1 compared test performance between two groups, participants who either took notes by hand or by typing notes and the interaction effect of question type on lecture comprehension, using a mixed-measures ANOVA. The dependent measure consisted of 20 multiple-choice questions, split equally into factual and application questions (randomized when presented to participants).

There was a marginally significant interaction between question type and note-taking modality, $F(1,50)=4.03$, $p=.050$, $\eta_p^2=.074$, with a marginally significant simple main effect of note-taking modality at the application question type level, $F(1,50)=3.34$, $p=.074$, $\eta_p^2=.063$, but not at the factual question type level, $F(1,50)=0.018$, $p=.895$. The mean application questions score was marginally higher in handwritten than typed notes, with a mean difference of 0.962, $p=0.074$.

Figure 1

Experiment 1 Correct Responses for Note-Taking Modality versus Question Type



Note. The number of correctly answered questions collapsed across participants in Experiment 1. Error bars represent ±SEM.

Factual-type questions did not differentiate test performance between handwritten and typed notes, as illustrated in Figure 1. Participants who handwrote notes, however, were marginally better at answering application-type questions than those who typed.

Experiment 1 results add to the inconclusive nature of the note-taking literature while exploring this topic in an online lecture paradigm and from a level-of-encoding perspective. While there was a trend for handwritten notes to promote better learning of information at the time of encoding, the effect was marginally significant and only applicable to a particular type of question: application questions. This trend is interesting to consider, given that application questions test a deeper level of understanding and the ability to transfer lecture knowledge to a new context, compared to factual questions which test shallower rote recall, especially given how the literature couples handwriting as leading to deep encoding and typing promoting shallow encoding. This is a conversation akin to the studies investigating near- versus far-transfer question performance for listeners vs. note-takers, and our results trend in a parallel way: handwriting, which could promote summary and generation of information, leads to better performance on application (i.e., far-transfer of information) questions than typing. Given no overall differences between the note-taking modalities in factual questions (i.e., near-transfer of information), our typing condition almost acts like the listening condition in Peper and Richard's (1978) study.

Although handwriting notes could aid in encoding application-type information, differences in lecture comprehension between the two note-taking modalities were too small to make conclusive claims about the advantages of handwriting notes. Since participants could learn a similar amount of information using either modality, we would not advise educators to encourage students to take handwritten notes for their online lectures.

EXPERIMENTS 2A and 2B

Rationale

Experiments 2A and 2B explored whether giving participants instructions to summarize or transcribe their notes, while either typing or handwriting, affected information encoding in an 8-minute online lecture. We were specifically interested in examining the interaction between modality (typed/handwritten), structure (summarize/transcribe), and test question type (factual/application).

Students who take summarized notes outperform those who take verbatim notes (Slotte & Lonka, 1999), and we expect participants in the summarize condition to outperform those in the transcribe condition, regardless of note-taking modality. Given the slower pace of handwriting compared to typing, handwriting may lead to worse performance in the transcribe condition, as participants may be unable to take all necessary notes. It is also possible that the participants may encode information equally well using both note-taking modalities.

In addition to our manipulations of note modality and structure, we manipulated the retention interval across Experiment 2A (immediate) and Experiment 2B (delayed) to examine whether differences in learning across conditions (if any) apply to longer-term retention, and not just immediate testing.

Method

Participants. Participants were recruited in the same manner as in Experiment 1. In Experiment 2A, data from 80 participants were collected (57 females, 23 males). Their mean age was 18.4 years, with a standard deviation of 2.6. In Experiment 2B, data from 80 participants were collected (63 females, 17 males). Their mean age was 17.8 years, with a standard deviation of 5.2. Each participant completed the experiment within an hour.

Apparatus. The lecture, the distractor task, and the multiple choice test were shown on a 24-inch desktop monitor. Participants in the typed condition used Microsoft Word to type their notes on a 20-inch Mac laptop. Participants in the written condition wrote their notes using standard 8.5x11-inch lined paper.

Stimuli. The online lecture on Visual Memory was created and recorded in the style of the online Introductory Psychology lectures at McMaster University. Participants were given the 8-minute long online lecture on visual memory, followed by a working memory capacity distractor task. Upon completion, participants were given a post-lecture comprehension test containing 10 factual and 10 application-based multiple-choice questions.

Design and Procedure. This mixed-measures experiment contained two between-participants variables: participants were randomly assigned to a note-taking modality (handwritten or typed) and a note-taking instruction condition (summarize or transcribe) as they entered the experiment room. The within-participants condition was the test question type (factual or application).

Participants read and signed a consent form to proceed with the experiment. Participants then answered a questionnaire about past and current language or motor delays impeding their writing or typing. After the questionnaire, participants were instructed to take notes during an 8-minute Introductory Psychology-like online lecture given a certain note-taking modality (typed or handwritten) and note-taking instruction (summarized or transcribed). Participants were told the information from the lecture would be tested in the form of a multiple-choice test. Upon completion of the lecture, participants were given an automated operation span (OSPAN) task as a distractor task to test their working memory capacity (Unsworth et al., 2005). For the purpose of the current paper, we used the OSPAN task only as a more cognitively demanding distractor task, as opposed to using an algebra task. While we don't evaluate the results to include the OSPAN scores, we do investigate this individual difference factor in our future studies.

In experiment 2A, following the OSPAN task, a multiple-choice test (consisting of 10 factual and 10 application-based questions) was given to the participants. Once the test was successfully completed, participants were given a debrief form at the end of the experiment. In experiment 2B, we invited participants to leave after the OSPAN task. Those participants returned to the lab 24 hours later to complete the comprehension test.

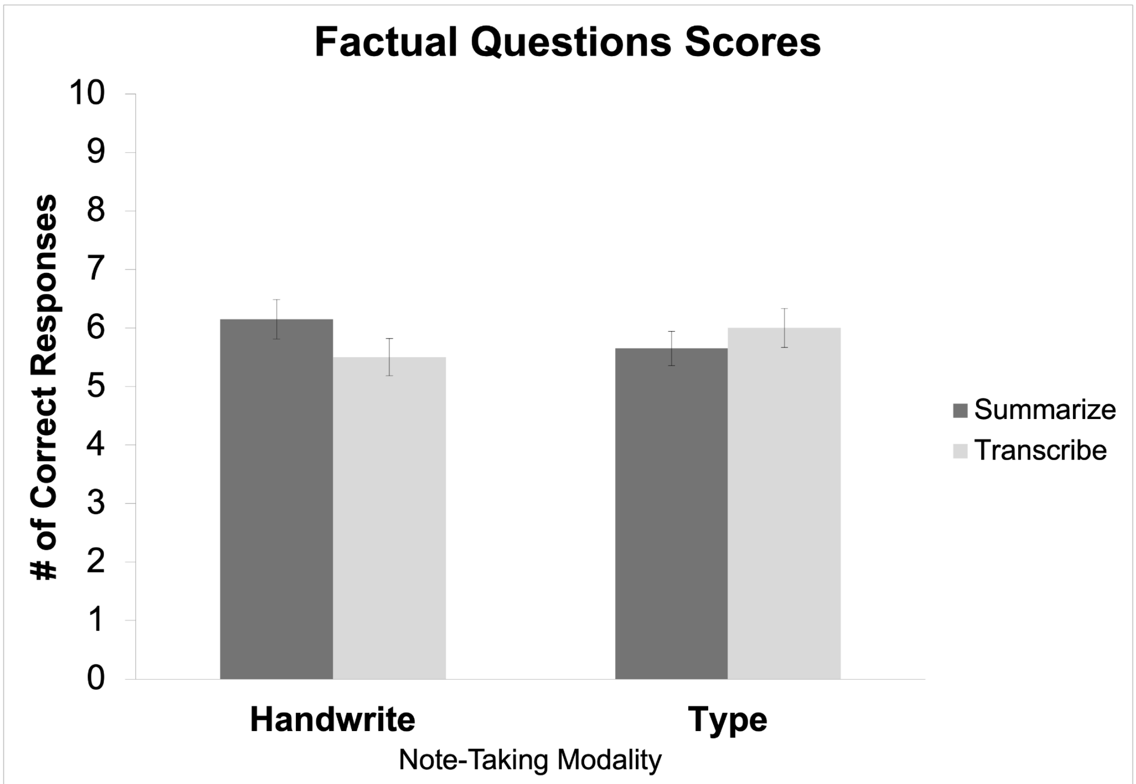
Results

Experiment 2A compared test performance between three independent variables, each with two levels: participants who either took notes by hand or by typing notes, instructions to summarize or transcribe the notes, and test question type. This 2x2x2 mixed measures design was analyzed using a three-way mixed ANOVA. The dependent measure consisted of 20 multiple-choice questions, split equally into factual and application questions (randomized when presented to participants). Factual multiple-choice question scores are shown in Figure 2, and application multiple-choice question scores are shown in Figure 3.

The three-way interaction between note modality, instruction, and type of question was not significant, $F(1,76)=0.37$, $p=.55$. There was a marginally significant two-way interaction between question type and note-taking modality, $F(1,76)=4.730$, $p=.058$. All other two-way interactions were not statistically significant ($p>.14$). There was a statistically significant simple main effect of note-taking modality at the application question type level, $F(1,76)=4.65$, $p=.034$, but not at the factual question type level, $F(1,76)=0.00$, $p=1.00$. All pairwise comparisons were performed for statistically significant simple main effects. The mean application questions score was higher in handwritten than typed notes, with a mean difference of 0.875, $p=0.034$.

Figure 2

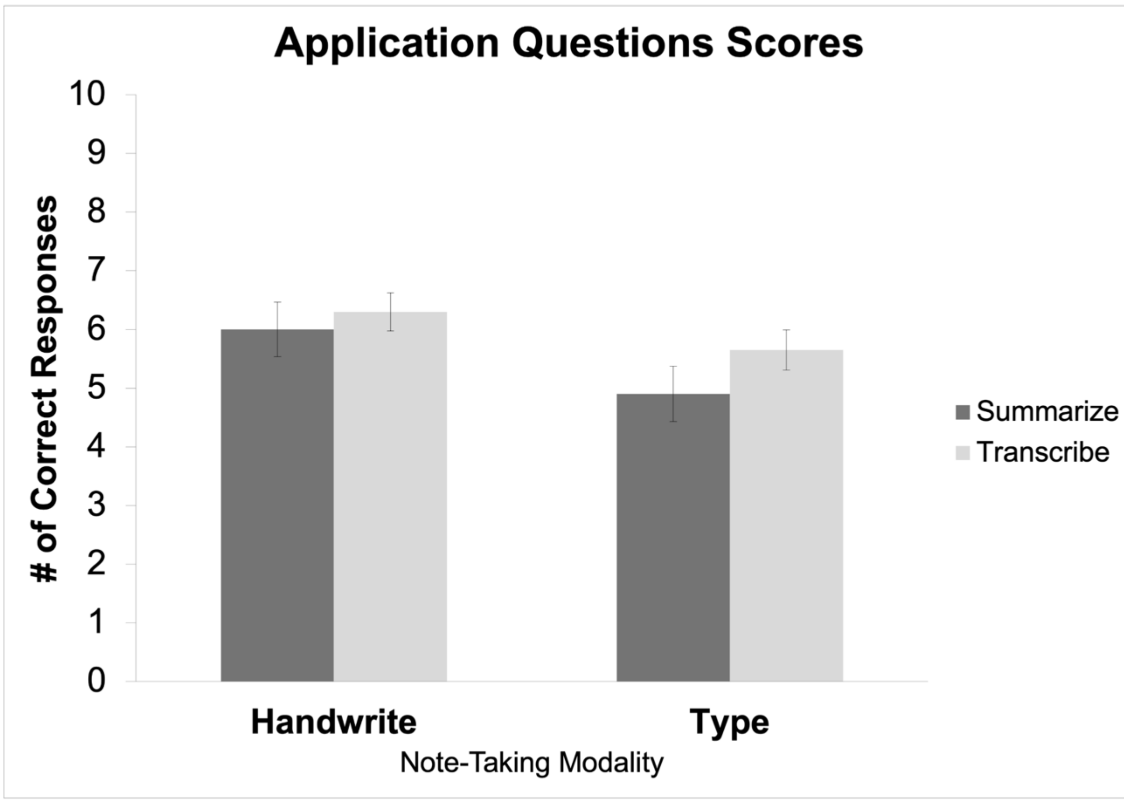
Experiment 2A Correct Factual Responses for Note Structure versus Note-Taking Modality



Note. The number of correctly answered factual questions collapsed across participants in Experiment 2A. Error bars represent ±SEM.

Figure 3

Experiment 2A Correct Application Responses for Note Structure versus Note-Taking Modality



Note. The number of correctly answered questions for application questions collapsed across participants in Experiment 2A. Error bars represent ±SEM.

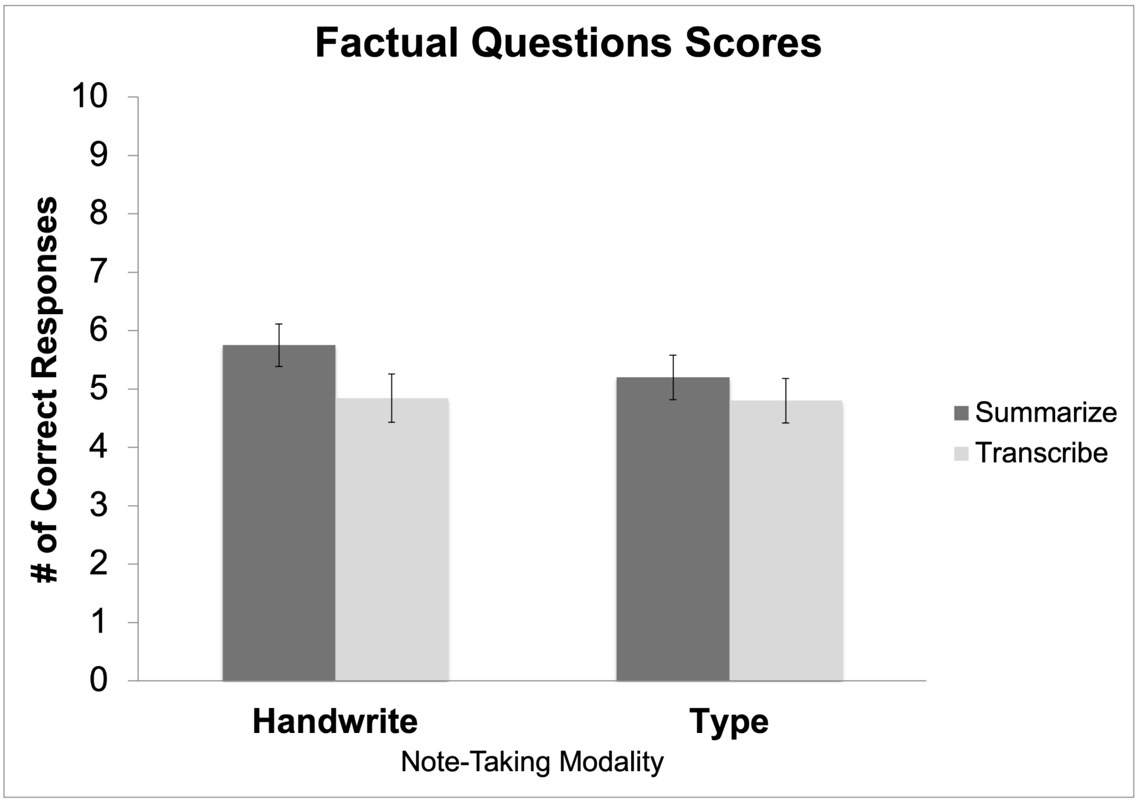
Like Experiment 1, participants who handwrote notes had significantly higher scores for application-type questions than those who typed, but there was no significant difference between the note-taking modalities and their assigned note-taking structure condition.

Experiment 2B's methodology was the same as Experiment 2B, except for one notable difference: the multiple-choice test occurred 24 hours post viewing the lecture. Factual multiple-choice question scores are shown in Figure 4 and application multiple-choice question scores are shown in Figure 5.

The three-way interaction between note modality, instruction, and type of question was not significant, $F(1,75)=0.35$, $p=.66$. There was a statistically significant two-way interaction between question type and note-taking structure, $F(1,75)=5.56$, $p=.021$. All other two-way interactions were not statistically significant ($p>.26$). There was a marginal simple main effect of note-taking structure at the factual question type level, $F(1,75)=2.89$, $p=.093$, but not at the application question type level, $F(1,75)=0.79$, $p=.38$. All pairwise comparisons were performed for statistically significant simple main effects. The mean factual questions score was marginally significant in summarized than transcribed notes, with a mean difference of 0.654, $p=0.093$.

Figure 4

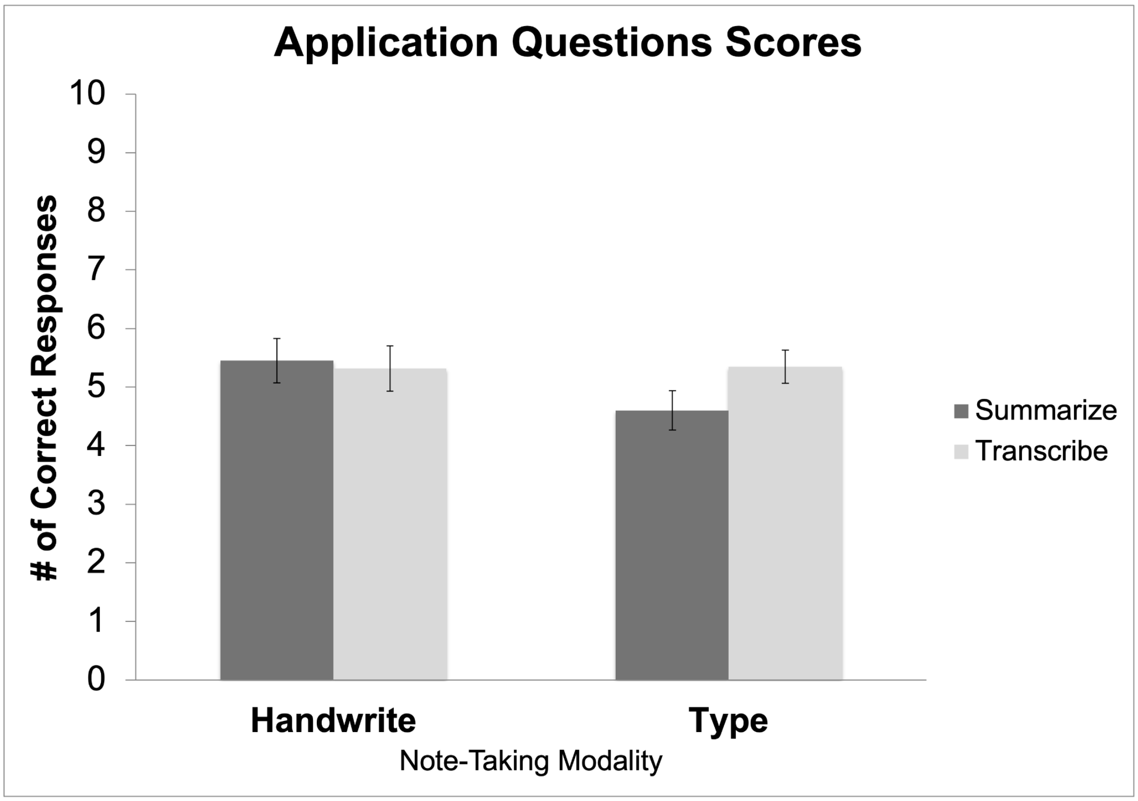
Experiment 2B Correct Factual Responses for Note Structure versus Note-Taking Modality



Note. The number of correctly answered factual questions collapsed across participants in Experiment 2B. Error bars represent ±SEM.

Figure 5

Experiment 2B Correct Application Responses for Note Structure versus Note-Taking Modality



Note. The number of correctly answered factual questions collapsed across participants in Experiment 2B. Error bars represent ±SEM.

Unlike Experiments 1 and 2A, the note-taking modality had no effect, not even marginal, on the type of question participants answered. Factual or application-type questions did not differentiate test performance between handwritten and typed notes, as illustrated in Figures 4 and 5.

Experiments 2A and 2B further confirm the inconclusive nature of the handwritten versus typed notes debate. While there was a trend for handwritten notes to promote better learning of information at the time of encoding, the effect only applied to a particular type of question: application questions. However, that effect disappeared once participants were tested 24 hours post-lecture. Instructing participants to summarize or transcribe their notes did not significantly affect their learning (only a marginal effect of factual questions on summarized notes on a delayed test). As an instructional check, we did a word count average of the typed notes: 170 words for the summarized condition and 337 words for the transcribe condition in Experiment 2A. Transcribers wrote almost double the number of words, although their test performance did not change. In experiment 2B, participants wrote on average 139 words for the summarized condition and 227 for the transcribe condition, similar to Experiment 2A (although lower on the transcribing side). Although the notes were not formally analyzed, the experimenters anecdotally noted how summarized notes, for both handwritten and typed notes, were not wholly comprised of generative type of statements. With technological advancements and the ubiquitous use of laptops/tablets, cohorts are shifting from a summarized, handwritten, shorthand-oriented note-taking style to a more transcription-based approach (Bui et al., 2014). While note-taking modality differences might have been prominent when students were just starting out to use laptops in the classroom (and potentially not adept at using them properly), current cohorts are not having the same issues and are just as experienced at taking notes via typing, as they are with handwriting (Morehead, Dunlosky, Rawson, et al., 2019; Witherby & Tauber, 2019). As we saw in Experiments 2A and 2B, students could learn a similar amount of information using both modalities, and instructions on how to structure their notes did not affect their learning.

EXPERIMENT 3

Rationale

In the previous studies, we explored whether lecture parameters modulate differences between note-taking modalities. Students report adapting their note-taking style to various lecture styles (Morehead, Dunlosky, & Rawson, 2019), so differences in note-taking modalities might arise when the learning conditions are varied. To keep the content consistent, we varied what type of multimedia information appeared on the lecture slides: text or images. We compared our main note-taking modalities and lecture styles by randomly assigning participants to either handwritten or typed conditions, in a redundant or complementary slide design. Participants were presented with an 8-minute module on visual memory, taken from the Introductory Psychology course at McMaster University. The content was kept stable; redundant slides had almost verbatim text on slides, and complementary slides had images and very little text that accompanied the audio recording (Fenesi et al., 2014), but the audio track was the same for all participants. Lecture parameters, such as the type of multimedia design, and note-taking could be interconnected, with the possibility of complementary lecture slides promoting summarized notes (typically seen in handwritten notes) and redundant lecture slides promoting transcription (typically seen in typed notes). Thus, we could expect to see an interaction between the note-taking modality and the lecture type. Based on previous research (Fenesi et al., 2014), lecture type has an overall effect on learning, with complementary slides promoting better learning of information for younger adults (while the opposite is true for older adults) (Fenesi et al., 2015). It is unclear, however, if the note-taking modality would be affected by the change in lecture slides.

Method

Participants. Data were collected from 80 individuals: 14 males and 66 females. Participants had a mean age of 18.6 years with a standard deviation of 0.82. This sample was drawn from an undergraduate experiment participant pool at McMaster University. The experiment was completed within 50 minutes, and participants received 1 credit at the end of the experiment.

Apparatus. Participants viewed their assigned lecture module on a 24-inch desktop monitor. Participants in the typed condition typed their notes into word-processing software on a 20-inch Mac laptop. Participants in the written condition wrote their notes on an 8.5 x 11-inch notepad. Results were analyzed using SPSS.

Stimuli. Participants were presented with an 8-minute long web lecture on visual memory, followed by a distractor task. A post-lecture test was given to assess the degree of lecture comprehension by using 10 factual and 10 application-based multiple-choice questions.

Design and Procedure. All participants were run individually. Participants first read and signed a consent form for the experiment. Participants then completed a questionnaire that inquired about hand dominance and any sensory and/or language impairments they currently have or have had in the past. Following this questionnaire, participants were administered their respective apparatus depending on their randomly assigned condition (typed or handwritten). The appropriate lecture module was launched depending on their randomly assigned condition (complementary or redundant slides). Participants were instructed to take notes as they would in a typical lecture, keeping in mind that they would be tested on the lecture content later in the experiment, without access to their notes. Upon completing the lecture module, students completed a distractor task. This distractor task was an operation span (OSPAN) task and measured the participant's working memory capacity (Unsworth et al., 2005). Once the OSPAN task was completed, participants completed a post-lecture multiple-choice test. This quiz consisted of 10 factual questions and 10 application questions. Upon completing the quiz, participants completed a questionnaire based on their in-class note-taking habits. Participants then received a debrief form.

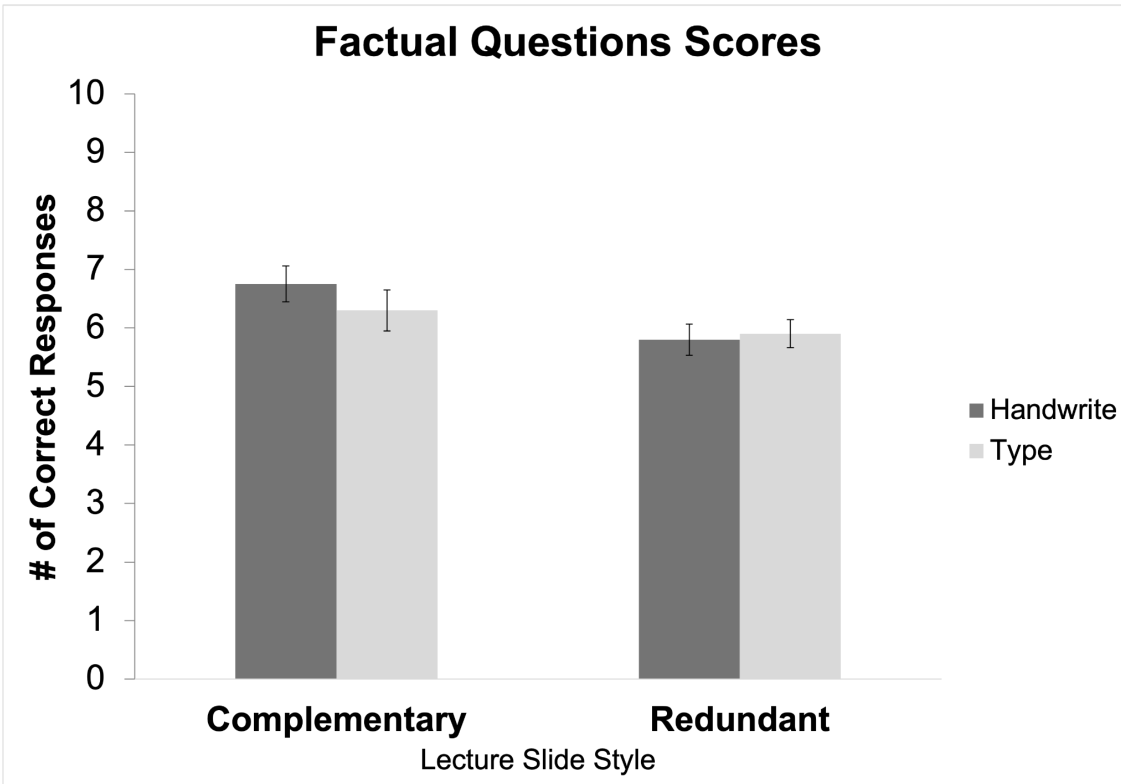
Results

Experiment 3 compared test performance between three independent variables, each with two levels: participants who either took notes by hand or by typing notes, redundant or complementary lecture slides, and test question type. This 2x2x2 mixed measures design was analyzed using a three-way mixed ANOVA. The dependent measure consisted of 20 multiple-choice questions, split equally into factual and application questions (randomized when presented to participants). Factual multiple-choice question scores are shown in Figure 6 and application multiple-choice question scores are shown in Figure 7.

The three-way interaction between note modality, lecture slide, and type of question was marginally significant, $F(1,76)=3.77$, $p=.056$, $\eta_p^2=.047$. There were no statistically significant simple two-way interactions of note-taking modality and lecture type at the factual question level, $F(1,76)=.88$, $p=.352$, nor at the application question level, $F(1,76)=1.66$, $p=.201$. Although there were no statistically significant simple two-way interactions, complementary slides led to a numerically higher performance (M=6.53, SD=1.47) when compared to redundant slides (M=5.85, SD=1.12).

Figure 6

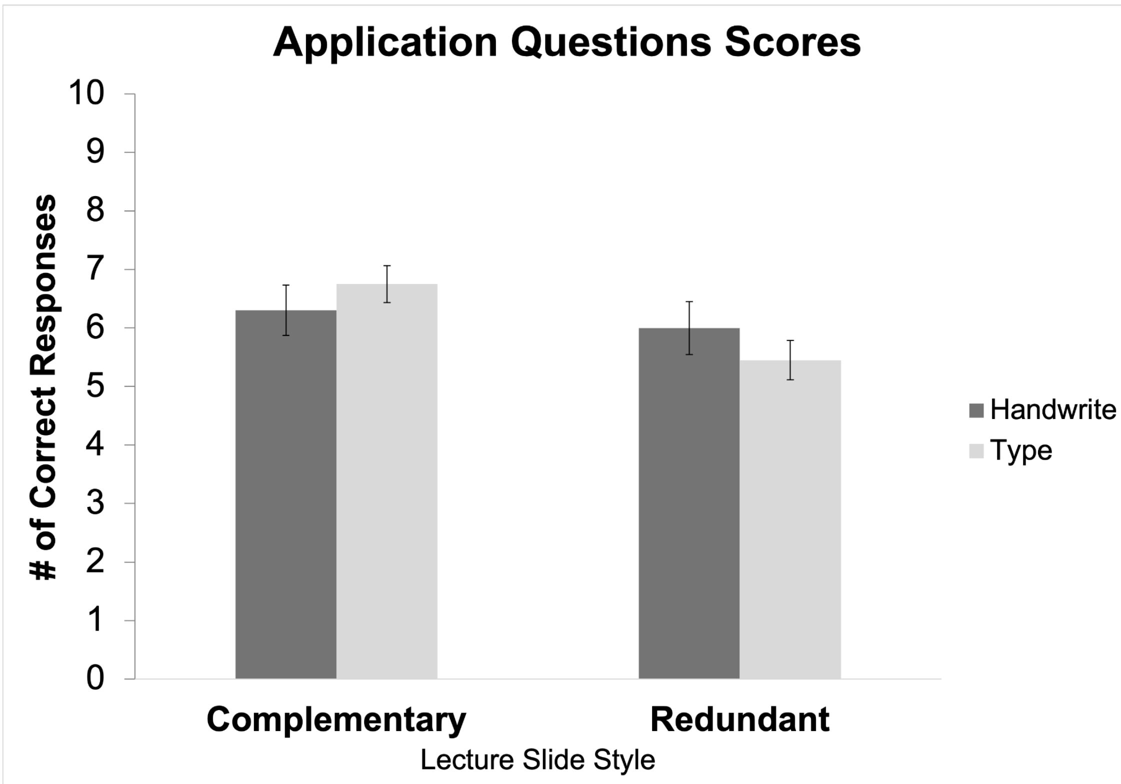
Experiment 3 Correct Factual Responses for Lecture Type versus Note-Taking Modality



Note. The number of correctly answered factual questions collapsed across participants in Experiment 3. Error bars represent ±SEM.

Figure 7

Experiment 3 Correct Application Responses for Lecture Type versus Note-Taking Modality



Note. The number of correctly answered application questions collapsed across participants in Experiment 3. Error bars represent ±SEM.

Unlike Experiments 1 and 2A, and like Experiment 2B, the note-taking modality had no effect on the type of question results. Factual and application-type questions did not differentiate test performance between handwritten and typed notes, as illustrated in Figures 6 and 7.

Experiment 3 found no significant differences between those who typed or handwrote their notes, even when the lecture parameters were manipulated. There was no marginal effect on application-type questions, even when the testing was immediate. We hypothesize this to be a cohort effect. While the first few studies were conducted in 2014-2015, Experiment 3 was completed in 2016-2017. Even though our conclusions are speculatory in nature, the results are clear: students were able to learn the same amount of information using both modalities, regardless of differences in lecture parameters and test question type. Although our interactions were not significant, lecture type did lead to significant results at both factual and application question levels (p=.024 and p=.043 respectively), following the same trend as Fenesi et al. (2014) on lecture type: complimentary-type slides lead to higher scores in younger adults. However, whether students write or type their notes, does not change the outcome of how much information they learn.

EXPERIMENT 4

Rationale

In the present study, we investigated a lecture manipulation designed to modulate note-taking by providing content context before lecture presentation and influencing the amount of background knowledge. Participants read a textbook passage complementary to an online Introductory Psychology lecture on Forming Impressions. Participants read the passage either before or after the lecture. If participants familiarize themselves with the lecture content before attending it, they will already have a schema of information about the topic. When participants have prior knowledge of the content, they may decide to summarize important points and focus more on the presentation rather than being busy transcribing the lecture, which could improve learning during the lecture. Following a 2x2x2 mixed-measures design, participants either typed or handwrote their notes and were assigned to read the passage either before ("pre" condition) or after ("post" condition) the lecture while tested with both factual and application questions. Participants were asked to take lecture notes using the modality they were assigned and were given a comprehension test within the same session. All participants were tested only after they completed the online lecture and the reading, regardless of passage presentation order. If content context provides an advantage in note-taking, we expect to see overall higher scores in the *pre-reading* condition. This advantage could apply to both note-taking modalities or to handwriting only. It could benefit both modalities if context helps organize notes (Kauffman et al., 2011). The *post-reading* condition serves as a control for delivering the same amount of content without influencing information processing while watching the lecture. It would be interesting, however, to see if providing a reading before a lecture versus after produces any benefits in learning.

Method

Participants. A total of 85 participants were recruited for the experiment, but 4 participants' data were excluded due to the participant's inability to follow the experiment protocol; only 81 participants' data were analyzed: 55 female, 26 male, and 4 unspecified participants were run. Their mean age was 18.8 years with a standard deviation of 2.

Stimuli. The presented online lecture on Forming Impressions was taken from the Introductory Psychology course at McMaster University. The module was 27 minutes long. Participants read a paper copy of a textbook passage complementary to the lecture. The passage was a preamble to the chapter on Forming Impressions and did not reveal the main points presented in the lecture.

Design and Procedure. This experiment was a 2x2x2 mixed measures design. Each of the three independent variables, note-taking modality, the timing of reading, and test question type, included two levels: handwritten versus typed notes, pre-lecture versus post-lecture reading, and factual versus application questions respectively. In the Pre-Lecture conditions, participants read the passage on Forming Impressions, completed a handedness questionnaire, and watched the lecture while taking typed or handwritten notes. In the Post-Lecture conditions, participants watched the online lecture, took notes, completed a handedness questionnaire, and read the passage. Participants then proceeded to complete a post-lecture multiple-choice test. This quiz consisted of 10 factual questions and 10 application questions (please see Appendix A for sample quiz questions; while these questions are specific to Forming Impressions, their format is representative of the rest of the questions throughout this paper). Upon completing the quiz, participants were debriefed and awarded their course credit.

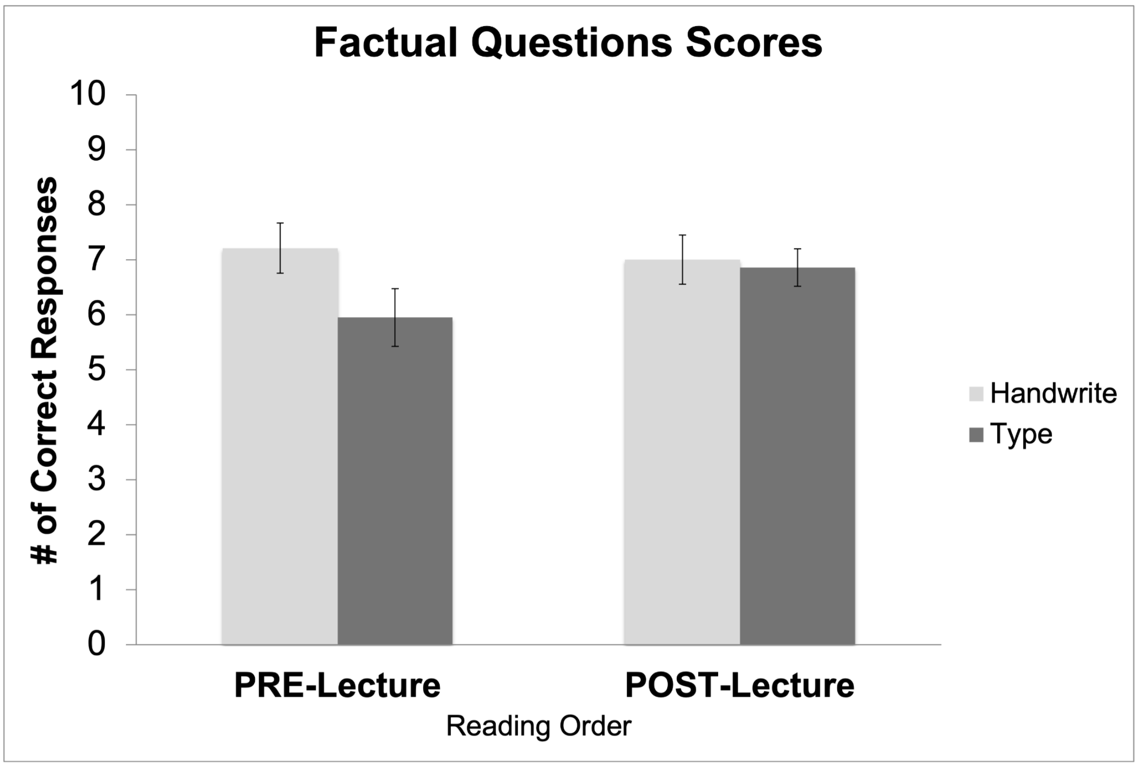
Results

Experiment 4 compared test performance between three independent variables, each with two levels: participants who either took notes by hand or by typing notes, a lecture reading presented either before or after they viewed the lecture, and test questions that were either factual or application based. This 2x2x2 design was analyzed using a three-way mixed measures ANOVA. The dependent measure consisted of 20 multiple-choice questions, split equally into factual and application questions (randomized when presented to participants). Factual multiple-choice question scores are shown in Figure 8, and application multiple-choice question scores are shown in Figure 9.

The three-way interaction between note modality, lecture reading time, and type of question was not significant, $F(1,77)=.023$, $p=.88$. There were no statistically significant simple two-way interactions of note-taking modality and lecture reading time, at either factual or application question level (all p's>.191).

Figure 8

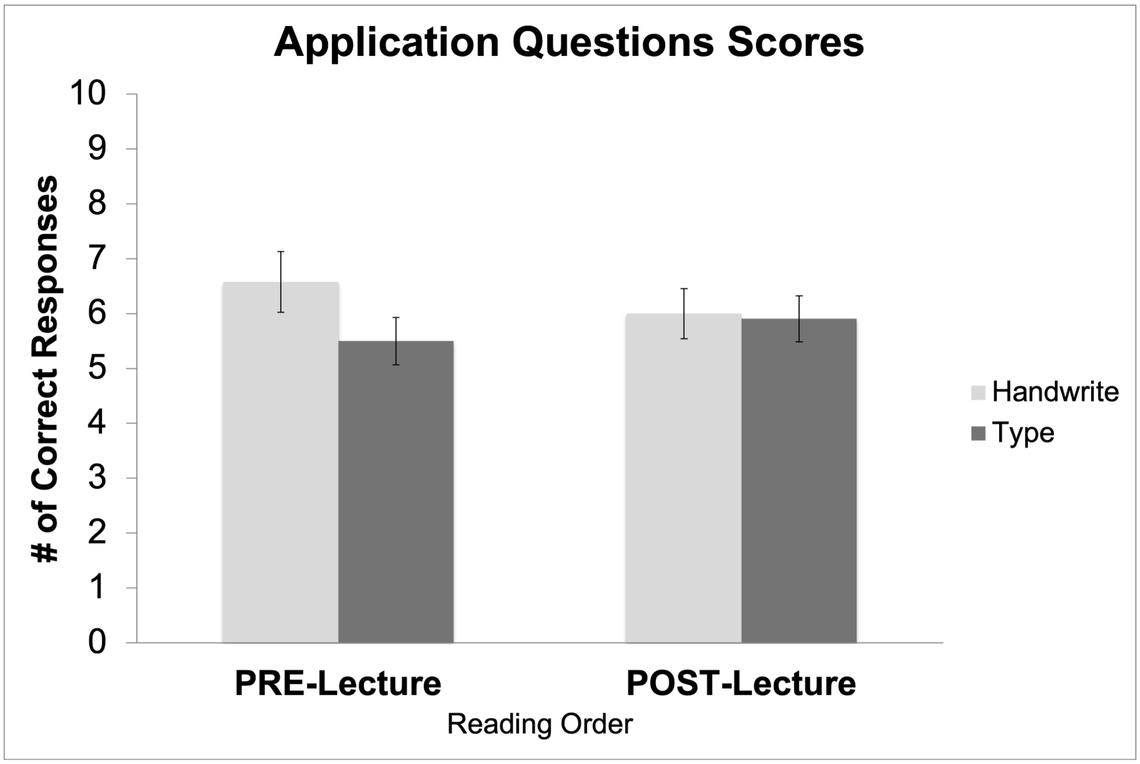
Experiment 4 Correct Factual Responses for Reading Order versus Note-Taking Modality



Note. The number of correctly answered factual questions collapsed across participants in Experiment 4. Error bars represent ±SEM.

Figure 9

Experiment 4 Correct Application Responses for Reading Order versus Note-Taking Modality



Note. The number of correctly answered application questions collapsed across participants in Experiment 4. Error bars represent ±SEM.

Unlike Experiments 1 and 2A, and like experiments 2B and 3, the note-taking modality had no effect on the type of question test results. Factual and application-type questions did not differentiate test performance between handwritten and typed notes. There was no effect on application-type questions, even when the testing was immediate. Experiment 4 found no significant differences between those who typed or handwrote their notes, even when their background knowledge on the lecture topic was manipulated.

Although statistical tests did not show any significant or marginal effects, there was an interesting numerical trend in the pre-lecture reading condition. While all other conditions maintained a similar score, those who typed in the pre-lecture reading condition performed numerically lower than all the other groups. In the factual questions and pre-lecture reading condition, typing group scored lower by 10.8% than the handwriting group. In the application questions and pre-lecture reading condition, typing group scored lower by 12.6% than the handwriting group (see Figures 8 and 9). Overall, in the pre-lecture reading condition, typing group scored lower by 11.7% than the handwriting group. Pre-lecture reading was detrimental, numerically at least, to those who typed. An 11.7% difference in scores could translate to at least one letter grade in test scores. We hypothesize that regardless of background knowledge, those who handwrite still process information similarly and do not easily modify their writing strategies. Since typing is more free-form, participants with background knowledge of the material could opt to write notes in “transcription” mode, without trying to encode as much of the lecture as they are writing notes, because 1. They already know something about the topic, and 2. When people type their notes, they can mindlessly transcribe without much cognitive effort, thus lightening their cognitive load. People who handwrite cannot afford to “check out” from the writing process because they cannot write as fast as a person speaks, while typing promotes such effortless transcription. While potentially detrimental to immediate encoding, mindless transcription could also lower cognitive load and thus lead to better learning in subsequent activities (Storm & Stone, 2015).

Participants performed equally well, whether they received the background reading before or after the lecture. Numerically, participants who typed encoded less of the information when given the background information, suggesting less engagement during the writing process than those who handwrote their notes. However, much caution should be given to this numerical trend since there were no significant (nor marginal) effects. At most, we can speculate that participants who type become more disengaged from the material if they already know something about it, since the typing modality allows participants to lighten their cognitive load and mindlessly transcribe information.

General Discussion

All studies reported here have one converging conclusion: there is no conclusive evidence for the benefit of handwriting over typing notes. Marginal and significant effects were only found in 2 of our immediate-test experiments and only at the application question level. Aside from the handwriting versus typing variable, we manipulated a few factors known to influence note-taking, such as summarizing, transcribing, background content knowledge, and type of slides (i.e., note structure and lecture parameters). These manipulations did not lead to a consistent difference in learning between participants who handwrote versus typed notes. A test delay of 24 hours and more recent experiments (experiments

3 and 4, completed in 2017 and 2018) did not yield any marginal effects. The borderline effects seem to go away with time: how long the test occurs after the lecture, and as newer cohorts are more used to technology (Morehead, Dunlosky, Rawson, et al., 2019). In the following discussion, we identify connections between our findings, the current state of the literature, and the applicability of this research in the educational system. We also showcase how a few features of the work presented here limit the conclusions we can draw about note-taking in the actual classroom and the practical applications of note-taking research in education.

Transitioning note-taking from high school to higher education. In high school, teachers either provide students with lesson notes or prompt them very often on what to write down. When those students reach university, the structured guidance disappears. Professors rarely provide class notes or prompt note-taking. University "Welcome Week" activities focus on getting new students accustomed to the residences, campus, and social facets of university life. Very few activities acclimatize students to the academic challenges of transitioning from high school models of guided learning to the university's "hands-off" approach. Technology also affects how students acquire lecture material at the high school and university levels. Whiteboards and handouts are being replaced by online learning platforms and slideshow presentations. There has also been a shift in how students take notes over the last few decades (Morehead, Dunlosky, Rawson, et al., 2019; Witherby & Tauber, 2019). Increased transcription rates in note-taking (Mueller & Oppenheimer, 2014) could be partly due to laptop use, lecture pace, and students' note-taking capacity. Students entering university might transcribe more because they are unsure of how to synthesize information. Summarizing notes and the encoding benefits of generating information might not play a role until students learn how to take good notes. If that is the case, laptops could help note-taking beginners, if not in an encoding capacity, at least for the benefit of reviewing notes after lectures (Bui et al., 2013).

Limitations with participant pools: who are we including? In our studies, we recruited mostly first-year participants (due to restraints in our participant pool), who are novice note-takers and thus present a limitation to our results. Handwriting did not increase our participant's learning, but their novice status could have stripped any encoding benefits of handwriting and levelled the playing field between handwritten and typed notes. In all of our experiments, we assigned the note-taking modality to have more control over the experiments, avoid self-selection into the preferred method of note-taking, and maintain consistency with most of the literature. In reality, students pick how they take notes, and the literature would benefit from classroom note-taking studies that include self-selection for ecologically valid results.

Limitations with the note-taking scope and transfer appropriate processing. Our studies only looked at the encoding aspect of note-taking, as we did not let participants review their notes. Reviewing and studying notes is a key aspect of the note-taking process and scope. In a fast-paced lecture, typing enables students to take more notes, thus providing them with a more comprehensive record of the content than a person who handwrites notes. The fast pace of speech also makes it difficult for those who handwrite to keep up with their notes while also trying to encode the information through generative strategies. In this scenario, students who handwrite incur a double loss: fewer notes and potentially poorer encoding. There's also the future direction consideration of note-taking studies and transfer-appropriate processing (TAP) (Morris et al., 1977), which states that people remember more information when the cognitive processes at the time of the test match the cognitive processes at the time of encoding. How will participants perform when their note-taking modality is matched or mismatched with the test-taking modality? For example, handwritten encoding and handwritten test, or typed encoding and typed test, and the crossover scenario of handwritten encoding but typed test, and typed encoding but handwritten test. Depending on the course type, students are sometimes tested in person for the first time during a final exam with a handwritten test, when they have been tested all term with online, typed quizzes. Future research should explore the effects of TAP and note-taking, in a variety of course settings and testing scenarios (e.g., in-person, blended, hybrid, or online courses, and handwritten versus typed tests).

Limitations with the type of lecture. Course materials and lecture technology are also evolving. Lectures are packed with idea units, and using slideshows and online modules enable educators to include more content information for the same amount of presentation time. In our experiments, we used online modules to promote ecological validity, since most first-year courses in our faculty have online modules as the main source of lecture information. While modules are shorter in duration than live lectures, an 8-minute module can contain just as much information as a 30-minute live lecture. While we maintained ecological validity compared to our first-year courses, any advantages to handwriting notes could have been eradicated by using online modules. The literature would benefit from having the same lecture content delivered via two lecture types instead of just different slide types (as seen in Experiment 3). One lecture can be an online module, while the other can be a live recording of someone presenting the information in a live lecture environment. The pace and lengths of the lectures would likely be different, but the content would stay constant. For future studies, we also encourage researchers to employ a within-participants design: half of the session in module format and the other half in a live lecture format. This design would answer many interesting questions about students' note-taking habits, including 1. Do participants modify their note-taking style throughout the lecture sessions, thus "adapting" to the situation? and 2. Do their test scores change depending on note-taking modality and whether they "adapted" to the lecture style?

Note-taking training and inclusive education. Handwriting is not inherently better than typing. Laptop use in the classroom has become a controversial topic, and we need a more extensive review and replication of the literature, in a myriad of instances, before we can draw any concrete conclusions. Banning laptops might provide a simple solution for educators who read popular media articles renouncing laptops, and thus cherry-pick conclusions based on their own bias toward technology, but the practice of banning laptops becomes hindering and alienating for entire populations of learners (Rocco, 2005). There are advantages to using laptops for students with various individual differences and learning exceptionalities (Bui & Myerson, 2014). Education has been made easier and even possible for groups of students who cannot take notes for various reasons (e.g., motor or sensory issues).

Campus resources do not cover everyone's needs; while there are services for course note-takers, those services are limited. Students with low working memory capacity, or learning differences, have been enabled to take better notes using technology and hybrid learning models (Bui & Myerson, 2014; Otten, 2022). Instead of banning laptops, which is not a feasible nor an inclusive solution given the integration of post-pandemic technology into our learning systems, educators can work on engaging with their students during lectures and encouraging note-taking support. When it comes to the handwriting versus typing debate, for which we can only conclude "there is no conclusive evidence", educators can shift their focus on training students to take good notes or directing them to educational resources on note-taking. Educational institutions (from K-12 to post-secondary education) could also embed note-taking skills within the curriculum, as some studies have seen increased note-taking efficiency and accessibility within general populations and populations with learning disabilities when they provided scaffolding structures of compensatory supports (Boyle, 2010b, 2012).

Note-taking is a complex process. As researchers and educators, we should promote information on how to take good notes and inform learners about the various accessibility mechanisms available for note-taking in general. Telling students they are not allowed to use their laptops to take notes is a great way to get their attention, but following through with it is a detrimental strategy for their education. Instead of “ditch the laptop and pick up a pen”, we should say “today’s lesson is on how to support effective and inclusive note-taking”. Now *that’s* noteworthy.

References

Aben, B., Stapert, S., & Blokland, A. (2012). About the Distinction between Working Memory and Short-Term Memory. *Frontiers in Psychology., 3*(301), 1–9. https://doi.org/10.3389/fpsyg.2012.00301

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of learning and Motivation*, *8*, 47–89. https://doi.org/10.1016/s0079-7421(08)60452-1

Bahr, Sarah. (2022, January 21). Retrieved October 10, 2022, from https://www.nytimes.com/2022/01/21/insider/the-case-for-writing-longhand-its-about-trying-to-create-that-little-space-of-freedom.html

Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. *Psychology and the real world: Essays illustrating fundamental contributions to society, 2*, 59–68.

Boekaerts, M., Zeidner, M., Pintrich, P. R., & Pintrich, P. R. (Eds.). (1999). Handbook of self-regulation. Elsevier Science & Technology.

Boyle, J. R. (2010a). Strategic Note-Taking for Middle-School Students with Learning Disabilities in Science Classes. *Learning Disability Quarterly*, *33*(2), 93–109. https://doi.org/10.1177/073194871003300203

Boyle, J. R. (2010b). Note-Taking Skills of Middle School Students With and Without Learning Disabilities. *Journal of Learning Disabilities*, *43*(6), 530–540. https://doi.org/10.1177/0022219410371679

Boyle, J. R. (2012). Note-Taking and Secondary Students with Learning

Disabilities: Challenges and Solutions. *Learning Disabilities Research & Practice*, *27*(2), 90–101. https://doi.org/10.1111/j.1540-5826.2012.00354.x

Brown, D. G., & Petitto, K. R. (2003). The status of ubiquitous computing. *Educause Review, 38*(3), 24–33.

Bui, D. C., & Myerson, J. (2014). The role of working memory abilities in lecture note-taking. *Learning and Individual Differences*, *33*, 12–22. https://doi.org/10.1016/j.lindif.2014.05.002

Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, *105*(2), 299–309. 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

Cowan, N., Rouder, J. N., Blume, C. L., & Saults, J. S. (2012). Models of verbal working memory capacity: What does it take to make them work?. *Psychological review, 119*(3), 480–499. https://doi.org/10.1037/a0027791.supp

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684. https://doi.org/10.1016/S0022-5371(72)80001-X

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

Dunkel, P., & Davy, S. (1989). The heuristic of lecture notetaking: Perceptions of American & international students regarding the value & practice of notetaking. *English for Specific Purposes*, *8*(1), 33–50. https://doi.org/10.1016/0889-4906(89)90005-7

Einstein, G. O., Morris, J., & Smith, S. (1985). Note-taking, individual differences, and memory for lecture information. *Journal of Educational psychology, 77*(5), 522–532. https://doi.org/10.1037/0022-0663.77.5.522

Fenesi, B., Heisz, J. J., Savage, P. I., Shore, D. I., & Kim, J. A. (2014). Combining Best-Practice and Experimental Approaches: Redundancy, Images, and Misperceptions in Multimedia Learning. *The Journal of Experimental Education*, *82*(2), 253–263. https://doi.org/10.1080/00220973.2012.745472

Fenesi, B., Vandermorris, S., Kim, J. A., Shore, D. I., & Heisz, J. J. (2015). One size does not fit all: Older adults benefit from redundant text in multimedia instruction. *Frontiers in Psychology*, *6*, 1–9. https://doi.org/10.3389/fpsyg.2015.01076

Fisher, J. L., & Harris, M. B. (1973). Effect of note taking and review on recall. *Journal of Educational Psychology*, *65*(3), 321–325. https://doi.org/10.1037/h0035640

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

Hughes, C. A., & Suritsky, S. K. (1994). Note-Taking Skills of University Students With and Without Learning Disabilities. *Journal of Learning Disabilities*, *27*(1), 20–24. https://doi.org/10.1177/002221949402700105

Kauffman, D. F., Zhao, R., & Yang, Y.-S. (2011). Effects of online note taking formats and self-monitoring prompts on learning from online text: Using technology to enhance self-regulated learning. *Contemporary Educational Psychology*, *36*(4), 313–322. https://doi.org/10.1016/j.cedpsych.2011.04.001

Kiewra, K. A. (1985). Students' note-taking behaviors and the efficacy of providing the instructor's notes for review. *Contemporary Educational Psychology*, *10*(4), 378–386. https://doi.org/10.1016/0361-476X(85)90034-7

Kiewra, K. A. (1987). Notetaking and review: The research and its implications. *Instructional Science*, *16*(3), 233–249. https://doi.org/10.1007/BF00120252

Kiewra, K. A. (1989). A review of note-taking: The encoding-storage paradigm and beyond. *Educational Psychology Review*, *1*(2), 147–172. https://doi.org/10.1007/BF01326640

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

Kobayashi, K. (2006). Combined Effects of Note Taking/Reviewing on Learning and the Enhancement through Interventions: A meta analytic review.

Educational Psychology, *26*(3), 459–477. https://doi.org/10.1080/01443410500342070

Landrum, R. E. (2010). Faculty and student perceptions of providing instructor lecture notes to students: Match or mismatch? *Journal of Instructional Psychology, 37*, 216–221. https://link.gale.com/apps/doc/A240185498/AONE?u=anon~5164cd8e&sid=googleScholar&xid=427bedd4

Magdolen, C. (2022, September 14). Caroline Magdolen | Why I handwrite my notes on paper. The DP. Retrieved October 10, 2022, from https://www.thedp.com/article/2022/09/why-i-handwrite-my-notes-on-paper

Maxwell, S. E., Lau, M. Y., & Howard, G. S. (2015). Is psychology suffering from a replication crisis? What does “failure to replicate” really mean? *American Psychologist*, *70*(6), 487–498. https://doi.org/10.1037/a0039400

May, C. (2014, June 3). A Learning Secret: Don’t Take Notes with a Laptop. Scientific American. Retrieved October 10, 2022, from https://www.scientificamerican.com/article/a-learning-secret-don-t-take-notes-with-a-laptop/

Morehead, K., Dunlosky, J., & Rawson, K. A. (2019). 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. (2019).

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

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. J*ournal of Verbal Learning and Verbal Behavior, 16*(5), 519–533. https://doi.org/10.1016/S0022-5371(77)80016-9

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

Oefinger, L. M., & Peverly, S. T. (2020). The Lecture Note-Taking Skills of Adolescents With and Without Learning Disabilities. *Journal of Learning Disabilities*, *53*(3), 176–188. https://doi.org/10.1177/0022219419897268

Otten, H. (2022, September 2). Return to in-person courses leaves some students frustrated over loss of accommodations. The Fulcrum. Retrieved October 10, 2022, from https://thefulcrum.ca/news/

Palmatier, R. A., & Bennett, J. M. (1974). Notetaking habits of college students. *Journal of Reading, 18*, 215–218.

Palkovitz, R. J., & Lore, R. K. (1980). Note Taking and Note Review: Why Students Fail Questions Based on Lecture Material. *Teaching of Psychology*, *7*(3), 159–161. https://doi.org/10.1207/s15328023top0703_8

Peper, R. J., and Richard, E. M. (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., Brobst, K. E., Graham, M., & Shaw, R. (2003). College adults are not good at self-regulation: A study on the relationship of self-regulation, note taking, and test taking. *Journal of Educational Psychology*, *95*(2), 335–346. https://doi.org/10.1037/0022-0663.95.2.335

Peverly, S. T., Garner, J. K., & Vekaria, P. C. (2014). Both handwriting speed and selective attention are important to lecture note-taking. *Reading and Writing*, *27*(1), 1–30. https://doi.org/10.1007/s11145-013-9431-x

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

Peverly, S. T., & Sumowski, J. F. (2012). What Variables Predict Quality of Text Notes and are Text Notes Related to Performance on Different Types of Tests?: Text notetaking. *Applied Cognitive Psychology*, *26*(1), 104–117. https://doi.org/10.1002/acp.1802

Peverly, S. T., Vekaria, P. C., Reddington, L. A., Sumowski, J. F., Johnson, K. R., & Ramsay, C. M. (2013). The Relationship of Handwriting Speed, Working Memory, Language Comprehension and Outlines to Lecture Note-taking and Test-taking among College Students: Cognitive processes and note-taking. *Applied Cognitive Psychology*, *27*(1), 115–126.

https://doi.org/10.1002/acp.2881

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

Reddington, L. A., Peverly, S. T., & Block, C. J. (2015). An examination of some of the cognitive and motivation variables related to gender differences in lecture note-taking. *Reading and Writing*, *28*(8), 1155–1185. https://doi.org/10.1007/s11145-015-9566-z

Rickards, J. P., & Friedman, F. (1978). The encoding versus the external storage hypothesis in note taking. *Contemporary Educational Psychology*, *3*(2), 136–143. https://doi.org/10.1016/0361-476X(78)90020-6

Rocco, T. (2005). The invisible people: Disability, diversity, and issues of power in adult education. Presented at the Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education, Northern Illinois University, DeKalb, IL, October 9–11, 2002.

Sana, F., Fenesi, B., & Kim, J. A. (2011). A Case Study of the Introductory Psychology Blended Learning Model at McMaster University. *The Canadian Journal for the Scholarship of Teaching and Learning*, *2*(1). https://doi.org/10.5206/cjsotl-rcacea.2011.1.6

Schellings, G. L. M., & Hout-Wolters, B. H. A. M. V. (1995). Main Points in an Instructional Text, as Identified by Students and by Their Teachers. *Reading Research Quarterly*, *30*(4), 742–756.

https://doi.org/10.2307/748196

Slotte, V., & Lonka, K. (1999). Review and Process Effects of Spontaneous Note-Taking on Text Comprehension. *Contemporary Educational Psychology*, *24*(1), 1–20. https://doi.org/10.1006/ceps.1998.0980

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

Summers, J., & Catarro, F. (2003). Assessment of handwriting speed and factors influencing written output of university students in examinations. *Australian Occupational Therapy Journal*, *50*(3), 148–157. https://doi.org/10.1046/j.1440-1630.2003.00310.x

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*(3), 498–505. https://doi.org/10.3758/BF03192720

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), 323–338. https://doi.org/10.1037/0022-0663.86.3.323

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

Appendix A

Sample Quiz Questions

Topic: Forming Impressions

Factual Questions

Q: Which of the following correctly describes an attribution theory?

A. Correspondent inference theory asks whether an individual behaves similarly in a variety of situations.
B. Correspondent inference theory asks whether an individual behaves similarly to how others would behave in that situation.
C. Covariation theory asks whether an individual's behaviour is driven by hidden motives.
D. Covariation theory asks whether an individual's behaviour often behaves similarly in a given situation*.

Q: Which of the following is the correct description of the representativeness heuristic?

A. It is the phenomenon whereby you make a judgment based on a comparison to a prototype*.
B. It is the phenomenon whereby you make a judgment based on information accessible to you.
C. It is the phenomenon whereby you make a judgment based on fact.
D. It is the phenomenon whereby you make a judgment based on how recently you have been exposed to a similar instance.

Application Questions

Q: Two teenage boys on a field trip at a local museum in India were throwing around a football. While playing, one of the expensive paintings was damaged. Which of the following is the most likely response from the witnesses of the incident?

A. **Bashir, the forty-year-old Indian curator of the museum, said 'boys will be boys', and this was a one-time mistake*.**
B. Faiza, an eleven-year-old Indian girl who was near the boys while they were playing, said the boys seem to have done it because they are irresponsible.
C. Jacob, a fifteen-year-old visiting from America, said the boys' destruction of paintings was likely restricted to this single occurrence.
D. Winston, an American art collector in his late forties, said that it seems the boys had made a mistake, and no harm was done.

Q: Greg has been monitoring the behaviours of his friend Jerry, trying to find proof of the covariation theory. As he sits and reflects, he identifies different situations that can be resolved. In which case has Greg correctly analyzed behaviour according to the covariation theory?

A. **On their camping trip together, all of their other friends jumped off a cliff into the lake, but Jerry refused to follow*.**
B. At their graduation party, Jerry chose to have the chocolate cake instead of the vanilla cake.

C. At the house party last month, Jerry came along only because he planned on getting in a fight to release some stress.
D. Jerry always dresses in a professional manner; therefore, Greg assumes Jerry is a businessman, despite being told he is a student.

CHAPTER 4

TAKE NOTE: THE EFFECTS OF NOTE-TAKING STRATEGIES AND INDIVIDUAL DIFFERENCES ON LECTURE COMPREHENSION

Irina Ghilic, Lisa Lorentz, Taha Arshad, Ashley Avarino, and David I. Shore

Abstract

Background: Educators rarely dispute the importance of note-taking. Notes help learners encode information, and provide them with a record of classroom content for later study; which modality leads to better learning is still debated. We investigate effects of note-taking modalities beyond their influence on final comprehension scores. In this paper, we explore a cognitive offloading manipulation by priming students to expect to study their notes, and correlate individual differences (working memory capacity and regular note-taking habits) with lecture comprehension.

Method: We instructed participants to take notes while watching a lecture, and some were told they would be able to study their notes before a test, while others were told they would not have access to their notes before the test. However, none of the participants got to study their notes. We tested this procedure with both an immediate and a delayed test (with different cohorts of participants). Participants also completed a working memory capacity test, and answered questions about their note-taking habits.

Results: For an immediate test, participant's lecture comprehension correlated with their working memory scores: the higher their working memory capacity, the higher the scores. If participants were assigned a note-taking modality that mismatched their usual note habits, those with a lower working memory capacity showed a positive correlation between their capacities and their test scores. These differences were not found in the delayed-test condition, although there was still a similar trend for the mismatched and lower working memory conditions.

Conclusions: This paper demonstrates the importance of exploring individual differences in note-taking. Future research would benefit from actual classroom studies, where the extrinsic motivation for students to do their best is higher than in our relatively short lab studies. Future studies should also investigate the practical application of individual differences and note-taking in diverse educational settings.

Keywords: Cognitive offloading, note-taking, individual differences, working memory capacity, note-taking habits, classroom research, inclusive note-taking.

Introduction

You take a seat for your last lecture, pull out the laptop, and the battery is dead. You begin to panic when the instructor starts presenting their slides. The student beside you notices your predicament and offers you a spare pen and a couple of sheets of lined paper. You are baffled: do people still write their notes by hand? Laptop note-taking has become increasingly common within universities (Bui et al., 2013; Morehead et al., 2019; Witherby & Tauber, 2019). However, much debate surrounds whether or not laptop note-taking is advantageous and if taking notes by hand would lead to better learning (Mueller & Oppenheimer, 2014). You might not know that your ability to retain lecture information is influenced by multiple factors when it comes to note-taking.

1. Factors Affecting Retention of Lecture Material

Saving Notes and Cognitive Offloading. Regardless of the note-taking modality (e.g., handwritten or typed notes), the expectation that notes can be re-studied before a test decreases the amount of information retained at encoding due to "cognitive offloading" (Risko & Gilbert, 2016; Sparrow et al., 2011, 2011; Storm et al., 2017). Cognitive offloading refers to relying on external resources to store information, such as taking notes and using a calendar application, instead of relying on internal resources, such as memory stores. An individual may be experiencing offloading when taking notes they can study later since taking notes may decrease the probability of actively processing the information "in the moment". Because there is no need to memorize the information during the note-taking process, the individual can offload the information into their note-taking device instead of trying to work through the process of transferring information from short-term to long-term memory. Consequently, using this external memory storage results in difficulty retrieving the information without access to the external memory stores (Sparrow et al., 2011).

Cognitive offloading is convenient and sometimes helpful, and individuals who engage in it are more likely to do it again (Storm et al., 2017). In a study by Storm et al. (2017), participants were required to answer a series of questions using the internet or from memory. Those who used the internet were engaging in the benefits of cognitive offloading, as they were not required to use their internal memory stores to answer the questions. Individuals who initially used the internet were significantly more likely to use it for future searches, despite not being prompted to do so. While the ability to re-study notes before a test is perceived as beneficial to students, the cognitive offloading of information via notes may inhibit certain aspects of "learning", denoted in this offloading example as a decrease in immediate information retention. However, this is not the only example of a widely-accepted academic practice that might reduce learning: typing notes instead of handwriting them may also decrease the retention of information.

Typing, Handwriting, and Depth of Processing. Typing notes could decrease immediate retention, as it encourages verbatim transcription (Mueller & Oppenheimer, 2014). Transcription consists of recreating a word-for-word account of the verbal information recorded via notes, resulting in a shallow level of information encoding. Summarizing information results in a deeper level of encoding than transcription, as actively summarizing information requires greater cognitive effort. Kiewra (1982) reports that participants who took verbatim notes on a reading achieved lower scores on immediate and delayed post-reading tests than those who took summarized notes.

In contrast, some note-taking strategies are generative, increasing comprehension and encoding, such as summarizing content. Generative strategies encourage students to integrate new material and prior knowledge (Peper & Richard, 1978). Students are active learners when using generative strategies; connecting new information and prior knowledge adds meaning to newly learned material (Di Vesta & Gray, 1972), resulting in greater content retention (Kiewra et al., 1989). For example, matrix-style notes connect lecture ideas through chart graphics and produce higher recall rates than regular text notes. However, generative strategies require more cognitive resources for comprehension and to keep the information in working memory (Makany et al., 2009). Summarizing lecture content requires students to listen to a lecture, comprehend the material, and keep this information in working memory to create a summary (Kiewra et al., 1989). Although summarizing and making connections between concepts use beneficial generative processes, these processes are also cognitively demanding and result in students having fewer notes. While verbatim transcription does not generate meaningful connections, increasing the number of notes recorded may benefit students. Many students can type faster than they can handwrite, thus making verbatim transcription more accessible.

Compared to handwritten notes, typed notes encourage more verbatim transcription (Mueller & Oppenheimer, 2014) and multitasking due to computer-related distractions (Fried, 2008). Both of these factors affect our cognitive processes and decrease the amount of information retained after taking notes (Adler & Benbunan-Fich, 2012), thus impairing immediate lecture comprehension. This contrasts with handwritten notes, which encourage deeper information processing, resulting in better material retention (Annis & Davis, 1975; Kiewra, 1989).

Note Quantity. Typing notes increases note quantity. Stacy and Cain (2015) noted that taking notes via laptop allows for “speed, legibility, and searchability,” potentially increasing comprehension and recall. Bui, Myerson, and Hale (2013) had participants write or type their notes, and transcribe or organize them while listening to a lecture. The laptop-transcribe condition performed significantly better on immediate testing than any other group. In a second study, the test time was also manipulated; participants were either in a test delay group or a no-test delay group. Performance was worse for those in the laptop-transcribe condition when the test was delayed. These results indicate there may be an encoding benefit for laptop-transcribe conditions, but this benefit is only observed for immediate recall. However, all of their tests were factually based (i.e., the questions didn’t require the application of information to newer scenarios), while the encoding effect is seen mainly for conceptual questions (i.e., questions that dig deeper into the understanding and application of content) (Kiewra, 1989). Thus, the short-term encoding benefit found in the first study may not generalize to conceptual questions that require a deeper understanding of learned material. While the short-term encoding benefits for laptop note takers have been demonstrated for factual recall, there may be a long-term benefit for handwritten notes when the lecture comprehension test requires learners to showcase a deeper understanding of lecture material later. We hypothesize that the generative effect of handwriting notes helps learners forge more meaningful content connections and transfer the information into long-term memory, while potentially hindering their ability to focus on immediate factual details. On the other hand, those who type the lecture content verbatim have a comprehensive record of the factual lecture details primed in their short-term memory. However, without an effort to forge connections and comprehend the information at a deeper level (or without a chance to review the notes), those who type have a lower probability of transferring the information from short-term into long-term memory.

Influences of multitasking. Typing notes can also decrease learning due to extensive multitasking opportunities (Fried, 2008; Kraushaar & Novak, 2010; Sana et al., 2013). Multitasking impairs cognitive processes (Adler & Benbunan-Fich, 2012), forcing an individual's attentional resources to be split among numerous tasks. In a study by Sana, Weston, and Cepeda (2013), participants who could see the laptop screen of a multitasking confederate had lower test scores than those who could not. This study highlights that laptop multitasking decreases the laptop user's learning and hinders those around them. Interestingly, laptop note-takers who multitask during lectures also underestimate the extent of their multitasking behaviours (Kraushaar & Novak, 2010), implying that these individuals are unaware of the negative effects of multitasking distractions.

2. Factors Affecting the Studying of Notes

To achieve their learning goals, students need good study materials. Because students use class notes as the main source of lecture information (Dunkel & Davy, 1989; Morehead et al., 2019), the quality of their notes is essential to accurately monitor their progress toward learning goals.

Metacognitive awareness. A lack of metacognitive awareness—such as being unaware of the extent of one’s multi-tasking behaviours (Kraushaar & Novak, 2010)—can ultimately affect how learners study their notes, regardless of the quality of their notes. Students often review their notes when studying (Dunkel & Davy, 1989). The process of ‘studying’ can be identified through several features: it rarely includes teacher or peer intervention (thus making it a solitary activity), and it involves goal-setting and information synthesis, which often produce observable traces (such as notebook markings or highlighting of text), and the student usually arranges the study environment to their liking (Boekaerts et al., 1999).

Studying as Self-Regulated Learning. Through a metacognitive lens, studying can be defined as "self-regulated learning" (SRL). A complete model of studying as SRL has four stages: 1. Task definition; 2. Goal setting and planning; 3. Enactment; and 4. Adaptation. A crucial facet of SRL stages is the ability to accurately evaluate or make judgments about the information available at each stage. Accurate judgments about the complexity of study material, perception of the task, effort required, and the ability to execute a plan help students set realistic study goals and plans (Boekaerts et al., 1999).

Self-Regulated Learning and Note Taking. Although informative and effective for monitoring studying, self-regulated learning models and students' own judgments of their learning have not been widely applied in the note-taking literature. Note-taking research has predominantly investigated various note-taking modalities, techniques, and their effects on test performance, while very few studies have focused on the cognitive processes involved in note-taking (Piolat et al., 2005). Through a series of student interviews, Van Meter, Yokoi, and Pressley (1994) deemed students' note-taking characteristics as goal-directed and adaptive (i.e., based on lecture information density, speed of lecturer's speech, and prior domain knowledge). However, very few studies have tested the aforementioned note-taking characteristics. In one line of research, when presented with self-monitoring prompts ("Now would be a good time to ask yourself if you have collected all the important information"; Kauffman et al., 2011, p. 318), participants who were prompted achieved higher test scores than those who did not receive prompts. Simply asking students if they were certain about their notes and providing them with cues and opportunities to review the study materials improved monitoring accuracy and self-regulation of their note-taking session (Kauffman et al., 2011).

Individual differences in learning. Individual differences can affect our accurate monitoring and SRL process. The note-taking literature has recently taken a more in-depth approach to understand the effects of individual differences in note-taking and studying. One notable marker within the literature concerning learning and individual differences is Working Memory Capacity (WMC) (Hadwin et al., 1999). You can think of working memory as the active part of your memory system. There is a finite amount of information that we can process and store at any given time. As the information presented becomes more complex or attention-demanding, those finite resources start to deplete. Working memory has a limited capacity, so learning starts to suffer when individuals have difficulty maintaining task-relevant information in their working memory and accessing connected information from long-term memory, all while trying to ignore distractions (Cowan et al., 2005).

Because most of the to-be-remembered information passes through our working memory system, its capacity and function are key players in determining successful learning. Generally, a higher WMC is positively correlated with higher academic performance, including tasks like vocabulary learning, reading comprehension, and lecture note-taking (Fenesi, Sana, et al., 2015; Fenesi et al., 2016). Note-taking is a complex process, and it engages the various components of the multicomponent model of WMC, such as visual and verbal processing (please see Fenesi et al., 2015, for an extensive review on reconceptualizing working memory in educational research). Learning manipulations that work against our cognitive load affect our WMC, and those effects are more detrimental to those with a lower WMC (Fenesi et al., 2016). One size never fits all when it comes to education, and we even see principles that have been repeatedly shown to cause detriments (e.g., presenting redundant text in multimedia presentations), as having the opposite effect depending on the age of the participants (Fenesi et al., 2015)

3. The Present Study

Note-taking is a multi-faceted process, and research into it must consider the relation between various individual differences, offloading, SRL, and lecture comprehension. The current research aimed to investigate the impact of the participants' studying expectations and note-taking modality on lecture comprehension while also investigating the influence of WMC and individual note-taking differences on lecture comprehension. Participants took notes while viewing a lecture and were either falsely told that they would re-study their notes before the lecture-based test or correctly told they would be unable to do so.

The purpose of deceiving participants into believing they would be able to re-study their notes was to encourage cognitive offloading. In essence, if individuals believed they could re-study their notes, they might not be as focused on retaining the information presented to them during the note-taking process. They may offload the lecture information onto their notes instead of relying on their internal memory stores. We investigated these conditions with immediate and delayed testing conditions.

EXPERIMENTS 1 and 2

Methods

Participants

In Experiment 1, data were collected from 88 individuals (24 male), with an average age of 18.7. Data from 8 participants were excluded due to technical difficulties. All participants were McMaster University undergraduates completing the study for class credit. In Experiment 2, data were collected from 80 individuals (57 female), with an average age of 18.3. Data from 7 participants were excluded, due to participants not returning for the second part of the experiment.

Apparatus

Participants viewed a lecture on a 24-inch desktop screen using Google Chrome as the browser for watching the video lecture. Headphones were provided, and the volume was adjustable. For participants who took notes on a laptop, the notes were taken on a 20-inch PowerBook G4 using Microsoft Word 2001. For hand-written notes, notes were taken on lined paper (8 ½ inches by 11 inches) in a black ½ inch binder using a blue ink pen.

Stimuli

Participants viewed an 8-minute online lecture on memory, and they were instructed not to pause the lecture. The lecture had complementary features, with more visuals than text on the slides. Volume was adjustable. Participants completed an online automatic OSPAN task, testing working memory capacity (Unsworth et al., 2005). This task involved three practice sessions, the first being a letter span in which the participants were required to recall a series of letters and the order in which they appeared. The second practice session involved the presentation of a series of math operations, and the participant was required to report whether the number following a given math operation was a correct or incorrect answer. The final practice session mimicked the actual task where participants were required to perform the letter recall and math operations together. After the presentation of a math operation question, a letter was shown that participants were required to recall at a later time. This set of one math operation question and one letter was repeated in series ranging from 3 to 7 sets at which point participants were asked to recall the letters that were shown. The actual task followed this same procedure and participants' OSPAN score was recorded (Unsworth et al., 2005). A 20 multiple-choice question test was administered through PsycoPy, and all answers were automatically recorded on a Microsoft Excel spreadsheet. The test consisted of 10 factual and 10 application questions, each with 4 options (please see Appendix A for a sample of questions).

Procedure

Participants were brought into a room with a desk, chair, and computer. They were asked to sit in the desk chair, approximately 31 inches from the computer screen. A pre-experiment questionnaire was administered to ensure any reading, motor, attention, visual or linguistic discrepancies were documented. Instructions were then given for the note-taking phase.

In the note-taking phase, there were four possible conditions: typed-deception (TD), handwritten-deception (HD), typed-no deception (TND), or handwritten-no deception (HND). In all conditions, participants were instructed to take notes as they normally would in a class environment, while watching an 8-minute lecture that could not be paused. Non-deception participants were then instructed they would not be using their notes before taking the test. Deception participants were instructed they would be able to study their notes before taking the test and to consider this while taking notes. Participants were then given a laptop or a binder to take notes, depending on which condition they were randomly assigned to, and headphones for listening to the lecture. Participants were instructed to press a call button to inform the experimenter that they were done with the lecture. The experimenter then started the lecture module and left the room, returning only once the participant completed the lecture.

When the experimenter returned, the participant’s notes were taken away, and the participant was then given instructions on how to complete the OSPAN task. Instructions were also embedded within the automated, computerized task.

Once the instructions were given, the experimenter left the room until the OSPAN task was completed.

Following the OSPAN task, the experimenter provided instructions for the test phase. In the deception group, students were told they would not be able to use their notes. Before moving on, the experimenter ensured the participant was okay with this. Instructions for the test were then given, and the test was administered. The methodology remained the same for Experiment 2, with one notable exception: participants experienced the test after a delay of 48 hours. Once they completed the OSPAN task, participants were invited to come back in two days to complete the experiment. They were not given access to any materials once they left the lab, and participants returned 48 hours later to take the test, as described above.

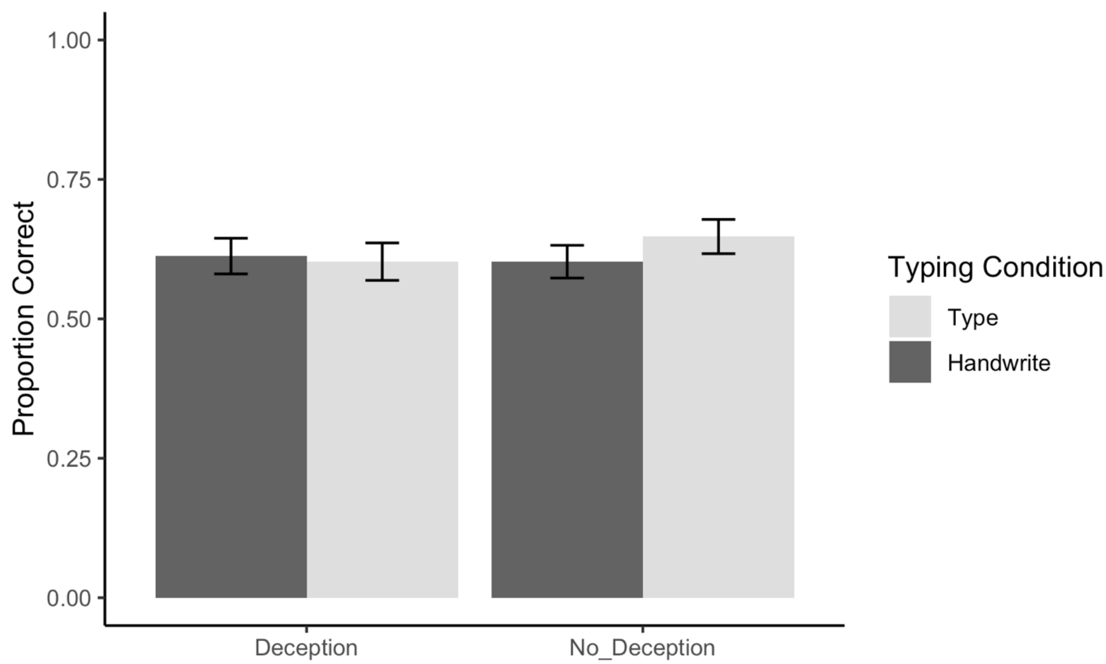
Following the test phase, participants completed a questionnaire about their typical note-taking habits. A debrief form was given to all participants; deception participants were asked to permit the experimenter to use their data, per ethics requirements.

EXPERIMENT 1

Results

Figure 1

Experiment 1 Proportion Correct Responses for Note-Taking Modality versus Deception Condition



Note. The average proportion of correct responses collapsed across participants in Experiment 1. Error bars represent ±*SEM*.

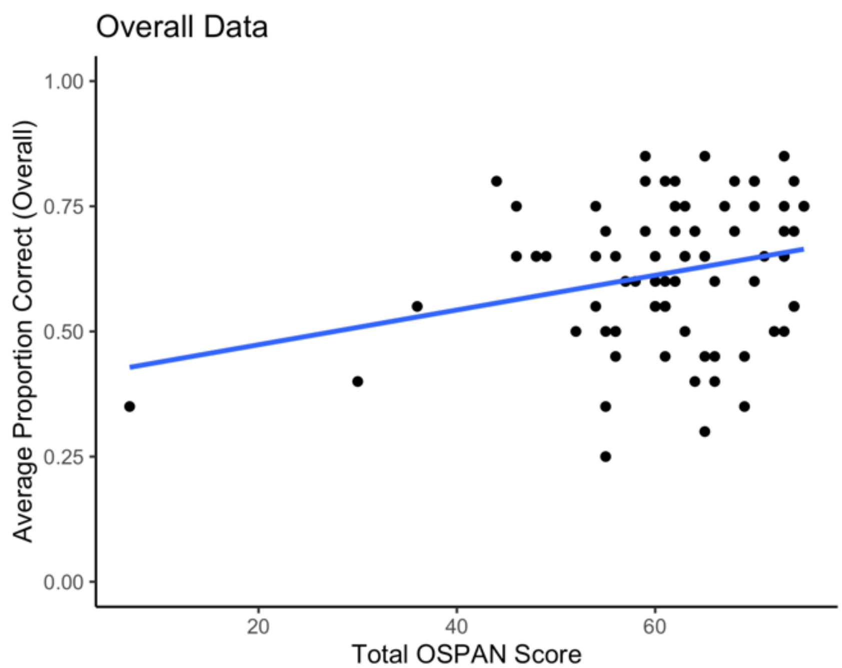
Proportion Correct. The average proportion of correct response values was calculated for each participant as the total number of items correctly answered, divided by the total number of questions (see Figure 1). The average proportion of correctly recalled values was submitted to a 2 x 2 x 2 mixed factor ANOVA that treated typing condition (read/type) and deception condition (no deception/deception) as a between-participants factor, and question type (factual/application) as a within-participants factor.

There were no significant effects, all *p*s>.384. In addition, we ran the same analysis but added a between-participants factor that distinguished whether the assigned typing condition (handwritten/typed) matched (match) or mismatched (mismatch) the participants' typical note-taking style (based on responses to the Note-Taking Questionnaire administered at the end of the experiment), all *p*s>.07.

Correlations with OSPAN. OSPAN performance was calculated as per the total score of Unsworth et al. (2005). OSPAN performance was significantly correlated with the overall average proportion scores (i.e., collapsed across question type); $r=.269$, $p=.016$ (Figure 2).

Figure 2

Experiment 1 Correlation between the average of proportion correct responses and total OSPAN Score

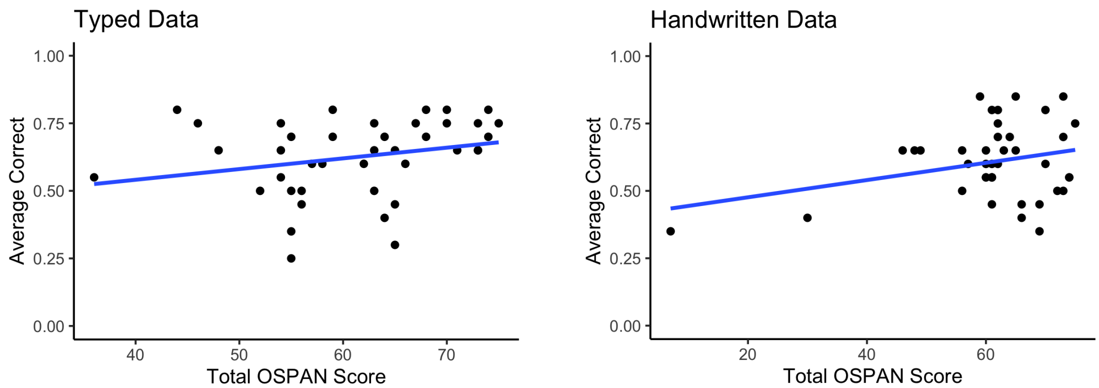


Note. Correlations between the total OSPAN score and average proportion correct overall performance for Experiment 1.

OSPAN by Note Type. Given our *a priori* interest in the effect of note-taking condition (handwritten/typed), we also calculated the previous correlation separately for typed and handwritten data. Although the correlation was numerically larger for handwritten, *r*=.292, *p*=.067, than typed, *r*=.251, *p*=.118, and approaching significance, neither data group was significantly correlated with OSPAN, nor did the correlations differ significantly from one another, *Fisher's Z*=-0.190*, p*=0.849 (Figure 3).

Figure 3

Experiment 1 Correlation between the average proportion of correct responses, total OSPAN Score, and note-taking modality

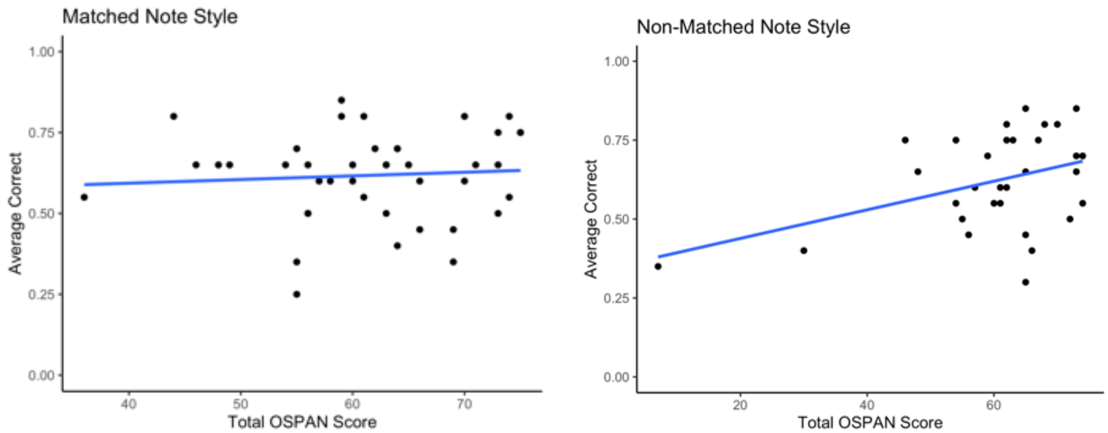


Note. Correlations between the total OSPAN score and average proportion correct overall performance, separated for typed versus handwritten data, for Experiment 1.

OSPAN by Note Type Match: To further assess the influence of working memory capacity, we also examined whether a match between the assigned note-taking condition (handwritten/typed) and the participants' typical note-taking style influenced the effect of OSPAN. To do this, we separated the data into participants whose designated note-taking style matched (n=42) and mismatched (n=31) their typical note-taking style. OSPAN was not significantly correlated with overall test performance for the Match Group *p*=.638, but was significantly correlated for the Mismatch Group *r*=.408, *p*=.023; however, these correlations did not significantly differ from one another, *Fisher's z*=-.145*,* *p*=.148 (Figure 4).

Figure 4

Experiment 1 Correlation between the average proportion of correct responses, total OSPAN Score, and note-taking style



Note. Correlations between the total OSPAN score and average proportion correct overall performance, separated by matched versus non-matched note-taking style, for Experiment 1.

Mini-Discussion of Experiment 1. The "deception" manipulation stemmed from our previous work in applied note-taking and cognitive offloading research. If participants are told they can study their notes, will they offload more of that information in their notes, to not burden their cognitive load with information they will have access to later? On the other hand, if they knew they would not be able to study the notes after taking them, would they remember the information better than those who relied on offloading and later studying? Experiment 1 did not yield any significant results in overall test performance between the note-taking conditions, nor was there an influence of the experimental manipulation of deception. There is support in the note-taking literature for no effects between handwritten and typed notes, including our research team’s previous studies on note-taking modality and connecting offloading to a classroom-like lecture (Ghilic, I. et al., 2022. Forget-Me-Not: The Effects of Note-Taking on Cognitive Offloading and Learning. [Unpublished manuscript]).

Although our previous research shows the benefit of offloading and saving information, much like Storm and Stone (2015), the effects of note-taking were only apparent when the study materials consisted of recalling word lists (and not replicated with lecture-like materials and recognition-based quizzes), and only when we investigated note-taking individual differences. In laboratory studies that mimic the real-classroom environment, effects might be harder to tease apart and often lurk under the surface of overall test performance (Fenesi et al., 2014, 2016; Fenesi, Sana, et al., 2015).

In the present work, we wanted to look at participants’ working memory capacity scores and their potential influence on lecture comprehension. Since we assigned the note-taking condition, we were also interested in knowing our participant’s regular note-taking preferences, and mapping those preferences with their performance and working memory scores. OSPAN performance was significantly correlated with the overall average proportion of correct responses: the higher their working memory capacity, the better their scores. It is interesting to note that handwriting versus typing notes did not yield different correlations with the participant’s working memory capacity: the capacity does not seem to matter, whether participants take notes by hand or laptop, which further supports the hypothesis of no inherent benefits of taking notes by hand versus by typing.

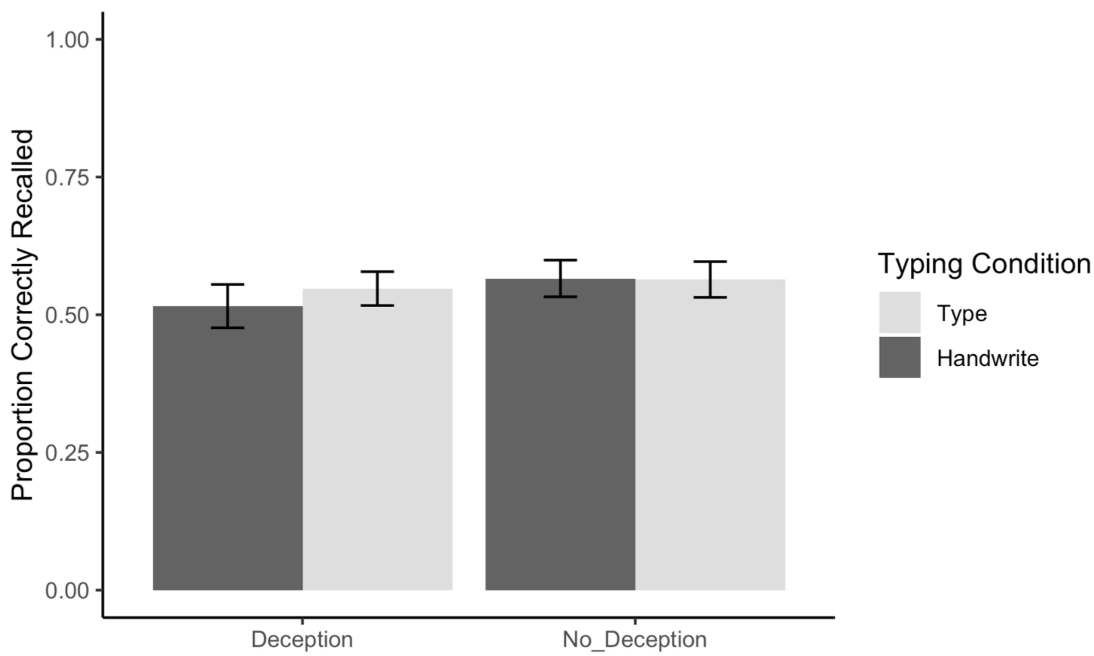
The OSPAN scores, when related to the note-taking match condition, prompt an interesting conversation: while OSPAN was not significantly correlated with overall test performance for the Match Group, it was significantly correlated for the Mismatch Group: the lower the working memory capacity, the more the mismatched note-taking condition negatively impacted participant's scores. Although we are cautious of this result due to the potential argument of outliers driving the effect, individual differences like working memory capacity should be an important consideration in laboratory note-taking data collection, especially when assigning participants to a note-taking condition. The conversation about "outliers", when investigating individual differences, also merits further discussion, and instead of excluding participants outside of a standard deviation range, future research should also strive to recruit a more robust and representative sample of the population.

EXPERIMENT 2

Results

Figure 5

Experiment 2 Proportion Correct Responses for Note-Taking Modality versus Deception Condition



Note. The average proportion of correct responses collapsed across participants in Experiment 2. Error bars represent ±*SEM*.

Proportion Correct. Due to data loss, with participants not returning for the second part of the experiment 48 hours after the first session, there were unequal numbers of participants across the between-subjects cells (Handwrite x Deception n=16, Handwrite x No Deception=19, Type x Deception=20, Type x No Deception=18). The average proportion of correct response values was calculated for each participant as the total number of items correctly answered divided by the total number of questions (see Figure 5). The average proportion of correctly recalled values was submitted to a 2x2x2 mixed factor ANOVA that treated typing condition (read/type) and deception condition (no deception/deception) as a between-participants factor, and question type (factual/application) as a within-participants factor.

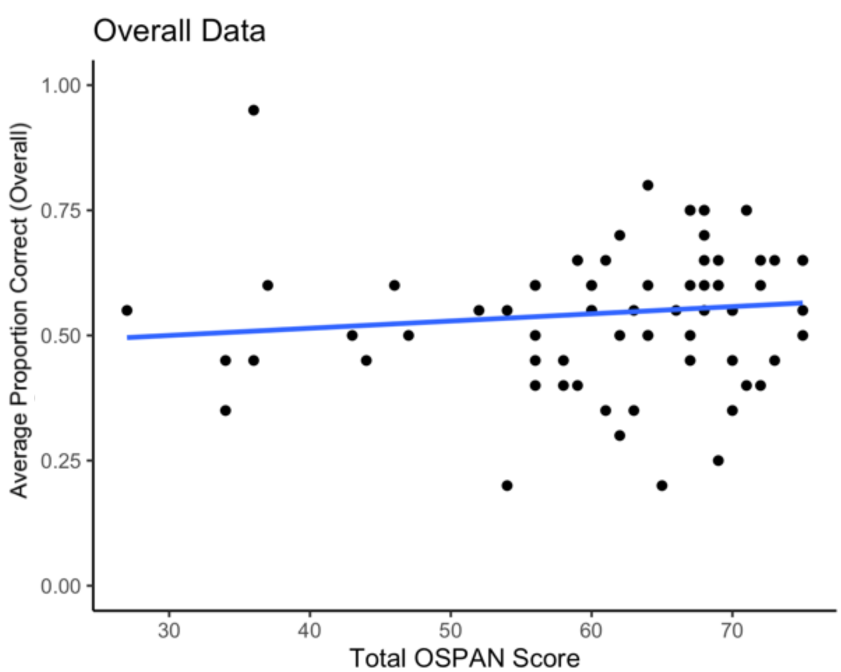
There were no significant effects, all *p*s>.112. In addition, we ran the same analysis but added a between-participants factor that distinguished whether the assigned typing condition (handwritten/typed) matched (match) or mismatched (mismatch) the participants' typical note-taking style (based on responses to the Note-Taking Questionnaire administered at the end of the experiment), all *p*s>.140.

Experiment-Wide Analysis: To examine potential differences in trends across Experiments 1 and 2, data from Experiments 1 and 2 were submitted to an ANOVA that treated the note-taking condition (read/type) and the deception condition (no deception/deception) as between-participants factors, and question type (factual/application) as a within-participants factor, as well as Experiment (1/2) as a between-subjects factor. The main effect of the Experiment was significant $F(1,145)=4.12$, $p=.044$, $\eta_p^2=.028$, with the performance overall higher in Experiment 1 (.62) than 2 (.55), all other *p*s>.191.

Correlations with OSPAN. As in Experiment 1, we used the OSPAN performance total score. Unlike Experiment 1, OSPAN performance was not significantly correlated with the overall average proportion correct (i.e., collapsed across question type); *p*=.346 (see Figure 6).

Figure 6

Experiment 2 Correlations between the average of proportion correct responses and total OSPAN Score

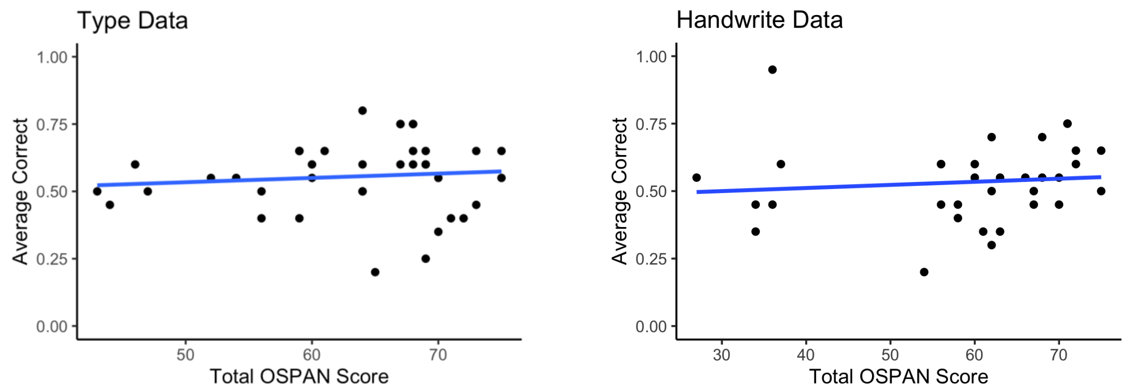


Note. Correlations between the total OSPAN score and average proportion correct overall performance for Experiment 2.

OSPAN by Note Type. Given our *a priori* interest in the effect of note-taking condition (handwritten/typed), we also calculated the previous correlation separately for typed and handwritten data. Unlike Experiment 1, there was no numerical difference between the handwritten, *r*=.103, *p*=.568, and typed, *r*=.101, *p*=.546 conditions; like Experiment 1, the correlations did not differ significantly from one another, *Fisher's Z*=-0.814*,* *p*=0.416 (see Figure 7).

Figure 7

Experiment 2 Correlations between the average proportion of correct responses, total OSPAN Score, and note-taking modality

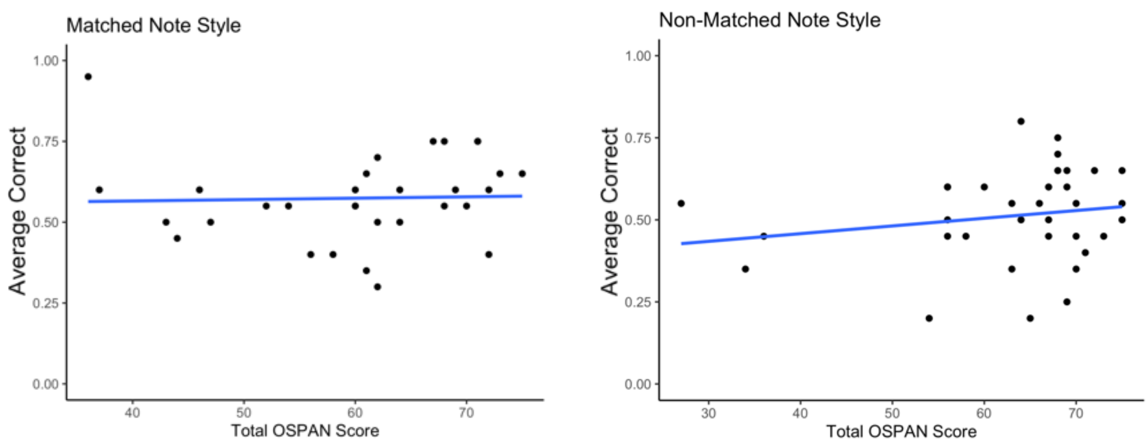


Note. Correlations between the total OSPAN score and average proportion correct overall performance, separated for typed versus handwritten data, for Experiment 2.

OSPAN by Note Type Match. To further assess the influence of OSPAN, we also examined whether a match between the assigned note-taking condition (handwritten/typed) and the participants' typical note-taking style influenced the effect of OSPAN. To do this, we separated the data into participants whose designated note-taking style matched (n=33) and mismatched (n=34) their typical note-taking style. OSPAN was not significantly correlated with Average Correct for the Match Group p=.858, nor the Mismatch Group p=.292; these correlations did not significantly differ from one another, *Fisher's* z=-.604, p=.546 (Figure 8).

Figure 8

Experiment 2 Correlations between the average of proportion correct responses, total OSPAN Score, and note-taking style



Note. Correlations between the total OSPAN score and average proportion correct overall performance, separated by matched versus non-matched note-taking style, for Experiment 2.

Mini-Discussion of Experiment 2. Experiment 2's test was delayed by 48 hours, which impacted the overall results compared to Experiment 1. The OSPAN performance was not significantly correlated with the overall average proportion of correct scores. This result is unsurprising given that the delayed test no longer relied on the participant's working memory capacity to remember the lecture information. Test performance was overall higher in Experiment 1—a testament to the decline in lecture information recall over time. Although the delay influenced the effect of OSPAN scores, we still wanted to investigate whether the matched and non-matched note-taking conditions, as related to OSPAN scores, correlated with overall performance. While these correlations were not significant in Experiment 2, their trends were similar to Experiment 1. We urge future research to continue investigating individual differences between participants since lecture note-taking is a complex phenomenon, and the decision to offload cognition within a lecture context can be affected by numerous factors.

General Discussion

The present study aimed to investigate the impact of participants' study expectations on the encoding effect of taking handwritten and typed notes, while also exploring the influence of studying expectation, working memory capacity, and individual note-taking differences on lecture comprehension.

Experiment 1 demonstrated the importance of investigating individual differences in note-taking research, such as considering working memory capacity and matching note-taking conditions to individual note-taking preferences. Although we approach our results cautiously, the trends in non-matching a participant's note-taking preference with their assigned experimental note-taking condition show a potentially detrimental correlation to their lecture performance *if* their working memory capacity is on the lower end of the spectrum. While people with a higher working memory capacity are not as affected by experimental manipulations that heighten their cognitive load (e.g., redundant versus complementary slides, relevant versus irrelevant images; Fenesi et al., 2014, 2016), those with a lower working memory capacity are often at a loss when it comes to lecture manipulations that burden their cognitive load, such as assigning them an unfamiliar note-taking condition.

Interestingly, overall OSPAN scores were significantly correlated with lecture comprehension on immediate testing: the higher a participant's working memory capacity, the better their scores. Working memory capacity, however, did not have a differential effect on the note-typing condition. Whether participants handwrite or type their notes, their note-taking condition, even when related to their working memory capacity or the failed promise to study their notes, does not influence their lecture comprehension.

Experiment 2 examined whether the above results would persist with a 48-hour delay in testing. In an educational setting, students rarely need to rely on their notes at the end of the lecture. Quizzes and tests are often administered after a delay. Those who expected to study their notes two days later, before the test, did not perform worse than those who were not expecting a study session. These results follow the same pattern as our previous, lecture-based cognitive offloading research, where we found no differences between participants who were told they could study their notes before a test and those who took no notes. Given the inconsistent effect when applied to a lecture-like environment, we encourage future studies to explore various offloading conditions, further investigate individual differences, and run in-depth analyses of note-taking quality.

Limitations with the Offloading Manipulation. A limitation of our study was excluding the opportunity for some participants to study their notes. While our previous studies only looked at immediate testing and studying, we believe delayed testing paired with studying might yield interesting results. Moreover, we told participants from the beginning whether they'll be studying their notes or not (even though part of that was deceptive). Future studies should allow participants to take notes as a means to learn the lecture, and only be cued to "saving" or "not saving" their notes once they have finished watching the lecture.

Educational Implications of Individual Differences. Due to the widely debated topic of note-taking (Bahr, 2022; Magdolen, 2022; May, 2014), and given the importance note-taking plays in our education and life in general, future research should explore note-taking and individual differences more systematically, especially in a real classroom environment. Our next steps are investigating note-taking habits and their correlation to quiz and final exam scores in a large Introductory Psychology class. Our preliminary investigations in the classroom have shown promising results, and we look forward to further investigating how various note-taking modalities (including some provided by the course, such as a comprehensive course handbook), correlate with students' scores and their metacognitive judgments of learning. We plan to explore the effect of note-taking modalities on course performance for open-book and closed-book tests, and evaluate short-term retention (i.e., weekly quizzes) and long-term retention evaluations (i.e., final exams). While classroom research has its challenges, we are excited by the intrinsic motivation and “real-world” stakes that note-taking has in a real course. As our ultimate research goal is to bridge the translation gap between educational research in note-taking and inclusive, practical applications for educators and students, we hope to learn more from our future research, by adapting note-taking research practices to the classroom learning experience.

References

Adler, R. F., & Benbunan-Fich, R. (2012). Juggling on a high wire: Multitasking effects on performance. *International Journal of Human-Computer Studies*, *70*(2), 156–168. https://doi.org/10.1016/j.ijhcs.2011.10.003

Annis, L., & Davis, J. K. (1975). The Effect of Encoding and an External Memory Device on Note Taking. *The Journal of Experimental Education*, *44*(2), 44–46. https://doi.org/10.1080/00220973.1975.11011522

Bahr, Sarah. (2022, January 21). Retrieved October 10, 2022, from https://www.nytimes.com/2022/01/21/insider/the-case-for-writing-longhand-its-about-trying-to-create-that-little-space-of-freedom.html

Boekaerts, M., Zeidner, M., Pintrich, P. R., & Pintrich, P. R. (Eds.). (1999). Handbook of self-regulation. Elsevier Science & Technology.

Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, *105*(2), 299–309. https://doi.org/10.1037/a0030367

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology*, *51*(1), 42–100. https://doi.org/10.1016/j.cogpsych.2004.12.001

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

Dunkel, P., & Davy, S. (1989). The heuristic of lecture notetaking: Perceptions of American & international students regarding the value & practice of notetaking. *English for Specific Purposes*, *8*(1), 33–50. https://doi.org/10.1016/0889-4906(89)90005-7

Fenesi, B., Heisz, J. J., Savage, P. I., Shore, D. I., & Kim, J. A. (2014). Combining Best-Practice and Experimental Approaches: Redundancy, Images, and Misperceptions in Multimedia Learning. *The Journal of Experimental Education*, *82*(2), 253–263. https://doi.org/10.1080/00220973.2012.745472

Fenesi, B., Kramer, E., & Kim, J. A. (2016). Split-Attention and Coherence Principles in Multimedia Instruction Can Rescue Performance for Learners with Lower Working Memory Capacity: WMC and multimedia learning. *Applied Cognitive Psychology*, *30*(5), 691–699. https://doi.org/10.1002/acp.3244

Fenesi, B., Sana, F., Kim, J. A., & Shore, D. I. (2015). Reconceptualizing Working Memory in Educational Research. *Educational Psychology Review*, *27*(2), 333–351. https://doi.org/10.1007/s10648-014-9286-y

Fenesi, B., Vandermorris, S., Kim, J. A., Shore, D. I., & Heisz, J. J. (2015). One size does not fit all: Older adults benefit from redundant text in multimedia instruction. *Frontiers in Psychology*, *6*, 1–9. https://doi.org/10.3389/fpsyg.2015.01076

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

Ghilic, I., Pachai, A. A., Lorentz, L., & Shore, D. I. (2022). Forget-Me-Not: The Effects of Note-Taking on Cognitive Offloading and Learning. [Unpublished manuscript].

Hadwin, A. F., Kirby, J. R., & Woodhouse, R. A. (1999). Individual differences in notetaking, summarization, and learning from lectures. *Alberta Journal of Educational Research, 45*(1), 1–17.

Kauffman, D. F., Zhao, R., & Yang, Y.-S. (2011). Effects of online note taking formats and self-monitoring prompts on learning from online text: Using technology to enhance self-regulated learning. *Contemporary Educational Psychology*, *36*(4), 313–322. https://doi.org/10.1016/j.cedpsych.2011.04.001

Kiewra, K. A. (1982). Theoretical orientations and instructional implications of notetaking and review. The Florida State University.

Kiewra, K. A. (1989). A review of note-taking: The encoding-storage paradigm and beyond. *Educational Psychology Review*, *1*(2), 147–172. https://doi.org/10.1007/BF01326640

Kiewra, K. A., Dubois, N. F., Christensen, M., Kim, S.-I., & Lindberg, N. (1989). A more equitable account of the note-taking functions in learning from lecture and from text. *Instructional Science*, *18*(3), 217–232. https://doi.org/10.1007/BF00053360

Kraushaar, J. M., & Novak, D. C. (2010). Examining the Effects of Student Multitasking With Laptops During the Lecture, *Journal of Information Systems Education 21*(12), 241–252.

Magdolen, C. (2022, September 14). Caroline Magdolen | Why I handwrite my notes on paper. The DP. Retrieved October 10, 2022, from https://www.thedp.com/article/2022/09/why-i-handwrite-my-notes-on-paper

Makany, T., Kemp, J., & Dror, I. E. (2009). Optimising the use of note-taking as an external cognitive aid for increasing learning. *British Journal of Educational Technology*, *40*(4), 619–635. https://doi.org/10.1111/j.1467-8535.2008.00906.x

May, C. (2014, June 3). A Learning Secret: Don't Take Notes with a Laptop. Scientific American. Retrieved October 10, 2022, from https://www.scientificamerican.com/article/a-learning-secret-don-t-take-notes-with-a-laptop/

Morehead, K., Dunlosky, J., Rawson, K. A., Blasiman, R., & Hollis, R. B. (2019). 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

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

Peper, R. J., and Richard, E. M. (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

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

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

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

Sparrow, B., Liu, J., & Wegner, D. M. (2011). Google Effects on Memory: Cognitive Consequences of Having Information at Our Fingertips. *Science*, *333*(6043), 776–778. https://doi.org/10.1126/science.1207745

Stacy, E. M., & Cain, J. (2015). Note-taking and Handouts in The Digital Age. *American Journal of Pharmaceutical Education*, *79*(7), 1–6. https://doi.org/10.5688/ajpe797107

Storm, B. C., Stone, S. M., & Benjamin, A. S. (2017). Using the Internet to access information inflates future use of the Internet to access other information. *Memory*, *25*(6), 717–723. https://doi.org/10.1080/09658211.2016.1210171

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*(3), 498–505. https://doi.org/10.3758/BF03192720

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), 323–338. https://doi.org/10.1037/0022-0663.86.3.323

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

Appendix A

Sample Quiz Questions

Topic: Visual Memory

Factual Questions

Q: The capacity of an individual's visual memory is correlated with which of the following?

A. Processing abilities, such as multi-tasking.

B. Spatial abilities, such as mental rotation.

C. Cognitive abilities, such as general comprehension*.

D. Motor abilities, such as hand-eye coordination.

Q: Which of the following best states the findings of the experiment by Zhang and Luck where participants were shown three coloured squares and asked to recall the colour of one particular square?

A. Participants showed either very high or very low accuracy*.

B. Participants showed a gradual decrease in accuracy as the latency to recall the colour increased.

C. Participants showed the highest accuracy when the colour of the square was yellow.

D. Participants showed a gradual increase in accuracy as the latency to recall the colour increased.

Application Questions

Q: Jessica works at a flower shop and has a great deal of experience with several different flowers. If Jessica were shown a picture of a wedding bouquet, what would we expect with regards to her visual memory?

A. The picture would not likely be transferred to visual long-term memory due to the number of similar images Jessica has previously seen.
B. The picture would likely remain in visual working memory until Jessica is distracted, at which point it would be eliminated from memory.
C. **The picture would likely be transferred from visual working memory to visual long-term memory*.**
D. The picture would likely enter visual working memory and be stored with great detail.

Q: Carlos is a firefighter in a small town who routinely extinguishes fires and escorts victims to local hospitals. Which of the following image descriptions best reflect Carlos' visual memory?

A. A picture of a burning building would be transferred to visual long-term memory, whereas a picture of a hospital would be eliminated from visual working memory.
B. A picture of a golf course would be transferred to visual working memory, whereas a picture of a burning building would be eliminated from visual working memory.

C. A picture of a roller coaster would be eliminated from visual long-term memory, whereas a picture of a hospital would be retained in visual long-term memory.

D. A picture of an ocean wave would be eliminated from working memory, whereas a picture of a burning building would be transferred to visual long-term memory*.

CHAPTER 5

GENERAL DISCUSSION

COGNITIVE OFFLOADING AND NOTE-TAKING: REFLECTING ON APPLIED RESEARCH AND INCLUSIVE LEARNING DESIGN

“One second, I need to write this down.” We are faced with important information that we want to remember throughout the day, regardless of whether we are prepared with our preferred "note-taking" tools. Some people might reach for a handwriting utensil, while others might choose mobile note-taking or voice-to-text options. No matter the modality, we all have a similar goal: maintaining a record of information “in the world” instead of only using our memory stores to recall information. How might we define, translate, and explore this valuable practice in our educational settings?

1. The Motivations and Contributions of the Current Thesis

The current thesis explored the impact of cognitive offloading, note-taking, and individual differences on learning. This research stemmed from the unsettling popularity of educators wanting to ban laptops in their classrooms (Bahr, 2022; Magdolen, 2022; May, 2014) due to widely publicized results on handwriting leading to superior learning compared to typed notes (Mueller & Oppenheimer, 2014). Part of the note-taking literature provides evidence on the benefits of handwriting, while some literature supports laptop note-taking. The fragmented nature of this collective body of research leaves researchers, learning designers, educators, and learners at a crossroads: what practical application could be gleaned from note-taking research and applied in the classroom? Conclusions from the literature were even harder to apply, given the types of materials used for the "learning" and "testing" components in some research studies. Mueller and Oppenheimer (2014), for example, used Graduate Record Examination (GRE) recorded passages as their "lecture" content. As educators and researchers, we were cautious about the ecological validity of note-taking research and awed by the complexity of the world of note-taking. The current thesis explores laboratory studies using novel materials and methods inspired by blended-classroom designs, with lectures and tests adapted from actual courses. Our research framework is built on the principles of cognitive offloading and individual differences throughout various note-taking conditions. The current thesis advances our knowledge of the intersectionality between cognitive offloading, note-taking, and inclusive learning design. It encourages our audience to view note-taking through an accessibility and inclusivity framework. Our next steps involve exploring long-term classroom research and investigating note-taking habits and their relation to class performance. We also plan to review alternative cognitive offloading practices within the critical disability literature since note-taking is not the same for everyone. People with motor or sight issues might not even be able to engage in the process of taking notes, and learners with other disabilities might be denied offloading. We hope to advance the applied framework of investigating cognitive offloading through a critical disability literature paradigm while inspiring educational communities to lead with empathy when thinking about students' varied needs and design for accessible, inclusive, and holistic learning experiences.

2. What the Data Chapters Taught Us: A Tale of Exploring Individual Differences

Chapter 2 built on the cognitive offloading and proactive interference research by Storm and Stone (2015) and added a note-taking manipulation to the study trials. We also developed an experimental design to work around the extensive procedural manipulation employed by Storm and Stone (2015), to decrease experimenter involvement and increase trial randomization, using a Psycho-Py delivered experimental procedure. Our new process replicated the offloading benefits found by Storm and Stone (2015) in Experiments 1A and 1B and showed varied effects between participants who studied lists of words by reading versus typing them. When investigating individual differences, the number of words typed at study did not make a difference in recall in Experiment 1A, when participants did not get to study what they typed. When participants got to restudy the word lists, however, the more accurate the typed record, the better the participant's recall. In Experiment 1B, by contrast, when participants were not able to study their notes, the more words they had typed at study, the lower their recall performance, leading to a deficit in learning in a time-crunch scenario in which participants had just enough time to type the words, and less time to potentially type *and* read the words; we infer that the lowered trial time encouraged participants to transcribe the words mindlessly.

Experiment 2 explored a cognitive offloading methodology, similar in theory to Experiments 1A and 1B, by introducing more ecologically-valid lecture materials and tests. We investigated whether participants would offload the first lecture information and boost their performance on the second lecture when taking notes on the first lecture. This initial study did not uncover any differences in performance between those who took notes for later study and those who watched the lecture. Chapter 2 provided a foundation for applying cognitive offloading to a note-taking paradigm and exploring potential differences beyond overall recall scores.

Chapter 3 explored a variety of note-taking manipulations, with two consistent key comparisons: lecture comprehension between typed and handwritten notes and test scores for factual and application questions. The experiments tested note-taking modality (handwritten/typed) versus note structure (summarized/transcribed), type of multimedia lecture slides (redundant/complementary slide information), content context (reading a textbook passage before or after the lecture), and type of test questions (factual/application). Instead of looking at overall test performance, we had an even split of factual (i.e., surface level) and application (i.e., deeper level) multiple choice questions, and we tested the interaction between the type of question and the experimental manipulations. The experiments in Chapter 3 have a similar thread in their conclusion: the learning superiority of handwritten notes is elusive, and we seldom see differences in lecture comprehension between handwritten and typed notes. We find a marginally significant encoding benefit to handwriting notes in Experiments 1 and 2A and only in the application questions. We conclude that handwriting is not inherently superior to typing, and multiple mechanisms are at play in the complex process of taking (and studying) notes. Our Chapter 3 studies were also limited to testing the encoding hypothesis: does a particular note-taking modality lead to better "immediate" learning? However, most people take notes and offload that information for later review. In our studies (as with most note-taking literature), we also assigned participants to a note-taking condition. These limitations inspired our Chapter 4 work, where we wanted to delve further into individual differences in memory capacity, its effect on immediate and delayed testing, and the influence of assigning a matched note-taking condition to a participant's usual method of taking notes.

Chapter 4 had two main goals: to investigate how participants' study expectations impact the encoding effect of handwritten and typed notes and to explore the influence of working memory capacity and individual note-taking differences on lecture comprehension. As we have seen in previous studies, looking at overall lecture comprehension (i.e., test performance) does not tell the entire story of the various effects of note-taking on learning. We see that lecture comprehension suffers for those lower on the working memory capacity spectrum when their usual note-taking habits do not match their assigned note-taking condition. Overall working memory capacity also correlates with immediate test scores: the higher the capacity, the higher the scores (regardless of note-taking condition). In a delayed test condition, the overall working memory correlations disappear since participants no longer rely on their short-term memory to complete the test. However, we did not find any differences between participants who took notes and expected a study session and participants who were not expecting to study their notes before the delayed test. The decision to offload cognition and rely on external memory stores for future studying is complex and can be affected by various factors, so we look to future studies to employ a variety of offloading conditions and individual differences in their research design.

Due to some of our methodological limitations, caution must be exercised when using these data to introduce practical applications when designing learning experiences. Instructing participants to take notes via a specific modality, recruiting mostly “novice” higher education students, removing participant’s control over the lecture presentation by their inability to pause and self-pace their study and review their notes, and not providing extrinsic motivation mechanisms for participants to strive to do their best, are a few limitations of our laboratory designs. The current studies are mostly discussed within the context of undergraduate-level lecture content, with first and second-year students acting as our participants. Future research should expand the scope of applied cognitive studies to other educational contexts and populations, such as non-traditional course structures, older adults, and neurodivergent people.

Our next steps are to take our research into the actual classroom and explore questions related to note-taking habits and their correlation to class performance on short-term, long-term, open-book, and closed-book tests. Our preliminary classroom investigations have yielded interesting, replicable results. We would like to expand the goal of our classroom research and include qualitative measures that explore note-taking accessibility in a large, blended course.

3. Beyond Encoding: Note-Taking and Lecture Considerations

Our research in cognitive offloading, note-taking, and underlying individual differences is one piece of the empirical literature jigsaw puzzle on the effects of note-taking on learning. Reviewing the literature we presented throughout our data chapters, it is surprising to see similar-looking experiments leading to different results. We have seen a replication crisis in psychology (Maxwell et al., 2015), and the field of note-taking is complex and fragmented. There are multiple note-taking factors to keep in mind: structure, style, content, completeness, individual differences, test procedure, notes review, cognitive load, and accessibility considerations. Likewise, several lecture considerations can influence how learners take notes: modality of lecture material, visual versus text-based, lecture speed, lecture structure, and topic (Jansen et al., 2017). Our research on note-taking and encoding in a lab environment, combined with the note-taking literature, has limited reach and influence in the decision-making process of how we might design and develop our real classroom learning experiences. While learning from cognitive research and discovering the “ideal” conditions in which we excel at learning, it is equally important to extend applied education research into ecologically valid and diverse environments.

The Cognitive Process of Taking Notes: Where Does the Research Fit?

Jansen et al. (2017) propose the contextualization of note-taking research into the 5-step cognitive process of taking notes: 1. Comprehend the lecture material; 2. Identify key points; 3. Link material to prior material and notes; 4. Paraphrase or summarize; and 5. Transform to written form. Experiments in this field can thus connect to one or more of these steps and obtain different results depending on which part of the puzzle they are exploring. Future experimental work could consider variables that span the entire process instead of only focusing on fragments of the note-taking process. Most of our research manipulations, for example, live in the first and fifth steps of the process, with variables touching on the fourth step.

When looking at these complex cognitive processes (i.e., note-taking and cognitive offloading), let us revisit the original motivation for this current thesis: the "villainization" of laptops as a medium for taking notes and previous trends of reducing laptop/tablet use in the classroom. Based on our findings and the broader literature, we propose that taking action against technology in the classroom is not only detrimental to learning: it is ableist. The increasing use of technology in note-taking and the classroom was prevalent before the COVID pandemic (Witherby & Tauber, 2019), so technology is here to stay. As learning designers and researchers, we should ask: how might we encourage note-taking and learning strategies that promote learning beyond the argument of note-taking modality? The current section summarizes a few research findings and provides tips for note-taking and learning strategies.

Promoting the Completeness of Notes. Flanigan and Titsworth (2020) saw that digital distraction was a stronger predictor of lecture comprehension than the note-taking method. However, regardless of distractions, there was a high proportion of incomplete idea units in students' notes (approx. 20%). While students were good at detecting the "superordinate" topics within a lecture, they were not as well-versed at identifying the "subordinate" topics—one-third of supporting lecture details were incomplete in students' notes. Luckily, only the total proportion of the complete idea units predicted lecture comprehension performance. Flanigan and Titsworth (2020) concluded that storing and studying incomplete idea units did not hinder learning: as the number of incomplete idea units increased, the number of complete ones increased significantly. Theoretically, we can explain these findings as having access to incomplete idea units leading to overcoming a recognition threshold, thus helping the recollection of complete idea units. *Tip #1:* As educators, we should strive for our students to have as many complete idea units as possible in their notes. We can promote the completion of idea units by taking lecture pauses and allowing students to compare their notes. We could also supplement the lecture information with various asynchronous formats, and we can streamline the presented content as both a synchronous and asynchronous option.

The Benefits of Providing Records of Notes. Multiple factors predict skill in note-taking strategies: transcription fluency, working memory capacity, spelling/grammar, and the ability to identify main ideas (Peverly et al., 2007). *Tip #2*: Providing students with the instructor's lecture notes, a transcript, or general lecture materials can free some of their cognitive load and working memory resources typically used for keeping up with the lecture content and use them for making content inferences, forging connections between topics, and summarizing information (Kiewra, 1985). While the literature exposes the advantages of both encoding information at the time of the lecture and of reviewing one's notes, we encourage educators to consider the benefits of reviewing good records of notes as allowing students to generate connections amongst complete idea units.

Working Memory Capacity and Laptop Transcription. There are similar cognitive demands between note-taking and working memory capacity (WMC) tasks (Bui & Myerson, 2014). However, the limited literature on the connection between WMC and note-taking has produced mixed results (Hadwin et al., 1999). From a technological perspective, however, Bui et al. (2013) have repeatedly replicated their findings on typed notes, idea units, and connections to WMC. We learn from Bui et al. (2013) that the proportion of correctly captured idea units is higher when participants are told to *transcribe* the lecture content on a laptop instead of *organizing* their notes. In the transcribed condition, the percentage of idea units was the same, regardless of WMC. In contrast, the organized condition showed a difference between individuals with high versus low WMC: a lower

WMC led to fewer idea units. *Tip #3:* Consider the demands on the learner's WMC and how we might work with students, given the increasing cognitive demands of our current educational setting (Bui & Myerson, 2014). How might students with varying strengths and individual differences navigate a frequently-changing learning landscape? Providing students with an organized learning environment, opportunities to get assistance and extra information, and the choice to use technology however is best for them are only a few steps by which we can decrease some of their over-burdened cognitive loads.

Alternative Ways to Engage in Note-Taking and Their Benefits. Mobile note-taking, guided notes, collaborative note-taking, and voice note tools are a few examples of ways learners can explore a note-taking mechanism that works for their circumstances. A 5-year note-taking study on mobile/tablet use by dental and medical students yielded positive results from the users, even though there was an initial push-back on the technology at a program level. Pyörälä et al. (2019) learned that providing medical and dental students with tablets also came with a few program requirement considerations. The mobile note-taking was maximized when the provided instructional content was compatible with the device. The students also needed to develop a system to organize their notes, digital libraries, and note-taking apps. Once they learned how to best use their new devices, students valued digital note-taking and having "on-demand" knowledge, as well as a robust study tool and "reservoir" of materials. Iannone and Miller (2019) and Rahayu et al. (2022) can attest to the helpfulness of instructor-guided lecture notes, as opposed to the traditional "chalk and talk" lecture. Students had an easier time organizing their notes when given the lecture headings and key information in advance; their notes were more ordered, easier to navigate, and helpful during reviews and revisions. The instructors also noted that once some of the note-taking pressure was relieved, class engagement increased! The note-taking pressure can also be reduced in collaborative note-taking scenarios (Courtney et al., 2022). Collaborative note-takers had higher scores on quizzes, as collaboration increased their engagement with the content while leading to better, summarized, and higher-quality notes. Another way to promote a more generative and conceptual understanding of lecture content is by using a voice-note-taking tool designed for digital learning environments (Khan et al., 2020). A voice-to-text tool can enable learners to elaborate more on the content they are trying to capture and have more idea units in their notes. These tools are often used for learners who require more accessible ways of taking notes, but they are seldom feasible in a live, in-person classroom. A voice-to-text tool is best suited for asynchronous, self-paced, and hybrid learning environments, which offer more choice and flexibility in the learner's experience.

4. Conclusion: Offloading in a Post-Pandemic World

A recent HEQCO report (Napierala et al., 2022) stated how the pandemic created new learning challenges and amplified existing barriers for some students. The post-pandemic practices of going back to in-person learning are disproportionately affecting learners. Low-income students prefer having hybrid courses, as it allows for balancing multiple priorities (e.g., work, family care), while affluent students prefer in-person classes. An online article from the University of Ottawa (Otten, 2022) highlights how over 80 students have been fighting for accessibility accommodations, and they face dropping out of school and losing their employment due to the demand for students to return to in-person classes, the COVID risk associated with being on campus, and accessibility barriers of in-person learning. One student stated that “every semester of the pandemic, I repeatedly requested my need for recorded lectures be formalized, and every semester, I was denied until Winter 2022. Students received multiple emails throughout the pandemic threatening to return to in-person learning,” she said. “That is how I received every single email: as a threat to the removal of the **inclusivity I had been denied until the entire population required it.**” Asch (2017) suggests a shift in viewing the ableist dichotomy of “disabled” and “not disabled.” Instead, they urge us to modify our environments, so they are not disabling.

We want our discussion to inspire and guide future research to address accessibility and inclusivity issues prevalent in this literature. Some groups are cut out entirely from our research population—note-taking (especially handwriting) does not apply or is vastly altered in some contexts. For example, people with specific motor or sensory considerations cannot take notes. As we draw conclusions from cognitive research on what variables lead to the “best” learning conditions, we should also consider the inclusivity of our statements.

The current thesis is at the intersection of applied cognitive research, cognitive offloading, note-taking, and individual differences. This research began as a means to understand how note-taking interacts with our cognitive processes and how to best leverage these processes to encourage durable learning. Our findings led us past seeking definitive recommendations since we saw how rigid cognitive "rules" and principles in applied cognition break down in the face of individual differences. Instead, our research inspired us to focus on how our learners differ and how our systems can be more inclusive of the population's diverse needs. Although our research is not directly testing inclusive design strategies, exploring individual differences and their effects on learning is a step towards considering the learner individually and holistically. From a learning experience perspective, we hope our research advances our collective knowledge of the multi-faceted approach to studying note-taking, the benefits and pitfalls of offloading cognition, and the importance of exploring individual differences in applied education research.

References

Asch, A. (2017). Critical race theory, feminism, and disability: Reflections on social justice and personal identity. *Ohio State Law Journal, 62*(1), 391–423. https://doi.org/10.4324/9781315257747-34

Bahr, Sarah. (2022, January 21). Retrieved October 10, 2022, from https://www.nytimes.com/2022/01/21/insider/the-case-for-writing-longhand-its-about-trying-to-create-that-little-space-of-freedom.html

Bui, D. C., & Myerson, J. (2014). The role of working memory abilities in lecture note-taking. *Learning and Individual Differences*, *33*, 12–22. https://doi.org/10.1016/j.lindif.2014.05.002

Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, *105*(2), 299–309. https://doi.org/10.1037/a0030367

Courtney, M., Costley, J., Baldwin, M., Lee, K., & Fanguy, M. (2022). Individual versus collaborative note-taking: Results of a quasi-experimental study on student note completeness, test performance, and academic writing. *The Internet and Higher Education*, *55*, 1–14. https://doi.org/10.1016/j.iheduc.2022.100873

Flanigan, A. E., & Titsworth, S. (2020). The impact of digital distraction on lecture note taking and student learning. *Instructional Science*, *48*(5), 495–524. https://doi.org/10.1007/s11251-020-09517-2

Hadwin, A. F., Kirby, J. R., & Woodhouse, R. A. (1999). Individual differences in notetaking, summarization, and learning from lectures. *Alberta Journal of Educational Research, 45*(1), 1–17.

Iannone, P., & Miller, D. (2019). Guided notes for university mathematics and their impact on students' note-taking behaviour. *Educational Studies in Mathematics*, *101*(3), 387–404. https://doi.org/10.1007/s10649-018-9872-x

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

Khan, A. A., Nawaz, S., Newn, J., Lodge, J. M., Bailey, J., & Velloso, E. (2020). *Using voice note-taking to promote learners' conceptual understanding* (arXiv:2012.02927). arXiv. http://arxiv.org/abs/2012.02927

Kiewra, K. A. (1985). Students' note-taking behaviors and the efficacy of providing the instructor's notes for review. *Contemporary Educational Psychology*, *10*(4), 378–386. https://doi.org/10.1016/0361-476X(85)90034-7

Magdolen, C. (2022, September 14). Caroline Magdolen | Why I handwrite my notes on paper. The DP. Retrieved October 10, 2022, from https://www.thedp.com/article/2022/09/why-i-handwrite-my-notes-on-paper

Maxwell, S. E., Lau, M. Y., & Howard, G. S. (2015). Is psychology suffering from a replication crisis? What does "failure to replicate" really mean? *American Psychologist*, *70*(6), 487–498. https://doi.org/10.1037/a0039400

May, C. (2014, June 3). A Learning Secret: Don't Take Notes with a Laptop.

Scientific American. Retrieved October 10, 2022, from https://www.scientificamerican.com/article/a-learning-secret-don-t-take-notes-with-a-laptop/

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

Napierala, J., Pilla, N., Pichette, J., & Colyar, J. (2022) *Ontario Learning During the COVID-19 Pandemic: Experiences of Ontario First-year Postsecondary Students in 2020–21*. Toronto: Higher Education Quality Council of Ontario.

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

Pyörälä, E., Mäenpää, S., Heinonen, L., Folger, D., Masalin, T., & Hervonen, H. (2019). The art of note taking with mobile devices in medical education. *BMC Medical Education*, *19*(1), 1–10. https://doi.org/10.1186/s12909-019-1529-7

Rahayu, A. T., Muchyidin, A., & Manfaat, B. (2022). The Application of The Guided Note-Taking (GNT) Learning Method and its Effect on Student's Understanding of Mathematics Concepts. *Journal of General Education and Humanities, 1*(1), 12–20. https://journal-gehu.com/index.php/gehu

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

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