

**Drawing benefits memory and comprehension by establishing and strengthening the link
between verbal and visual percepts**

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

Experiment 1 (Chapter 2) is published in *Aging, Neuropsychology, and Cognition* (Tran & Fernandes, 2023). Experiment 2 (Tran & Fernandes, 2026) is under review. Experiment 3 (Tran, White, & Fernandes, 2026) is under review. Experiment 4 (Chapter 4) is published in *Experimental Psychology* (Tran & Fernandes, 2024).

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Chapter 2:

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Abstract

Researchers have long been interested in identifying ways to enhance both the quantity and quality of human memory, and the mechanisms underlying their benefit. The use of drawing as an encoding technique has been shown to reliably improve memory for lists of words, definitions of terms, and autobiographical events. What remains unexplored is how the magnitude of the benefit from drawing compares to that from other encoding techniques, and its mechanism of action. In Experiment 1, I showed that drawing, writing, and reading aloud as encoding techniques yielded better memory than silently reading words, with drawing leading to the largest boost. Importantly, age differences in memory emerged only when drawing was used as the encoding strategy, in line with previously reported age-related deficits in generating imagery, or integrating it with motoric processes. Despite this, concrete relative to abstract words that were drawn during encoding were better retained, demonstrating a stable benefit of visuo-spatial representation, regardless of age. In Experiment 2, I assessed the extent to which personally generating one's own production was critical to the observed memory benefit. Replicating Experiment 1, drawing at encoding benefitted memory more than writing or reading words. This occurred regardless of whether it was performed or observed in-person or online. In line with common-coding-theory this finding suggests that perceiving an action activates the same motoric processes in the brain as performing it. However, the magnitude of the drawing benefit was greatest when performed rather than observed, suggesting an additional role of personal relevance in modulating the drawing benefit. In Experiment 3, I examined whether repetition by tracing one's initial drawing, or generating multiple novel related ones, differentially benefitted memory. The former enhanced free recall of target words more than the latter. This suggests that establishing a strong visual percept underlies drawing's benefit to memory. Finally, in Experiment 4, I assessed the utility of drawing as a cognitive tool in educational contexts. Drawing and paraphrasing of definitions of novel academic terms, during encoding, resulted in better performance on a multiple-choice test of concept comprehension, relative to silently reading. Results suggest that techniques that invoke re-representation of the to-be-remembered text into another format, be it into a picture (drawing) or personally relevant summary (paraphrasing), are particularly effective at improving cognitive task performance. The experiments in this dissertation suggest that a critical component of how drawing improves memory and comprehension is the linking of verbal information to concrete visual referents, which results in more easily retrievable representations.

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Dedication

For Missy, Mocha, Luna, and Micah.

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Chapter 1

General Introduction

Memory plays a critical role in our ability to function in our day-to-day lives (Baddeley et al., 2014). It influences performance on school exams, our ability to learn new languages, converse with loved ones, drive to work, arrive on time for appointments, and adhere to prescription medications. Memory is a process by which we acquire, store, and retrieve discrete pieces of information (McDermott & Roediger, 2018). In memory research, encoding refers to the process by which we perceive, attend to, and acquire new information (McDermott & Roediger, 2018). While we are constantly engaging in encoding in our day-to-day lives (McDermott & Roediger, 2018), this process can occur either passively or actively. The resulting representation can range from a shallow, perceptual one to a deeper, conceptual one (Craik & Lockhart, 1972).

Given the critical role of memory, it is unsurprising that researchers have long been interested in identifying what factors influence encoding. Within the literature, it has been established that a variety of factors can improve memory performance, including the schedule with which new information is studied or rehearsed (Ebbinghaus, 1885), how we opt to organize or chunk it (Tulving, 1962), the number of times we encode it (Bower & Winzenz, 1969), and how we test our retention (Izawa, 1967; Karpicke et al., 2009; Roediger III & Karpicke, 2006). As well, whether we associate to-be-learned new information with a mental image (Bower, 1970; Morris et al., 1978; Paivio & Csapo, 1973), or process it conceptually (deeper; Craik & Lockhart, 1972), or relate it to ourselves personally (Rogers et al., 1977), or generate it (Slamecka & Graf, 1978) can influence the strength of the memory representation. Importantly, some suggest that

memory is enhanced when it is initially encoded using more than one sensory modality (verbal and motoric; Engelkamp & Zimmer, 1985; Paivio & Csapo, 1973), as well as when it is bizarre (McDaniel, 1986), concrete (Paivio et al., 1994), emotional (valenced/arousing; Cahill & McGaugh, 1995), distinct (Hunt, 1995), or schema-consistent (Tse et al., 2011). Given this literature, it is clear that the method by which you acquire and encode information influences its memorability.

Relatedly, numerous studies have demonstrated enhancements to memory when using explicit encoding techniques such as method of loci (Bower, 1970), rote rehearsal (Craik & Lockhart, 1972), elaborative rehearsal (Craik & Lockhart, 1972), generation (Slamecka & Graf, 1978), enactment (Engelkamp & Zimmer, 1985), reading aloud (MacLeod et al., 2010), writing (Forrin et al., 2012), and drawing (Wammes et al., 2016). The more contemporary encoding techniques of reading aloud, writing, and drawing have been demonstrated to confer a reliable and large memory benefit compared to a variety of other strategies (e.g., rote rehearsal, elaborative rehearsal, visualizing; Fernandes et al., 2018; MacLeod & Bodner, 2017). With drawing being the most recent of these strategies to be investigated, there are still outstanding questions regarding the exact mechanism underlying its effectiveness. While it has been common to make claims about mechanistic commonalities between writing, reading aloud, and drawing (Bailey et al., 2021; Bodner et al., 2020; Bodner & MacLeod, 2016; Forrin & MacLeod, 2018), there is limited evidence regarding the similarity or difference in their underlying mechanisms of action. In fact, different explanations have been proposed to account for the memory benefit from production techniques (e.g. reading aloud and writing) and drawing: distinctiveness for production (aloud or written; MacLeod et al., 2010) and the integration of multimodal processing for drawing (Wammes et al., 2019).

Encoding Techniques

Based on this previous literature, it appears that while numerous encoding techniques can benefit memory, they likely do so in different ways. As distinct accounts have been proposed to explain the benefit of drawing, reading aloud, and writing, a direct comparison of these within the same population would be helpful in determining whether they operate similarly. Comparing various encoding techniques, each with distinct proposed mechanisms of action, can also help identify the most effective way to encode information. In this dissertation, I compared the effectiveness of various encoding techniques while manipulating several factors, including participants' age, level of personal engagement, method of repetition, and the level of abstraction required given the type of information that is to be encoded. These variables were manipulated to disentangle what mechanisms were critical to the memory benefit, with a particular focus on drawing. I first describe various encoding techniques and then describe my manipulations applied across four experiments.

Reading Aloud (Production)

It has been demonstrated that when words are read aloud (termed 'production'), later recall is enhanced compared to when they are read silently (MacLeod et al., 2010). The benefit of producing items aloud during encoding has been replicated numerous times (Forrin et al., 2012; Forrin & MacLeod, 2018; MacLeod & Bodner, 2017), across a variety of materials (Fawcett et al., 2012; Knutsen & Le Bigot, 2014; Ozubko et al., 2012) and durations (Kelly et al., 2022; Ozubko et al., 2012), and has been demonstrated in recognition, free recall, and cued recall (Conway & Gathercole, 1987; Jones & Pyc, 2014; Jonker et al., 2014; Knutsen & Le Bigot, 2014; MacLeod & Bodner, 2017). Importantly for the current thesis, the use of production has

been shown to enhance memory, not only for concrete words, but for materials with abstract properties (e.g. essays; Ozubko et al., 2012). I will return to this point later in the dissertation.

Distinctiveness and strength-based accounts have proposed that reading a word aloud (auditory production) either provides more distinct speech information or creates a stronger memory trace in comparison to silently reading. This distinct speech information invokes two encoding modalities, as reading aloud requires articulation (motor) and audition (auditory; Icht & Mama, 2015; Mama & Icht, 2016). A distinctiveness-based account suggests that there is both a benefit to produced words, and a cost to non-produced words. In support of this, the use of production in comparison to silent reading activates multiple regions within the temporal lobe (e.g. primary auditory cortex and planum temporale), as well as the precentral gyri, postcentral gyri, and inferior motor regions (Bailey et al., 2021). This coincides with the proposal that recruitment of distinct speech information is a critical contributor to the production benefit. The pattern of brain activity also could suggest that produced words activate significantly more brain regions, and are likely creating a ‘stronger’ memory trace. Thus, this also supports a strength-based account, which posits that reading aloud enhances a word's fluency and familiarity, making it easier to later retrieve (MacLeod & Bodner, 2017).

In both distinctiveness and strength-based accounts, the representation produced when speaking aloud invokes two encoding modalities as reading aloud requires articulation (motor) and audition (auditory; Bailey et al., 2021; Icht & Mama, 2015; Mama & Icht, 2016), resulting in either a more salient (distinctiveness account) or stronger (strength-based account) memory representation. In addition, both the distinctiveness and strength-based accounts seem to suggest that the production benefit is perceptually- rather than semantically-based. That is, production as an encoding technique does not require the user to think about the meaning conveyed by the text,

limiting its utility for stimuli that typically benefit from semantic elaboration, such as concepts and their definitions.

Writing

It also has been shown that items written at encoding are better remembered than those that are silently read (Forrin et al., 2012). It has been proposed that writing sentences promotes access to the meaning of words in order to make associations with other words, while considering syntactic and lexical rules, and incorporates a motoric representation while forming letters (Flower & Hayes, 1981). Researchers have argued that orthographic representations may activate more complex and multilevel processing of letter chunks that require phonological coherence (graphemes; Kandel & Spinelli, 2010). In addition, writing is generally slower than reading aloud, requiring the representation to remain active for longer (Bourdin & Fayol, 1994, 2002). Importantly for the current thesis, it has been demonstrated that when students wrote definitions of concrete words, they began writing sooner, wrote more, and produced higher-rated definitions in comparison to abstract words (Tirr et al., 1979). These findings suggest that the meanings of concrete words were accessed more quickly and supported richer semantic elaboration during written productions than the meanings of abstract words (Tirr et al., 1979).

Writing is often referred to as an orthographic form of the production technique (Forrin et al., 2012; MacLeod & Bodner, 2017) and it has been suggested that the memory benefit from producing items stems from the creation of a representation that invokes two encoding modalities, motor and verbal (Forrin et al., 2012; Sadoski et al., 1997). Similarly to auditory production, this combined representation has been proposed to increase the salience (distinctiveness account; MacLeod et al., 2010) or familiarity (strength-based account; Bodner & Taikh, 2012) of the to-be-remembered information, facilitating retrieval. While it is common to

group spoken and written production effects together (Bailey et al., 2021; Bodner & MacLeod, 2016; Forrin & MacLeod, 2018), there is still little evidence regarding similarities or differences in their mechanism of action.

Drawing

Early work from Peynircioglu (1989) demonstrated that generating one's own drawing during encoding was more beneficial to later memory performance than rating the quality of a presented image, copying a presented image, or connecting the dots in numbered order to create an image. Classic work has also shown that associating verbal materials with a strong visual representation, whether it be a mental image or a physical one, results in enhanced retrieval for that information (Bower, 1972; Paivio, 1979; Richardson, 1975). This is believed to occur because the information gets encoded more richly and diversely (Paivio & Csapo, 1973; Rissenberg & Glanzer, 1986; Shepard, 1967; Standing, 1973). This mnemonic benefit, from associating an image with a word, has also been extended to more complex educational materials such as conceptual diagrams (Ainsworth & Loizou, 2003; Carney & Levin, 2002; Rigney & Lutz, 1976). If the inclusion of graphical information improves retention, it follows that the active *creation* of graphical information might further improve retention.

More recent studies (Wammes et al., 2016) have shown that drawing a sketch of to-be-remembered information confers a benefit to memory beyond that gained from writing out the information, viewing it, imagining it, or generating semantic associates to it. This benefit is observed even when equating for the time spent actively engaging in the task (Tran & Fernandes, 2023b; Wammes et al., 2016). That is, participants can create a single drawing when given 10 seconds to encode, but are able to write 4.11 words on average, yet we still observe a benefit of

drawing over writing (Tran & Fernandes, 2023b). The technique is also effective regardless of the user's drawing ability (Meade, Ahmad, et al., 2020). In fact, an only slightly reduced drawing benefit is observed when participants cannot see their own drawings (no-ink drawings; Wammes et al., 2019), or if they are only given the chance to prepare to draw without actually completing it (Wammes, Roberts, et al., 2018). Importantly for the current thesis, drawing has been shown to boost memory for a variety of stimulus types including more abstract information (Roberts & Wammes, 2021; Tran & Fernandes, 2024a), emotional words (Tran & Fernandes, 2023b), scenes (Peynircioğlu, 1989), autobiographical events (Tran et al., 2022), and academic terms and their definitions (Wammes et al., 2017).

Wammes and colleagues (2019) suggest that during drawing, one must first generate an internal representation of the intended drawing, then implement a motor sequence to translate that image to the page, and finally, view the created pictorial representation. As such, it is possible that the reason drawing produces such strong memories is because it provides several different sources of encoded information, building a strong multimodal memory trace. Indeed, simply preparing mentally to draw an image, without even actually physically drawing it, is enough to provide significant benefits to memory (Wammes, Roberts, et al., 2018). Moreover, fMRI studies demonstrated that drawing evokes neural activity in occipital (V1, V2, precuneus, lateral occipital cortex), anterior prefrontal, parietal, and motor regions (Fan et al., 2020; Roberts et al., 2024; Vinci-Booher et al., 2019). Given this, the neural basis of the drawing effect likely stems from the creation and integration of pictorial/imagery-based, and motor-based representations of to-be-remembered information, with verbal ones.

An alternative explanation of the drawing benefit is that it can be described as visual paraphrasing. That is, drawing requires that the user re-represents the meaning of the to-be-

remembered information into a personally unique image that is generated by the user (Fernandes et al., 2018a; Tran & Fernandes, 2024b). Previous work suggests that personally transforming or re-representing information benefits memory and comprehension (Basaraba et al., 2013; Tran & Fernandes, 2024b; Wammes et al., 2016, 2017). While drawing has been demonstrated to be a reliable and robust encoding technique, it is still unknown why exactly it is so beneficial. Another outstanding question is how beneficial it is compared to other known encoding techniques, such as reading aloud. In addition, as drawing, reading aloud, and writing are commonly used in educational settings, it is important to compare how beneficial these techniques are in improving comprehension of to-be-remembered information.

Comparing encoding techniques

Drawing, reading aloud, and writing are all techniques that have applicability within a classroom setting. Notably, they are also motor-based strategies that are non-disruptive in educational settings. While previous literature has highlighted the mnemonic benefits of motor processing, other motor-based strategies, such as enactment, performing a meaningful action to help you remember information, are somewhat more disruptive in classroom settings (Engelkamp & Zimmer, 1985).

Based on this previous literature, it appears that while each of these encoding techniques can benefit memory, they likely do so in different ways. That is, different mechanisms of actions have been proposed for these various encoding techniques (Kandel & Spinelli, 2010; MacLeod & Bodner, 2017; Wammes et al., 2016). For instance, it seems that the degree of semantic elaboration required for each technique may differ. Drawing seems to facilitate a great deal of semantic elaboration when generating sketches to depict a given word. For example, one must decide, when conjuring an image to represent the target word ‘tiger’, whether it has a tail, spots,

a mane, or fur (Meade, Klein, et al., 2020) . Given that drawing is thought to incorporate pictorial and semantic representations, it may not only strengthen already existing links between the semantic conceptualization of a word and its sensory referent, but may also generate more tangible associations when there are few (in the case of abstract words).

Another point of difference between encoding techniques is the reliability in boosting memory performance across experiment designs. Whereas a benefit of drawing has been reliably observed in between-subjects designs (Tran & Fernandes, 2024a; Wammes et al., 2016), the typical memory benefit conferred from reading aloud as an encoding technique is largely absent in recall paradigms (Forrin & MacLeod, 2016; Jonker et al., 2014); a benefit is only seen for words at the end of the word list (Cyr et al., 2022). That is, whereas drawing confers an absolute benefit, that from reading aloud seems to be a relative benefit, requiring a less salient comparator. To our knowledge, the robustness of the memory benefit conferred by writing as an encoding technique, in a between-subjects paradigm, is less known. Because writing is often considered to be an orthographic form of production, we might expect a similar pattern of results to those already described for reading aloud as an encoding technique.

Concreteness Effect

Attributes of to-be-remembered stimuli, such as word concreteness, can influence memorability. Examining how this effect varies across encoding techniques may therefore help distinguish the mechanism by which different encoding techniques support memory. Previous studies have demonstrated that concrete words (e.g. apple), phrases, and sentences are more recognizable, discriminable, and memorable than abstract (e.g. justice) ones (Dirkx & Craik, 1992; Hamilton & Rajaram, 2001; Newcombe et al., 2012; Paivio et al., 1994; Peters & Daum, 2008; Sadoski et al., 1997, 1997; Schwanenflugel et al., 1988). Historically, dual code theory

(Paivio & Csapo, 1973) suggested that both non-verbal (sensory imagery) and verbal information can be used to represent information. Concrete items allow for both representations and are then better remembered than their abstract counterparts (Paivio & Csapo, 1973). According to dual-coding theory, concrete words are not only encoded verbally, but also represented non-verbally in an image-based system, whereby imagery is spontaneously elicited (Paivio & Csapo, 1973). In contrast, context-availability theory (Schwanenflugel, 1991) suggests that concrete words are better remembered because of the additional contextual information afforded by the known settings in which these items are physically encountered.

Regardless, these various frameworks suggest that memory for concrete words benefits from engaging more features (Paivio et al., 1968; Schwanenflugel & Shoben, 1983). More specifically, it has been proposed that concrete words have a more direct connection to an external sensory experience (Dove, 2016; Paivio et al., 1968). Concrete nouns typically refer to something that exists in the physical world around us, whereas abstract nouns are typically experienced within the mind (introspection) through ongoing cognition or through social communication (Barsalou & Wiemer-Hastings, 2005; Borghi & Cimatti, 2010; Dove, 2016; Paivio et al., 1968). Essentially, concrete materials are more memorable because individuals experience them in their day-to-day lives. In contrast, individuals may have relative difficulty accessing relevant information for abstract items.

Concreteness effects have been demonstrated in both pure (Walker & Hulme, 1999) and mixed list designs (Glanzer et al., 1993; Hamilton & Rajaram, 2001; Jessen et al., 2000; Kim et al., 2020; Marschark & Surian, 1992; Paivio et al., 1994; Peters & Daum, 2008; Richardson, 2003; Tran & Fernandes, 2023a), as well as in recognition (Glanzer et al., 1993; Glanzer & Adams, 1990; J. M. Kim et al., 2020) and free recall paradigms (Hamilton & Rajaram, 2001;

Richardson, 2003; Walker & Hulme, 1999). In general, there seems to be a processing advantage for concrete items that are thought to have a strong link to an external sensory referent across a variety of experimental paradigms. As such, encoding techniques that could be used to strengthen or create links between a word and a physical representation may be more beneficial for concrete than abstract word types.

More recently, it has been argued that concrete and abstract words are represented by different connective networks in the brain. A meta-analysis of neuroimaging studies suggests that concrete information elicits greater activation in areas known to be associated with visual, imagery, and spatial representations (e.g. left fusiform gyrus, bilateral posterior cingulate, left parahippocampal gyrus, and precuneus). In contrast, abstract concepts elicit greater activation in language processing regions (e.g. left middle temporal gyrus, the inferior frontal gyrus, the medial frontal cortex, and the bilateral temporal poles; Wang et al., 2010). In addition, abstract words have been shown to activate more widespread networks (Grossman et al., 2002; Pexman et al., 2007). One explanation for this is that abstract words are cognitively complex; they are experienced in a wider variety of circumstances (e.g. introspection, emotions, and communication; Barsalou & Wiemer-Hastings, 2005; Borghi & Cimatti, 2010) and not directly linked to any one sense. As such, when they are retrieved from memory, the features that make up the representation of the abstract concept must be integrated from a diverse set of brain regions (Barsalou & Wiemer-Hastings, 2005; Grossman et al., 2002; Pexman et al., 2007). Given these proposed differences in how concrete and abstract words are represented, we might expect that different encoding strategies would differentially benefit memory for each word type, depending on that technique's mechanism of action.

Interestingly, the memorial benefits conferred by stimulus-driven factors such as concreteness, and person-mediated strategies such as encoding techniques, are typically considered separately in the literature. However, examining their interaction would allow us to document differences or similarities in the mechanism underlying the drawing and production effects. In this thesis, we compared the effectiveness of various encoding strategies on memory for concrete versus abstract words. Specifically, we compared the effectiveness of drawing a picture, orthographic production (writing), and auditory production (reading aloud) during encoding, in enhancing later recall for both concrete and abstract words, relative to silently reading them.

Aging

Another factor known to influence memory is age. Normal aging is believed to affect memory primarily because of gradual changes in the brain's structure. The hippocampus and frontal regions, critical for forming new memories, tend to shrink with age (Raz et al., 2005). As well, blood flow to the brain decreases and neurotransmitter levels shift (Bartus et al., 1985; Mokhber et al., 2021; Raz et al., 2005; Raz & Rodrigue, 2006). These changes make it harder to encode new information quickly and to retrieve details on demand (Raz et al., 2005; Raz & Rodrigue, 2006). For this reason, performance on tests of memory function, be it for names, words, or spatial information, tends to be lower in older compared to younger adults (Light & Zelinski, 1983; Shaw et al., 2006). Given this, older adults may rely more heavily on external aids or encoding techniques, to support memory formation and retrieval (Craig & Rose, 2012). For example, writing out a grocery list, reciting directions aloud, generating an acronym, journaling about daily events, or setting reminders on a phone application could be used to aid in remembering.

Encoding techniques such as reading aloud, writing, and drawing confer robust and reliable improvements in memory performance across a range of experimental contexts (Fernandes et al., 2018a; Forrin et al., 2012; MacLeod et al., 2010; Wammes et al., 2016). As such, they could be particularly helpful in providing external support for older adults. In fact, the techniques of reading aloud and drawing have been previously shown to be beneficial for healthy older adults (Lin & MacLeod, 2012; Meade, Ahmad, et al., 2020). In addition, drawing even has been demonstrated to be an effective encoding technique for older adults with probable dementia (Meade et al., 2018). However, as these encoding techniques are thought to engage diverse cognitive processes, there may be differences in the magnitude of benefit each can confer to this population. In this thesis, I leveraged naturally occurring age-related differences that can impact memory, imagery, and multimodal processing abilities (Bailey et al., 2013; Cabeza & Dennis, 2012; de Dieuleveult et al., 2017; Dirx & Craik, 1992; Hika & Al Khalili, 2026; Raz et al., 2005) to further compare the mechanisms underlying various encoding techniques.

The current dissertation

As previously outlined, several important questions remain relatively unexplored. These include how drawing compares with other effective encoding techniques, which populations benefit most from drawing, why drawing is such an effective encoding technique, and whether drawing supports other cognitive tasks, such as comprehension.

In Experiment 1 of my PhD thesis, I assessed the generality of the drawing technique across the adult lifespan. Here, we showed that drawing was the most beneficial encoding strategy across all age groups. Importantly, age differences in memory emerged only when drawing was used as the encoding strategy, in line with previously reported age-related deficits in generating imagery, or integrating it with motoric processes. Despite this, concrete relative to

abstract words that were drawn during encoding were better retained, regardless of age, suggesting drawing facilitates formation of age-invariant visuo-spatial representations, allowing a benefit for concrete relative to abstract words to emerge for all age groups.

In the next phase of my PhD, I then examined the potential role of other factors known to enhance memorability, such as personal relevance, repetition, and elaborative generation. In Experiment 2, I aimed to determine whether observation of another person performing an encoding technique (in person or via video) conferred the same memory benefit as performing it. Overall, drawing at encoding benefitted memory more than writing or reading words, regardless of whether it was performed or observed in-person or via video. However, the magnitude of the drawing benefit was greatest when performed rather than observed, suggesting an additional role of personal relevance in modulating the drawing benefit.

In Experiment 3, my goal was to determine whether the memory benefit of drawing was enhanced more by strengthening an existing visual percept, or by generating multiple novel related ones. I asked participants to engage in encoding twice: on the second encoding trials they either re-drew their initial drawing, or they generated a new sketch. The former enhanced free recall of the target words in comparison to the latter, suggesting that generating multiple different semantically-related exemplars for a target does not increase the drawing benefit; establishing and strengthening a single visual percept is more important in enhancing memory. Further analyses of the quality and complexity of generated drawings (Experiment 3b) showed that initial drawings of target words were rated as more detailed and representative than second novel drawings. Importantly, however, none of these drawing quality measures correlated with subsequent memory. This suggests that the user's ability to draw does not impact the mnemonic

benefit afforded from drawing at encoding. Rather, a critical component is strengthening the link between a single generated visual percept and a target word.

Finally, in Experiment 4, I assessed the utility of drawing as a cognitive tool in real-world educational settings. More specifically, the benefit to evaluative comprehension was assessed. This refers to a higher-level form of understanding target information, in which a person not only recalls the content of material (e.g., a text, lecture, or study), but also can apply learned knowledge to novel scenarios (Basaraba et al., 2013). That is, evaluative comprehension demands a higher degree of abstraction, requiring one to consider ideas, conduct critical analyses, or apply the information presented (Basaraba et al., 2013). I asked participants to study term–definition pairs, and concept comprehension was later assessed using a multiple-choice test. Depending on the group, they were asked to engage in one of four encoding types: read aloud, draw, paraphrase or silently read. Drawing and paraphrasing at encoding resulted in better performance, relative to silently reading. The benefit of drawing on comprehension was comparable to established comprehension strategies, and significantly better than other memory encoding techniques. This establishes that creating links between a semantic conceptualization of a word and a visual representation by drawing at encoding can also aid in linking ideas to improve the quality of our understanding and facilitate comprehension.

Overall, my dissertation shows that drawing is a particularly effective encoding technique to aid retention of newly acquired information. Based on my data, I suggest that a critical component contributing to the effectiveness of drawing is that it forces the creation of a link between the semantic meaning of a word and a visual percept. What is more, personal relevance and repetition serve to strengthen that visual percept, maximizing the drawing benefit. This dissertation provides compelling evidence of the mnemonic benefit of connecting internal

conceptualizations of information with a perceptible visual representation, bridging internal and external representations. This dissertation shows that the drawing benefit, experienced by creating visual representations at encoding, occurs because it offers a means by which to concretize to-be-remembered information.

Chapter 2

Experiment 1: Age differences in effectiveness of encoding techniques on memory

Episodic memory abilities worsen with advancing age (Craik & Rose, 2012). The use of encoding techniques has been shown to enhance later recall for to-be-remembered words. These include deep levels of processing (Craik & Lockhart, 1972), generation (Slamecka & Graf, 1978), enactment (Cohen, 1989), production (MacLeod et al., 2010), and drawing (Wammes et al., 2016), to name a few. Though the mechanism of action for each of these likely differs, they all reliably increase the number of words that individuals can later recall, in comparison with more passive encoding strategies, such as silently reading. Applied to older adults, engaging in active strategies at encoding can reduce age-related deficits in episodic memory (Cheke, 2016; Craik & Rose, 2012; Meade, Ahmad, et al., 2020; Meade et al., 2018). It is unclear, however, whether some encoding strategies are more effective in enhancing memory in older adults than others.

Researchers have also long been interested in investigating why certain stimulus-driven factors influence memorability (Kensinger & Corkin, 2003; McDaniel, 1986). A classic example is the concreteness effect, the finding that concrete words are more memorable than abstract ones (Dirkx & Craik, 1992; Paivio et al., 1994; Peters & Daum, 2008; Sadoski et al., 1997). Interestingly, some findings suggest that the effect is reduced due to age-related attenuations in mental imagery abilities during typical aging (Huang et al., 2012; Rowe & Schnore, 1971; Peters & Daum, 2008). Here we compared the effectiveness of various encoding techniques on memory for concrete versus abstract words and examined how this stimulus factor interacted with age. Specifically, we compared the effectiveness of drawing, orthographic production (writing), and

auditory production (reading aloud) during encoding, in enhancing later recall for both concrete and abstract words relative to silently reading these words.

Memory Changes Associated with Typical Aging

Memory loss is often viewed as an inevitable aspect of typical aging (Maylor, 2005) and consistent age-related changes to memory have been documented within the literature (Raz et al., 2005). Aging-related deficits have been linked to reduced volume in widespread brain regions, especially within the medial temporal and prefrontal cortex (Raz et al., 2005). Reduction in overall brain volume and white matter tends to begin during middle age (about age 40), with the rate of decline increasing substantially around age 70 (Bartzokis et al., 2003; Scallan et al., 2003). Though we expected them to have better memory performance than older individuals (Ryan, 1992), it is also known that concerns about one's memory performance begin to emerge around middle age (Willis & Schaie, 1999), so here we sought to document whether these were detectable. On a related note, a review by Craik and Rose (2012) also concluded that observable age-related deficits in memory stem from an overall decline in self-initiated encoding in older adults. This is unsurprising as the frontal lobes, which are engaged during cognitive control processes, are particularly vulnerable to age-related deterioration (Cabeza & Dennis, 2012). These findings coincide with the notion that the ability to carry out self-initiated encoding declines in the course of human aging, and that older adults are, as a result, more reliant on support from the external environment (Craik, 1986).

Are these encoding techniques effective in older adults? We know that production, relative to silently reading during a study phase, benefits memory in younger (MacLeod et al., 2010) as well as older adults (Lin & MacLeod, 2012). Drawing as an encoding strategy also enhances memory for words, in younger adults (Wammes et al., 2016, 2017, 2019; Wammes,

Meade, et al., 2018; Wammes, Roberts, et al., 2018), cognitively typical older adults and those with probable dementia (Meade et al., 2018). It has also been shown to boost the accuracy and level of detail one can retrieve from an autobiographical memory in both younger and older adults (Tran et al., 2022). Meade and colleagues (2018, 2020) suggested that drawing engages visuo-perceptual processing areas that remain relatively intact with advancing age (Raz et al., 2005), and that this may account for the reduction in age-related memory deficits that they observed.

Thus, can it really be said that aging is associated with poorer memory abilities? Or is it more apt to describe aging as Naveh-Benjamin and colleagues have in their (2007) publication, a change in one's ability to spontaneously apply encoding strategies. What is unclear is whether reading aloud, writing, and drawing are differentially able to enhance memory in older adults. Given that these encoding strategies engage diverse cognitive processes, there may be differences in the magnitude of benefit each can confer, particularly in older adults who experience brain changes in frontal and some temporal regions, with relatively intact occipital lobe functions.

Concreteness effect and healthy aging

Given that the frontal region is negatively impacted during normal aging (Raz et al., 2005), the magnitude of the concreteness effects can be expected to change as one ages, with poorer memory for abstract items in older adults. On a related note, however, mental imagery has been shown to decline with age (Dirkx & Craik, 1992), which could reduce memory for concrete items. Past work comparing memory for concrete and abstract words has yielded mixed results. Some studies report a greater magnitude benefit to memory for concrete relative to abstract words in typically aging adults (Rowe & Schnore, 1971), while others report the opposite

(Huang et al., 2012; Peters & Daum, 2008). It may be that these mixed results occurred because participants were engaging in different encoding strategies, and this interacted with the concreteness effect. That is, the strategy being privately employed by older adults could inadvertently facilitate or interfere with memory for concrete and abstract words, depending on the strategy's underlying mechanism.

Current Study

It is clear that encoding strategies can enhance one's later recall of to-be-remembered words. It is also known that the capacity for mental imagery, an ability that typically declines with age, is often associated with concreteness effects (Breedin et al., 1994; Huang et al., 2012; Paivio et al., 1994; Peters & Daum, 2008; Sadoski et al., 1997; Smith et al., 1990). What remains unknown is how encoding techniques compare relative to each other, within different age groups, and how this might vary for concrete versus abstract stimuli. In our study, we compared the effectiveness of different encoding techniques across the adult age range (in younger, middle-aged, and older adult age groups). We asked participants to encode a set of visually presented concrete and abstract words, using four different encoding strategies (randomly and intermixed, within-subject): silently read, read aloud, write, or draw a picture of the target. We then compared recall for the entire set of encoded words in a typed free recall test.

In line with typical episodic memory declines reported with aging, we predicted that memory performance in young adults would be significantly higher than in older adults. A main effect of word type was also predicted, whereby memory for concrete words would be better than for abstract ones. In addition, we predicted that encoding type might interact with word type such that the non-image-based encoding strategies such as reading aloud, (production), and writing

would confer similar benefits to memory for concrete as for abstract words. In our previous study, we hypothesized that the drawing effect may be larger in older than younger adults due to the relative preservation of primary visual processing regions with age (Raz et al., 2005). It is possible, however, that drawing as an encoding technique may not be as beneficial to older adults, relative to young and middle-aged adults, either because a) aging impacts one's ability to use imagery (Dirkx & Craik, 1992) or b) the benefit from drawing requires integrating multiple representations (image, motor, semantic; Wammes et al., 2016), and such abilities may be more limited in older adults as the frontal lobes, and executive function, decline with age (de Dieuleveult et al., 2017; Hika & Al Khalili, 2026; Kroger et al., 2002; Sommers et al., 2005; Stephen et al., 2010; Stine et al., 1990; Walden et al., 1993).

Materials and Methods

Participants

300 participants were recruited from Prolific (www.prolific.co; 170 female; 128 male, 2 preferred not to say), 100 younger adults (age range 18-35; $M_{\text{age}} = 25.87$, $SD_{\text{age}} = 5.12$), 100 middle-aged adults (age range 40-60; $M_{\text{age}} = 49.79$, $SD_{\text{age}} = 4.53$), and 100 older adults (age-range 65-89; $M_{\text{age}} = 69.16$, $SD_{\text{age}} = 3.99$). G*Power was used to determine the minimum number of participants needed to detect a significant effect ($\eta^2 = 0.15$), based on a related study by Peters & Daum (2008). This indicated that we only needed a sample size of 9 to detect a significant interaction. Because this effect size was based on a study design in which there were only two word types (Concrete and Abstract), and here we were examining the influence of word type across four different encoding techniques, we opted to recruit 100 participants per age group (~5x the sample used in Peters & Daum, 2008). We excluded data from those who scored below 30% on the Mill Hill Vocabulary Scale (MHVS; Raven, 1983), indicating poor English language

competency (Raven, 1983). Seven participants were excluded, and additional participants were run in their place.

Older adults were also asked to complete the cognitive failures questionnaire (CFQ; Broadbent et al., 1982) to assess the frequency with which they experienced cognitive failures, as an indirect indicator of typical aging. Our scores ranged from 7 – 65 on a scale of 1 – 100 ($M = 29.51$, $SD = 12.18$), which is similar to that of a community sample of 1,000 older adults without a formal diagnosis of dementia (Zlatar et al., 2014).

Materials

Word List.

Words were selected as stimuli, from the English Lexicon Project (ELP) which includes descriptive characteristics, including word length, type of word, and the number of syllables. From the ELP (Balota et al., 2007), 24 abstract words, and 24 concrete words were selected. Words included in our stimulus set had a maximum of two syllables, and six letters, and were of medium frequency ($M = 2.89$, $SD = 0.61$; Balota et al., 2007). On a 5-point scale, concrete words received ratings above 4 ($M = 4.99$, $SD = 0.02$), whereas abstract words received ratings below 2 ($M = 1.80$, $SD = 0.22$), in line with Brysbaert and colleagues' (2014) classification of each word type. All words selected did not have varying UK/USA spellings.

Procedure

The entire experiment was conducted using the online data collection platform Prolific. Participants were recruited from the UK, USA, and Canada. Once participants signed up for the study, they were redirected to a Qualtrics link. After providing online consent, participants were shown a pre-recorded video explaining the task to be performed for each 'Prompt' they would be shown in the study. Stimulus presentation and response recording were administered using

Qualtrics. An incidental memory paradigm was used. Participants were told that researchers were interested in examining what technique was best for learning words.

In the video, participants were told that on each trial, a prompt would appear at the top of the computer screen, one at a time, randomly, in orange font (Verdana 86-point font). The prompts were always one of the following: Silently read, Read aloud, Write or Draw. They were told that they should perform the task indicated by the prompt, to the target word that was simultaneously presented underneath it, in the middle of the computer screen in black font (Verdana 76-point font). Demonstrations of the task required for each of these prompts were provided in the pre-recorded video using both visual and auditory instructions (<https://tinyurl.com/shntran>). For each trial, both the prompt and a to-be-remembered target word were shown simultaneously on the computer screen for 10sec. Following this, an auditory tone was heard for 500ms indicating that the trial was over, and the next one would begin. The duration of the Experimental Phase was 8 minutes. For the ‘silently read’ prompt, participants were instructed to read the word underneath it ‘in their head’, repeatedly until the next trial, and that no audible noises should be made by them during this task. For the ‘Read aloud’ prompt, participants were instructed to speak aloud the word shown underneath the prompt, repeatedly until the next trial, at a volume that they would use to speak with someone sitting next to them. For the ‘Write’ prompt, participants were instructed to write out the word shown underneath it, repeatedly until the next trial. For the ‘Draw’ prompt, participants were instructed to draw a sketch depicting the word shown underneath it, adding detail to their image until the next trial.

In the video, participants were also asked to bring 5 blank sheets of paper measuring 8½x11 inches to their workstations. They were then told to draw lines (two vertical and one horizontal) on these five separate sheets of paper, in landscape orientation. This resulted in the

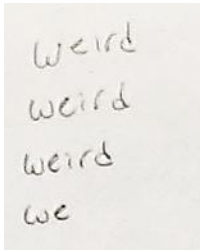
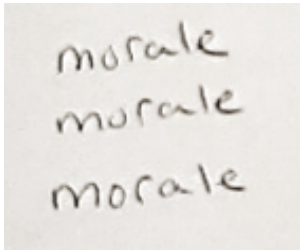
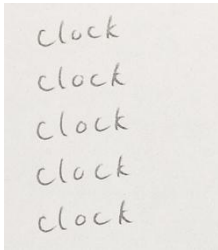
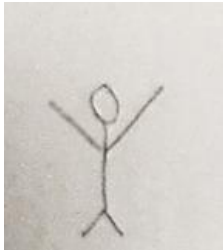
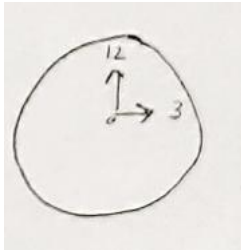
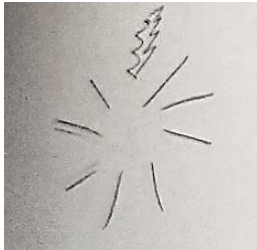
creation of 6 boxes on each sheet of paper. These were subsequently used in the ‘Write’ and ‘Draw’ Encoding types, such that participants could insert their writings and drawings separately for each of those trials, within each separate box. One of the sheets was used for the practice phase, and the remaining 4 were used in the experimental phase. During the Practice Phase, participants completed a sample of each of the four encoding prompts (Silently read, Read aloud, Write, Draw).

Following the video, participants completed the Experimental Phase in which 48 prompt-target word pairings were presented during encoding, intermixed randomly, with 12 prompts of each type (Silently read, Read aloud, Write, Draw). Half of the target words paired with each prompt (6) were concrete, and the other half (6) were abstract words. After participants were presented with all 48 prompt-word pairings, they were told to fold their papers containing their written words and drawings and place them underneath their chairs (to prevent them from rehearsing those targets). Participants were then asked to count aloud backward by threes, starting at 99 to prevent rehearsal.

Participants were then asked to recall as many words as possible from the Encoding phase. A single 770x72 pixels text box with a 20,000-character limit was presented in the middle of the screen. Below it, a countdown timer indicated the remaining time for recall. After 2-minutes, the screen automatically advanced to the instructions for the next task. Following the recall phase, participants completed Set A of the MHVS (Raven, 1983) and the CFQ (Broadbent et al., 1982). These scales were administered using Qualtrics. After the experiment, all participants were asked to take photos of their writings and drawings to confirm the fidelity of the manipulation, and upload these electronically to Prolific (see Figure 1 for samples).

Figure 1

Samples of Targets Given a Write or Draw Prompt During Encoding, From a Randomly Selected Participant's Sheet of Paper, for Experiment 1

Write		
		
weird	morale	clock
Draw		
		
power	clock	effect

Results

Proportion recall.

The proportion of words recalled was tabulated separately for each Encoding type (Silently read, Read aloud, Write, Draw) and Word type (Concrete, Abstract) as the number of correct words recalled divided by 6. See Table 1 for the means.

Table 1

Mean Proportion of Concrete and Abstract Target Words Recalled (and Standard Deviation) in Each Age Group, Following Each Encoding Type, for Experiment 1

Encoding Type	Word Type		Age Group		
			Young	Middle	Old
			(age range 18-35)	(age range 40-60)	(age range 65-89)
Silent Reading	Concrete	<i>M</i>	0.06	0.06	0.11
		<i>SD</i>	(0.12)	(0.12)	(0.21)
	Abstract	<i>M</i>	0.06	0.06	0.05
		<i>SD</i>	(0.11)	(0.12)	(0.11)
Read Aloud	Concrete	<i>M</i>	0.11	0.11	0.13
		<i>SD</i>	(0.15)	(0.16)	(0.19)
	Abstract	<i>M</i>	0.10	0.09	0.12
		<i>SD</i>	(0.14)	(0.14)	(0.2)
Write	Concrete	<i>M</i>	0.26	0.22	0.20
		<i>SD</i>	(0.23)	(0.23)	(0.22)
	Abstract	<i>M</i>	0.20	0.20	0.15
		<i>SD</i>	(0.20)	(0.21)	(0.19)
Draw	Concrete	<i>M</i>	0.57	0.52	0.44
		<i>SD</i>	(0.28)	(0.32)	(0.28)
	Abstract	<i>M</i>	0.45	0.38	0.26
		<i>SD</i>	(0.25)	(0.24)	(0.21)

Data were analyzed in a 3 Age (Younger, Middle, Older) x 4 Encoding type (Silently Reading, Read Aloud, Writing, and Drawing) x 2 Word type (Concrete and Abstract) mixed ANOVA with the first being a between- and the others being within-subject variables¹. Sphericity was not met, $\chi^2(5) = 107.50, p < .001$, so Greenhouse & Geisser (1959) corrections were applied when determining significance. There was a main effect of Word type, $F(1, 297) = 68.56, MSE = 0.03, p < .001, \eta_p^2 = 0.19$, such that a greater proportion of concrete words were recalled relative to abstract ones. There was a main effect of Encoding type, $F(2.47, 734.11) = 347.35, MSE = 0.06, p < .001, \eta_p^2 = 0.54$, such that a greater proportion of words drawn at encoding were recalled relative to those written, $F(1, 299) = 235.07, MSE = 0.07, p < .001, \eta_p^2 = 0.44$, read aloud, $F(1, 299) = 558.01, MSE = 0.06, p < .001, \eta_p^2 = 0.65$, and read silently, $F(1, 299) = 767.46, MSE = 0.05, p < .001, \eta_p^2 = 0.72$. The use of writing at encoding also resulted in better recall in comparison to reading aloud, $F(1, 299) = 52.98, MSE = 0.05, p < .001, \eta_p^2 = 0.15$, and silently reading, $F(1, 299) = 130.01, MSE = 0.04, p < .001, \eta_p^2 = 0.30$. Finally, words read aloud at encoding were better recalled than those silently read, $F(1, 299) = 29.94, MSE = 0.02, p < .001, \eta_p^2 = 0.09$. There was also a main effect for Age group, $F(2, 297) = 5.76, MSE = 0.01, p < .05, \eta_p^2 = 0.04$, such that recall was higher overall, in younger than older adults $t(198) = 3.61, SE = 0.01, p < .05$). There was, however, no significant difference between the middle age group and the other two age groups ($p > .05$).

There was a significant Encoding type X Age group interaction, $F(4.94, 734.11) = 7.13, MSE = 0.06, p < .001, \eta_p^2 = 0.05$; see Figure 2. To understand the interaction, we conducted

¹ The pattern of results remained the same when education and vocabulary scores were added as covariates.

separate 1-way ANOVAs to examine the effect of Age group (Younger, Middle, and Older) for each level of Encoding type (Silently read, Read aloud, Write, and Draw). There was no effect of Age group on the proportion recalled, for words read silently, $F(2, 297) = 1.17$, $MSE = 0.01$, $p = .312$, $\eta_p^2 = 0.01$, read aloud, $F(2, 297) = 0.90$, $MSE = 0.02$, $p = .409$, $\eta_p^2 = 0.01$, and written at encoding, $F(2, 297) = 2.28$, $MSE = 0.03$, $p = .104$, $\eta_p^2 = 0.02$. In contrast, for words drawn at encoding, the effect of Age group was significant, $F(2, 297) = 14.48$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = 0.09$. The difference between middle-aged and older adults was significant, $t(198) = 3.34$, $SE = 0.03$, $p = .001$, as was the difference between young adults and older adults, $t(198) = 5.49$, $SE = 0.03$, $p < .001$. There was also a trend such that young adults recalled more than middle-aged ones, $t(198) = 1.89$, $SE = 0.03$, $p = .060$.

Figure 2

Proportion of Recall Following Each Encoding Type, in Each Age Group, for Experiment 1



There was also a Word type X Encoding type interaction, $F(2.42, 719.56) = 18.43$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = 0.06$. To understand the interaction, we conducted paired sample t -tests to compare memory for the different Word types (concrete, abstract), following each Encoding type (Read Silently, Read Aloud, Write, and Draw). A greater proportion of concrete words were later recalled in comparison to abstract ones when the encoding technique was Silent reading, $t(299) = 2.37$, $SE = 0.01$, $p < .05$, $d = 0.14$, Write, $t(299) = 3.21$, $SE = 0.01$, $p = .001$, $d = 0.19$, and Draw, $t(299) = 7.37$, $SE = 0.02$, $p < .001$, $d = 0.43$. In contrast, there was no concreteness effect when participants read words aloud (Production) at encoding, $t(299) = 0.77$, $SE = 0.01$, $p = .442$, $d = 0.04$. Finally, there was no significant Word type X Age group interaction, $F(2, 197) = 2.01$, $MSE = 0.03$, $p = .136$, $\eta_p^2 = 0.01$, and no significant Encoding type X Word type X Age group, $F(4.85, 719.56) = 0.94$, $MSE = 0.04$, $p = .451$, $\eta_p^2 = 0.01$.

Age as a continuous variable

Categorical distinctions were made between younger, middle, and older adults, as structural changes to the brain and concerns about memory begin to occur in middle age (Bartzokis et al., 2003; Scahill et al., 2003). To ensure that potential age differences were not being masked by the use of such an arbitrary age classification, we opted to include age as a continuous factor. Including a continuous variable typically affords greater statistical power and sensitivity, parsimony, and a simpler interpretation (Lazic, 2008). We conducted a two-stage hierarchical multiple regression with Proportion of Recall as the dependent variable. Age, as a continuous variable was entered at stage one of the regression. Encoding type (dummy coded), Word type (dummy coded), and the interaction terms were entered at stage two (see Table 2).

Table 2

Summary of Hierarchical Regression Analysis for Variables Predicting Proportion of Recall, for Experiment 1

Predictors	<i>b</i>	<i>t</i>	<i>SE</i>	<i>p</i>	<i>R</i> ²	<i>adjR</i> ²	ΔR^2	$\Delta adjR^2$
Step 1					0.00	0.00		
Age	-0.00	-3.31	0.00	.001				
Step 2					0.34	0.34	0.34	0.33
Age (continuous)	0.00	1.28	0.00	.20				
Read Aloud	0.08	1.83	0.04	.07				
Write	0.34	7.61	0.04	< .001				
Draw	0.70	15.72	0.04	< .001				
Abstract	0.01	0.31	0.03	.76				
Read Aloud x Abstract	0.02	0.69	0.03	.49				
Write x Abstract	0.00	-1.11	0.03	.27				
Draw x Abstract	-0.10	-3.15	0.03	<.05				
Read Aloud x Age	-0.00	-0.43	0.00	.67				
Write x Age	-0.00	-2.56	0.00	.01				
Draw x Age	-0.00	-4.77	0.00	< .001				
Abstract x Age	-0.00	-1.44	0.00	.15				

*Silent Reading and Concrete are the referent groups

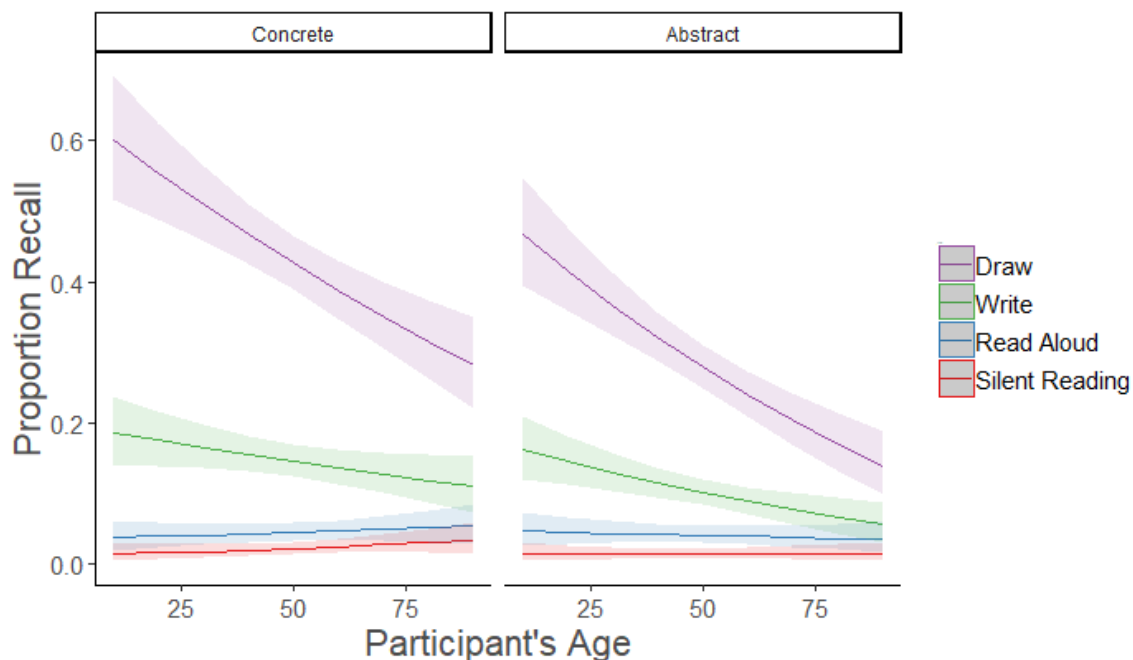
Residual and scatter plots indicated the assumptions of normality and linearity were satisfied (Hair, 1998). The Variance Inflation Factor indicated that the assumption of multicollinearity was met (Hair, 1998), and a non-significant Durbin-Watson test ($p = .062$) indicated that the observations in the dataset were independent. However, the test for non-constant error variance indicated that the assumption of homoscedasticity was violated, and a square root transformation was applied to the response variable to reduce heteroscedasticity.

The hierarchical multiple regression revealed that in Step 1, Age contributed significantly to the regression model, $F(1, 2398) = 10.95$, $MSE = 0.10$ ($p = .001$) and accounted for 0.41% of the variance in proportion recall (See Figure 3). Introducing Encoding type, Word type, and their interaction terms explained an additional 33.41% of variance in proportion recall, and this

change in R^2 was significant, $F(11, 2387) = 111.04$, $MSE = 0.03$, $p < .001$. When all predictors were included in the regression model, Age was no longer a significant predictor of proportion recall. Together the predictors accounted for 33.82% of the variance in proportion recall, $F(12, 2387) = 103.20$, $MSE = 0.07$, $p < .001$.

Figure 3

Proportion Recall Following Each Encoding Type for Concrete and Abstract Words, Across Age, From Experiment 1. Error Bands Indicate 95% Confidence Intervals



Discussion

We compared the effectiveness of different encoding techniques across the adult age range, on memory for concrete versus abstract words. Regardless of age group, we showed that drawing, writing, and reading aloud yielded better memory than silently reading words, with drawing leading to the largest boost in memory performance. While memory performance did decrease as age increased, it interacted with the encoding technique. Importantly, age differences in memory emerged only when drawing was used as the encoding strategy. In addition, our

regression showed that age was not a significant predictor of proportion recall when encoding strategy and word type were included in the model. Our findings suggest that whether age differences in memory emerge depends on the strategy used at encoding, and the type of information being encoded.

Encoding technique and Concreteness effects

Our findings showed that the mnemonic benefit conferred through using drawing as an encoding tool is particularly reliable and robust across the adult age range. However, the relative magnitude of benefit from this technique, relative to the others, was significantly limited with advancing age. Drawing as an encoding technique may not be as beneficial to older adults, relative to the other encoding techniques, either because a) aging impacts one's ability to use imagery (**Dirkx & Craik, 1992**) or b) the benefit from drawing requires integrating multiple representations (image, motor, semantic; Wammes et al., 2016), and such abilities may be more limited in older adults as the frontal lobes, and executive function, decline with age. Future research can tease apart these alternative explanations. We note that in a previous study conducted in patients with dementia, the quality of the drawing created during encoding did not differ for words that were later remembered compared to words that were not. As such, the quality of the drawing does not seem to influence word memorability (**Meade, Ahmad, et al., 2020**). In addition, it has been demonstrated that simply preparing to draw confers a greater mnemonic benefit than actually writing (**Wammes, Roberts, et al., 2018**). Given these results, it seems that it is the ability to conceptualize a drawing, rather than the drawing itself, that drives the memory benefit. Regardless, the fact that age did not contribute significantly to memory performance once encoding strategy and word type were taken into account is in line with the production deficiency hypothesis (**Kausler, 1994**) and the compensation hypothesis (**Cabeza &**

Dennis, 2012) which suggest that the aging brain can adapt and perform better on memory assessments when provided effective supports to do so.

Interestingly, there was no concreteness effect when participants read words aloud (production). Such a result suggests that this technique enhances memory by some means other than semantic meaning. If semantics played a role, we would have expected a larger boost to memory for concrete than abstract words, as was observed following the write and draw encoding techniques. Combined with the previous finding that production benefits occur for pronounceable non-words (MacLeod et al., 2010), our results suggest that whatever the mechanism for the production effect (MacLeod et al., 2010), it is not semantically-based. This finding was consistent across all age groups (see Figure 3). In contrast, we also showed that concrete relative to abstract words that were drawn or written during encoding were better retained, regardless of age, suggesting these encoding techniques facilitate the formation of a visuo-spatial representation, allowing a benefit for concrete relative to abstract words to emerge. While the net benefit to memory was greatest following drawing, production seems to offer a means of enhancing memory that is free of semantics. The current findings show that the mechanistic explanations for orthographic production, auditory production, and drawing, are distinct and can differentially interact with stimulus-driven factors such as concreteness.

Differences between younger, middle, and older adults

While there was a significant difference between the younger and older age groups, there was no difference between the middle age group and the two aforementioned ones. As previously mentioned, the observed reduction in brain volume and white matter during typical aging begins around the age of 40 (**Bartzokis et al., 2003; Scallan et al., 2003**). The results from the current study suggest that although reliable evidence indicates that observable structural

changes begin to occur in middle age, this does not always impact memory performance in this age group, when encoding strategy and word type are taken into account.

Limitations

A potential limitation of all online studies is that they depend on the integrity of participants to complete the experimental procedure in accordance with what is specified by the researchers. In our current experiment, participants were pre-screened so that only those with a 99% approval rating from other researchers (using the Prolific platform) were able to enroll in the study. Further, the researchers provided participants with a step-by-step video explaining the requirements for each task. There was also a temporal delay on the instruction page such that participants were prevented from proceeding until they had viewed the task instructions in their entirety. Participants were also able to rewind the instruction video in case they missed any details. In addition, the majority of the experiment was automated such that each trial was timed and advanced automatically to the next one. Further, participants were warned ahead of time that failure to submit (upload) their completed writings and drawings (which showed they completed those tasks) would result in loss of compensation and exclusion of data from our study.

In addition, before the incidental memory test, participants were told to place their sheet of paper with the fixation cross on top of their writings and drawings, and then told to fold them up and place the papers underneath their chairs. Prior to the presentation of the Recall text box, participants were told that their compensation would not be contingent on how well they performed on the recall test. Participants were also explicitly told not to look back at their sheets of paper. We note that no participant had perfect recall, suggesting that cheating did not occur. As well, other studies suggest that online data collection results in data quality equal to those gathered using in-person procedures, for both younger and older adults (Bui et al., 2015).

Conclusions

Here we showed that across age groups, drawing, writing, and reading aloud as encoding techniques yielded better memory than silently reading words, with drawing leading to the largest boost. While memory performance decreased as age increased, it interacted with the encoding technique. Age differences in memory emerged only when drawing was used as the encoding strategy, in line with previously reported age-related deficits in generating imagery, or integrating it with motoric processes. Despite this, concrete relative to abstract words that were drawn or written during encoding were better retained, regardless of age, suggesting these techniques facilitate the formation of age-invariant visuo-spatial representations, allowing a benefit for concrete relative to abstract words to emerge for all age groups. We conclude that whether age differences in memory emerge depends on the strategy used at encoding, and the type of information being encoded.

Chapter 3

Experiment 2: Can students learn effectively by observation alone?

Experiment 1 showed that drawing was the most effective encoding technique, regardless of age group. In Experiment 2, to better specify the critical component driving the effect, I examined the importance of personally engaging in the encoding technique in gaining a benefit. The utility of encoding techniques within educational contexts is also important to consider. Both drawing and writing are effective tools that can be implemented with relatively little disruption to others within a classroom setting (Kiewra, 1985; Kiewra & Benton, 1988; Mueller & Oppenheimer, 2014; Van Meter & Garner, 2005). Within an in-person or online classroom setting, watching an instructor write or draw out information is a common occurrence for students. The goal of Experiment 2 was to determine whether learners could benefit differentially from writing and drawing, and also from doing these encoding techniques themselves, compared to viewing someone else engage in them. According to *common-coding theory* (Prinz, 1984), observing motor-based actions can activate some of the same process involved in performing that action. As writing and drawing are both heavily motor-based encoding techniques, users may similarly benefit from watching them. As learners often report that the lack of social presence in an online setting decreases their motivation (Garrison & Cleveland-Innes, 2005; Inoue, 2007; Mykota & Duncan, 2007), a secondary goal was to determine whether social presence during observation matters. To this end, we manipulated whether the observation took place in-person or in an online video format.

Writing and drawing to encode new information

Of relevance to an educational context, drawing as a study technique can improve recall of abstract information (Roberts & Wammes, 2021; Tran & Fernandes, 2023a, 2024a) as well as

terms and their associated definitions (Wammes et al., 2017). In addition to improving one's memory, it has even been shown to improve comprehension and application of newly learned vocabulary in comparison to other encoding strategies such as viewing texts and images, reading aloud, and imagining information (Ainsworth & Th Loizou, 2003; Fiorella & Mayer, 2016; Fiorella & Zhang, 2018; B. S. Kim et al., 2024; Leopold & Leutner, 2012; Mayer, 2014; Schmeck et al., 2014; Tran & Fernandes, 2024b; Wammes et al., 2017). The use of drawing can even improve the level of detail within one's recollections of events in comparison to writing or imagining to-be-remembered information (Meade et al., 2020; Tran et al., 2022). It has also been shown that drawing can lead to metacognitive benefits such as improving the learner's judgement of learning (Schleinschok et al., 2017).

Given the applicability of writing and drawing as encoding techniques in a classroom setting, the current experiment aimed to assess the efficacy of these strategies when they are simply observed rather than performed. From a theoretical point of view, it is important to determine the relative contribution of self-engaged motoric action to the representation of target information. From an applied perspective, in educational settings, students often find themselves passively watching a teacher explain new vocabulary, new terms and their definitions, or new concepts. The degree to which students could benefit from drawing versus other encoding techniques, when they are simply observing versus performing the tasks themselves holds important pedagogical value.

Reliability of memory benefits when encoding tasks are performed versus observed

A review of the literature provides converging evidence that actually creating a drawing of the information you are trying to remember or understand is more beneficial than simply

viewing an illustration, text, or some combination of both, representing that same information (Mayer, 2014; Schmeck et al., 2014; Tran & Fernandes, 2023a; Wammes et al., 2019; Wiley, 2019). In a series of experiments, Wammes and colleagues (2019) included a no-ink drawing condition. Here, the strokes generated by participants on a tablet were not displayed to them. Essentially, participants in this condition only saw a blank white screen and were prevented from seeing their end product (Wammes et al., 2019). While no-ink drawing did improve later recall in comparison to writing as a means to encode to-be-remembered words, the benefit was not as large as that from traditional drawing. The reduced benefit conferred from no-ink drawing suggests that while viewing an image can benefit one's memory, there is still an additional benefit to actually creating the drawing. The actual process of generating a drawing seems to be a critical component of this encoding strategy (Wammes et al., 2019). Here, we sought to compare the magnitude of the drawing benefit depending on whether the learner was actively drawing or was observing another person draw. In doing so, we could shed light on possible mechanisms underlying the drawing benefit, such as the role of personal relevance.

Whether one needs to personally generate and engage in a motor action to gain a memory advantage, or simply observe it, has been a debate. According to common coding theory, there is a shared representation for perception and action such that performing an action activates the perceptual concept tied to that action and, similarly, perceiving an event activates the action related to that event (Prinz, 1984). Furthermore, performing and observing a motor action should lead to similar brain activation due to activity of mirror neurons (Chandrasekharan et al., 2010; Tye-Murray et al., 2013; van der Wel et al., 2013). These are a class of neurons that modulate their activity when an individual executes a specific motor act, as well as when they observe the same or similar act performed by another person (Kilner & Lemon, 2013). Mirror neurons have

been touted to be fundamental for action understanding (Gallese & Sinigaglia, 2011) and imitation of action and speech (Iacoboni et al., 1999). Mirror neuron activation has been observed in the human premotor, somatosensory, and parietal areas for observed and executed actions (Chandrasekharan et al., 2010; di Pellegrino et al., 1992, 1992; Gazzola & Keysers, 2009; Heyes, 2010; Iacoboni et al., 1999). Whether the benefit from particular encoding techniques can similarly be found when performed versus observed is an open question. Given this literature, we predicted that performing and observing someone else performing writings and drawings within a memory paradigm should result in a similar benefit. Both encoding formats would evoke motoric processing based on common coding theory, contributing to a multimodal representation.

Whether observation alone could confer the same magnitude of memorial advantage as performing an action has been previously examined within the enactment literature. The enactment benefit refers to the memory advantage obtained when one engages in an action that depicts the to-be-remembered target information, be it a word (Engelkamp & Krumnacker, 1980), phrase (Cohen, 1989), or concept (Saltz & Donnenwerth-Nolan, 1981; Stull et al., 2018), compared to when that information is silently read. There is disagreement in the field regarding whether or not the action must be performed directly by the learner (Subject-Performed Task; SPT) or whether it is equally beneficial to simply observe the action performed by another (Experimenter-Performed Task; EPT; Cohen, 1983, 1983, 1989; Cohen et al., 1987; Engelkamp & Dehn, 2000; Engelkamp & Zimmer, 1983, 1985; Roberts et al., 2022; Sidhu & Pexman, 2016; Zimmer & Engelkamp, 1996). The discrepancy in these findings is thought to occur because SPTs improve item-specific processing, resulting in a greater mnemonic benefit than EPTs in a mixed-list design or on a recognition test (Steffens et al., 2015). In contrast, EPTs enhance

relational processing, resulting in a similar mnemonic benefit to SPTs in a pure-list design or on a recall test (Steffens et al., 2015).

Relating these findings within the enactment literature to writing and drawing, both of these latter encoding techniques also evoke motor processing and likely a corresponding multimodal representation: motoric and verbal in the case of writing (Forrin et al., 2012) and motoric, verbal, and pictorial in the case of drawing (Wammes et al., 2019). According to findings from the enactment literature, we would expect a similar mnemonic benefit when observing another person write and draw as when performing these tasks oneself if motoric processing plays a major role underlying their benefits. In addition, as SPTs and EPTs have been shown to yield similar benefits when the memory test is free recall (Steffens et al., 2015), observing as well as performing the act of writing and drawing in the current study should confer a comparable memory enhancement. If, however, writing and drawing are beneficial because they enhance item-specific processing, performing these tasks at encoding, more so than observing them, would produce a larger benefit in our mixed-list design.

Reliability of memory benefits from encoding tasks in online video format

Another motivation for the current experiment was to determine if encoding techniques could be used to optimize the delivery of important information in an online setting. Online learning has increased over the past decade (Bates, 2018; Donovan et al., 2019). A survey of university professors across Canada also found that the majority (69%) believe that online courses and programs will increase within the next two or more years (N. Johnson, 2023). Given the increased popularity of online education and the use of asynchronous video lectures, it is important to determine ways to optimize learning in such environments. Evaluating whether

encoding techniques, known to benefit memory in lab-based studies, can be similarly beneficial when observed in an online video as when observed in person is critical.

Social presence is one critical factor that differs between in-person and online learning settings and that can impact learning performance. Social presence is defined as people's perceptions of others being present (Cui et al., 2013). In an online setting, there are few opportunities for course participants and the instructor to interact, thus social presence is unsurprisingly lower than when compared to in-person settings (Bettinger et al., 2017). Critically, learners typically report that a lack of social presence in an online setting decreases their motivation (Garrison & Cleveland-Innes, 2005; Inoue, 2007; Mykota & Duncan, 2007). This issue is then further compounded as the lack of others means that online learning environments are particularly independent, requiring higher levels of motivation to self-regulate in comparison to traditional classrooms (Dabbagh & Kitsantas, 2004). As online learning environments inherently decreases a learner's motivation, but require that learners are particularly self-motivated to succeed, it is important to examine whether encoding techniques are still effective in an online independent learning environment.

A learner's motivation is a strong predictor of and significantly affects online learning efficacy (Artino & Stephens, 2009; Muilenburg & Berge, 2005; Sankaran & Bui, 2001; Waschull, 2005; Zhu et al., 2022). A learner's motivation has been shown to facilitate memory formation (Astleitner & Wiesner, 2004; Duan et al., 2020; Gruber et al., 2014; Loewenstein, 1994; Ryan & Deci, 2000). Increased motivation also has been associated with better learning performance (Robbins et al., 2004; Sachs, 2001; Sankaran & Bui, 2001; Weiner, 1990; Yin & Yuan, 2021), using all learning materials (Li & Tsai, 2017), and investing more time into learning and completing assignments (Li & Tsai, 2017). As such, the lack of motivation inherent

in an online environment could impact the efficacy of memory encoding techniques and would be valuable to assess.

Current Study

Experiment 2 aimed to determine whether the encoding techniques of writing and drawing would be equally beneficial to memory performance when observed as when performed by the learner. Given previous literature (Fernandes et al., 2018a; Meade et al., 2019; Tran & Fernandes, 2023a, 2024a; Wammes et al., 2016, 2019; Wammes, Meade, et al., 2018; Wammes, Roberts, et al., 2018), we predicted a main effect of Encoding type. That is, a greater proportion of words drawn than written at encoding should be recalled, though both drawing and writing at encoding should benefit memory more so than silent-reading. In addition, if motoric processing largely contributes to the mnemonic benefit for both writing and drawing, we also predicted no difference between performing and observing based on the mirror neuron literature. This is because according to common-coding theory, there should be a shared action representation for the observation and the act of writing and drawing.

If social presence or motivation play a role in the effectiveness of encoding techniques, we expect that overall memory would be lowest for those participants observing encoding online, but only somewhat lower in those observing in person compared to performing the encoding technique themselves. If social presence during observation matters, the magnitude of any benefit from the encoding techniques would be significantly reduced when observation occurs via online videos. Finally, we predicted a significant Encoding Type X Performance Group interaction. Drawing is hypothesized to promote the integration of representations from multiple modalities (verbal/semantic, motoric, and pictorial). That is, drawing requires one to think deeply about the meaning of the text in order to transform it to create a personally relevant drawing

(Tran & Fernandes, 2024b). If creating a personally meaningful image is key to the drawing benefit, this effect should be strongest when people draw the image themselves, and weaker when they only watch someone else do it in person or online. Thus, the drawing benefit could be larger for those performing than observing encoding. Importantly, participants in all three groups were asked to Silently Read as a control condition; there is no reason to expect any differences in memory in this condition, across performance groups.

Materials and Methods

Approval for this study was granted by the University of Waterloo Human Research Ethics Board (REB# 45385).

Participants

G*Power was used to determine the minimum number of participants needed to detect a significant interaction, assuming a medium effect size (Cohen's $f = 0.25$). This indicated that we only needed a sample size of 36 to achieve a power of .80 in a mixed ANOVA, though we collected additional data as the effect size was unknown. A total of 135 participants (108 females; 25 males, 2 prefer not to say; $M_{\text{age}} = 20.18$, $SD_{\text{age}} = 2.96$) enrolled in a psychology course at the University of Waterloo were recruited for this study and received course credit as remuneration for 45 min of their time. The Mill Hill Vocabulary Scale (MHVS; Raven, 1983; Raven & Raven, 2003), was used to assess English Proficiency as part of the inclusion criteria. No participants were excluded based on this criterion (all participants achieved scores greater than 30%; Raven, 1983).

Word List

A word list was generated using the English Lexicon Project (ELP) which includes descriptive characteristics of words, including word length, type, and the number of syllables (Balota et al., 2007). Words included in our stimulus set had a maximum of two syllables, and six letters, and were of medium frequency (LgSUBTLWF; $M = 2.81$, $SD = 0.49$; Balota et al., 2007). All words were concrete words and had a rating of greater than 4 ($M = 4.99$, $SD = 0.01$), on a 5-point Concreteness rating scale, in line with Brysbaert and colleagues' (2014) classification of Concrete words. None of the words selected had varying UK/USA spellings (See Appendix A).

Procedure

Participants signed up for the study through self-selection using an online participant management software (Sona Systems, n.d). Informed consent, a demographic questionnaire, stimulus presentation, and retrieval response recording were administered using Qualtrics (Qualtrics, Provo, UT, 2022). Participants were not informed about the later memory test. Participants were told that researchers were interested in examining what technique was best for learning words. A prompt with an encoding instruction (DRAW, WRITE, or SILENTLY READ) was shown prior to presentation of each target word. On each trial, a prompt would appear at the top of the computer screen, one at a time, in orange font (Verdana 76-point) on a white background. The prompts were presented intermixed during the encoding block.

Before the Study Phase, there was a Practice Session in which a practice word was presented alongside each of the 3 prompts, one at a time. Once participants finished the Practice Phase, they were presented with a screen reminding them of the prompt instructions. No recall test was administered for the Practice session words. Participants were then instructed to proceed to the next screen once they were ready to begin the Study Phase.

Study Phase. Participants were presented with 24 words, alongside 8 prompts of each Strategy Type (Silently read, Write, and Draw). For each trial, both the prompt and a to-be-remembered target word were shown simultaneously on the computer screen for 10 seconds. Following this, an auditory tone was heard for 500ms indicating that the trial was over. Participants were instructed to stop what they were doing once they heard the tone, and wait for the next prompt-word pair to appear. After the tone, the next prompt-word pairing immediately appeared on the screen. For the Silently read prompt, all participants, regardless of their assigned group (Performer, Observer, Online), were instructed to read the words shown underneath the prompt, repeatedly, in their heads. In addition, all participants were specifically told not to mouth or whisper the words.

Participants in the Performer group were instructed to actually engage in each of the encoding techniques indicated by the prompt. That is, participants were told to write the word out repeatedly when presented with the WRITE prompt, on a notepad. For the DRAW prompt, participants were told to draw a picture of the word on a notepad using a pencil, and to continue to add details until they heard the tone indicating the next trial would begin. During data collection, each Performer was paired with another participant who was in the Observer in-person group. Once the Performer and Observer consented to participate, they were instructed to sit next to each other for the entirety of the Study Phase. The roles of Performer and Observer were determined based on who signed up for the SONA timeslot first. The first participant to sign up for the timeslot was assigned the Performer role. The second person to sign-up for the SONA timeslot was assigned the Observer in-person role. During the Practice and Experimental Sessions, they were instructed to look at the computer screen and pay attention to the word and the prompt being presented when they first appeared, and to then watch their ‘partner’ (the

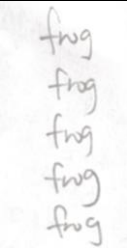
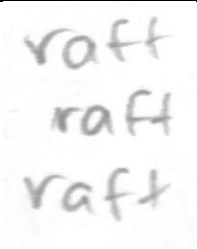
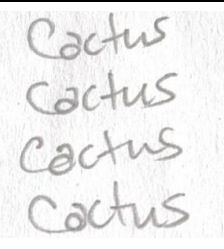
Performer) write or draw on each trial. When the prompt indicated to Silently read, both participants were instructed to do so.

Data from participants in the Observer-online group were collected individually, in the same lab room. Like those in the Observer-in-person group, these participants were told that they would be watching someone else write or draw out the words following those prompts, or would engage in silent-reading when instructed. The critical difference, however, was that they watched videos of another person engaging in writing or drawing following those prompts. On each trial, a 10-second video would autoplay directly under the prompt and target word on drawing or writing trials. The videos were 560 pixels in height and 310 pixels in width. Each video was pre-recorded such that the viewer would see only a person's hands writing or drawing out a word on a whiteboard with an EXPO® marker. Figure 4a shows samples of writings and drawings created by participants in the Performer group that the Observer-in-person would have seen. Figure 4b shows sample write and draw trials viewed by those in the Observer-online group.

Figure 4

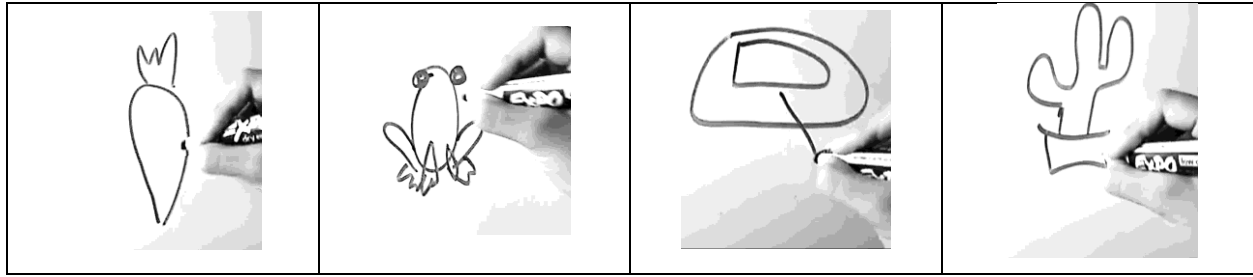
Panel A. *Samples of Productions on Write and Draw Trials Created by Participants in the Performer Group, and Seen by Those in the Observer-in-Person Group, for Experiment 2.* Panel B. *Sample Write and Draw Trials Viewed by Participants in the Observer-Online Group, for Experiment 2*

Panel A

Writings			
			
Drawings			
			

Panel B

Writings			
			
Drawings			



After the Study phase Performers and Observers were separated and were given instructions for the Recall phase on separate computers. Regardless of Performance Group, following presentation of all the words in the encoding phase, participants were asked to count backward by threes, aloud, starting at 99 to prevent any rehearsal. Participants were then given 2 minutes to recall as many words as possible from the encoding phase on their own computers. A single 770x72 pixels text box with a 20,000-character limit was presented in the middle of the screen. Below the text box, participants were also given a count-down timer to indicate the remaining time available for recall. After 2 minutes, the screen automatically advanced to the instructions for the MHVS. Following the recall phase, participants completed Set A of the MHVS (Raven, 1983). Lastly, participants were also asked to rate how motivated they were during the study on a scale from 1 – 10, with 1 being "completely unmotivated" and 10 being "extremely motivated".

Results

The number of words recalled was tabulated separately for each Encoding Strategy Type (Silently read, Write, Draw), Performance Group (Performer, Observer-in-person, Observer-online). See Table 3 for means. We then calculated proportion recall by dividing the number of words correctly recalled in each condition by 8 (there were 8 trials of each encoding type: Silently read, Write, and Draw). Because encoding context might influence participants'

motivation and subsequent memory performance, we initially conducted an ANCOVA with self-reported motivation as a covariate. Motivation was not a significant covariate in the model ($p = .211$, $BF_{10} = 0.188$). In addition, motivation scores did not correlate with memory performance ($ps > .05$), nor change the pattern of results reported here, in our 3 Encoding Strategy Type (Silently read, Write, Draw), X 3 and Performance Group (Performer, Observer-in-person, Observer-online) mixed ANOVA². As sphericity was met ($\chi^2(2) = 2.53$ $p = .282$), and each analysis only included three groups, Fisher's LSD was used for all pairwise comparisons. Bayes factors were calculated using JASP software using the default Cauchy prior ($r = .707$; JASP Team, 2024). All interpretations of Bayes Factors statistics are in accordance with the guidelines set out by Lee and Wagenmakers (2013), whereby $BF_{10} > 1$ favours the alternative hypothesis. Posterior odds have been corrected for multiple comparisons by fixing the prior probability of the null hypothesis to 0.5 across all tests (Westfall et al., 1997).

Table 3

Mean Number (and Standard Deviation) of Words Recalled Following Each Encoding Strategy by Group, for Experiment 2

	Silently Read	Write	Draw
Performer	1.33 (1.05)	2.20 (1.51)	5.43 (1.28)
Observer-in-person	1.39 (1.55)	2.22 (1.04)	4.93 (1.60)
Observer-online	1.82 (1.56)	2.22 (1.65)	4.49 (1.27)

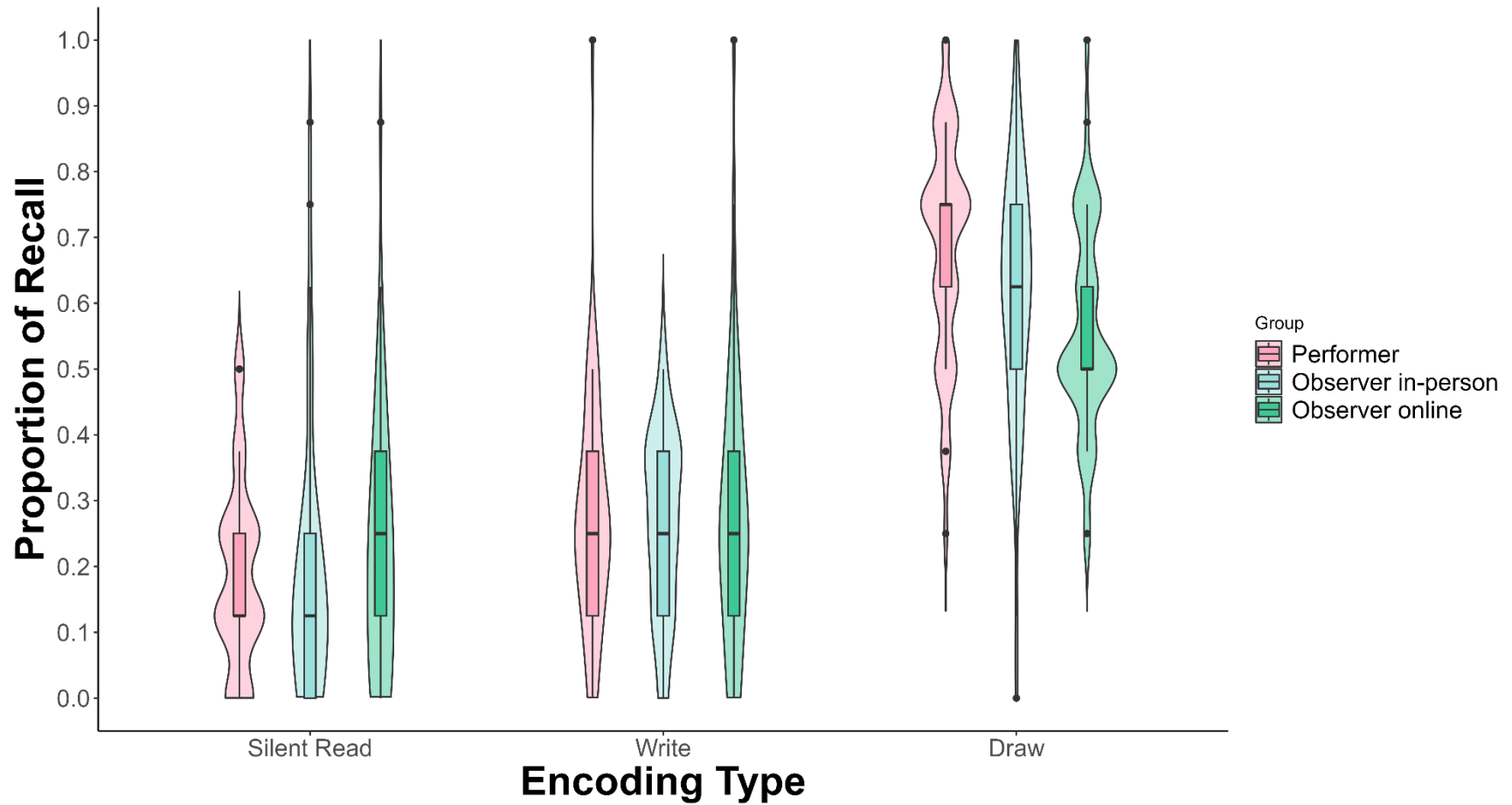
² Given the verbal nature of the memory task, we conducted an ANCOVA with MHVS score included as a covariate. The pattern of results remained the same as that reported here. MHVS scores did not correlate significantly with memory performance ($p = .15$). MHVS scores were not a significant covariate ($p = .057$, $BF_{10} = 0.188$) and did not significantly interact with any other variable ($ps > .05$).

There was a main effect of Encoding Type, $F(2, 264) = 220.21$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = 0.10$, $BF_{10} = 1.34 \times 10^{63}$. More specifically, a greater proportion of words drawn at encoding were recalled relative to those written, $t(134) = 16.30$, $SE = 0.02$, $p < .001$, $d = 1.95$, $BF_{10} = 5.99 \times 10^{28}$, and silently read, $t(134) = 19.60$, $SE = 0.02$, $p < .001$, $d = 1.96$, $BF_{10} = 8.01 \times 10^{32}$, in line with the standard 'drawing effect'. As well, there was a greater proportion of words recalled that were written compared to silently read at encoding, $t(134) = 3.30$, $SE = 0.02$, $p < .001$, $d = 0.40$, $BF_{10} = 302.48$. There was no main effect of Performance Group, $F(2, 132) = 0.94$, $MSE = 0.03$, $p = 0.394$, $\eta_p^2 = .001$, $BF_{10} = 0.05$.

Importantly, there was also a significant Encoding Type X Performance Group interaction, $F(4, 264) = 2.88$, $MSE = 0.03$, $p = .023$, $\eta_p^2 = 0.04$, $BF_{10} = 1.71 \times 10^{62}$. For words that were drawn at encoding, the proportion recalled was higher for those in the Perform group than in both the Observer-in-person group, $t(88) = 2.01$, $SE = 0.04$, $p = .038$, $d = 0.42$, $BF_{10} = 1.27$, and Observer-online group, $t(88) = 3.58$, $SE = 0.03$, $p < .001$, $d = 0.76$, $BF_{10} = 98.19$. Notably, memory performance of those in the Observer-in-person and Observer-online groups did not significantly differ from each other, $t(88) = 1.26$, $SE = 0.04$, $p = .106$, $d = 0.27$, $BF_{10} = 0.44$. Recall did not differ across Groups (Performer, Observer, Online) for words that were silently read, $F(2, 132) = 0.80$, $MSE = 0.03$, $p = .452$, $\eta_p^2 = 0.01$, $BF_{10} = 0.14$, or written, $F(2, 132) = 0.10$, $MSE = 0.03$, $p = .902$, $\eta_p^2 = 0.00$, $BF_{10} = 0.08$, at encoding. Figure 5 depicts performance by group and condition.

Figure 5

Proportion of Words Recalled Following Each Encoding Type in Experiment 2



Note. This violin plot depicts a mirrored kernel probability density of our data. The box indicates the interquartile range based on the median which is indicated by the thick midline. Dots that fall above or below the end of the whiskers indicate outliers.

Discussion

In Experiment 2, we compared the effectiveness of observing (in-person and online) versus performing encoding techniques, on recall of a set of target words. We aimed to determine whether writing and drawing would be equally beneficial when observed relative to being performed by the learner. Based on common-coding theory, observing another person performing these encoding techniques ought to confer a similar benefit as performing it oneself. We reasoned, however, that the relative lack of social presence and motivation in an online versus in-person environment could impact the efficacy of these encoding techniques when they are observed, if these are contributing factors to their effectiveness.

We found that across all three groups, the use of drawing at encoding resulted in the greatest benefit to memory, followed by writing, and then silently reading. This replicates previous findings of the drawing effect (Wammes et al., 2016), across a wide range of materials (Tran et al., 2022; Tran & Fernandes, 2023b, 2023a, 2024b; Wammes et al., 2017), and populations (Meade et al., 2018; Meade et al., 2020; Tran & Fernandes, 2023a, 2024a). This pattern of results was also consistent when motivation was included as a covariate. Such a novel finding suggests that participants' self-reported motivation did not influence the observed differences in memory performance.

Importantly, the significant interaction of Encoding strategy and Performance Group shows that the benefit of drawing and writing may stem from different underlying mechanisms. For one, it has been shown that motoric processing is involved in both writing

and drawing (Forrin et al., 2012; Wammes et al., 2019). The current findings further support that while motoric processing is a critical component of the drawing benefit, it cannot entirely account for the effect. It has been proposed that drawing does not just combine information from various modalities, but also helps integrate them (Wammes et al., 2019), creating links between the to-be-remembered information and an observable visual representation. Alternatively, it has also been suggested that one must engage in elaborative processing and think deeply about the meaning of the text and then re-represent or possibly transform the given information into an image that is personally generated (Tran & Fernandes, 2024b). In contrast, writing can be thought of as perceptual repetition of the to-be-remembered information. It could be this personally relevant linking or transformative aspect that makes creating your own personal drawing more beneficial than watching another create an image that is not personally representative to the observer. Perhaps personally thinking about and creating your own image of a word is more memorable because it is an image that you yourself created and better represents the meaning of the word for you as an individual learner. Although drawing improved memory more than writing or reading in all contexts, the benefit was strongest when people drew the items themselves. This pattern suggests that personal relevance further enhances the benefit of drawing on memory. Thus, for some strategies, performing it matters more than others, to gain maximal effectiveness.

It has been shown that in a mixed-list design, SPTs confer a larger mnemonic benefit than EPTs (Steffens et al., 2015). In contrast, it has also been shown that SPTs and EPTs can result in a similar mnemonic benefit when a recall paradigm is used (Steffens et al., 2015).

Likewise, common coding theory (Prinz, 1984) posits that the use and observation of writing should confer a similar memory benefit to later retrieval, particularly if motor processing largely underlies the benefit of this encoding technique. In line with these latter frameworks, we found no significant difference between the observation and the act of writing. This suggests that the mnemonic benefit conferred from writing items at encoding is due largely to motoric processing. Another possible explanation is that writing is a more passive perceptual repetition task and as suggested by the education literature, social presence is harder to establish through written communication (Garrison & Cleveland-Innes, 2005; Tu & McIsaac, 2002). The lack of visual (images) and auditory (speech) cues in written formats of communication also reduces feelings of social presence (Garrison & Cleveland-Innes, 2005; Tu & McIsaac, 2002). As such, this lack of social presence experienced through written communication, combined with it being more of a passive perceptual repetition task, may explain why it did not interact with Group.

The benefit of observing another draw has practical implications for the educational setting. Students frequently watch instructors illustrate new concepts and terms, and the finding that observing drawing improved memory beyond writing and silent reading supports this common instructional practice. The findings also have implications for rehabilitation and long-term care. Although Experiment 1 demonstrated that older adults benefit from actively drawing during encoding, observing another person draw may extend drawing-based memory support to those who have difficulty drawing independently. For example, an older adult with fine-motor limitations may still benefit from watching a caregiver sketch a

personal event, exercise sequence or medication routine. The observational drawing benefit broadens the usefulness of drawing as an encoding technique.

Limitations and Future Directions

For all three Encoding Types, there was no significant difference in overall memory, between observing online and in-person. This finding is inconsistent with suggestions based on some previous findings that motivation is lowered due to a lack of social presence in online settings, and this impairs learning (Garrison & Cleveland-Innes, 2005; Inoue, 2007; Mykota & Duncan, 2007). As motivation did not significantly influence the relation between Encoding Type and Group, it seems that all participants were equally motivated regardless of the encoding context. While the invariability in motivation found in this current study could have arisen because participants in our study took part for course credit, additional research should look to replicate this aspect of our findings, as it would be important to determine whether and to what extent online learning impacts motivation and subsequent retention of new information. For example, participants could be allowed to choose their preferred method of encoding; alternatively, the amount of credit or compensation provided for completing the study could be manipulated to be either a flat rate or performance based. Future studies could also use a more comprehensive motivation assessment such as the Intrinsic Motivation Inventory (Ryan, 1982) to better capture nuance in level of motivation. In addition, future work could assess dyad groups in a lecture hall to recreate a more realistic classroom setting and further increase social presence.

Conclusion

Here we showed that, regardless of Performance Group (performing, observing-in-person, observing-online), both drawing and writing as encoding techniques led to higher levels of memory than did silently reading of to-be-remembered words. The magnitude of the benefit from drawing was maximal when performed rather than observed, though writing led to equivalent benefits across Group. This pattern of results was consistent even when motivation was accounted for in the model. While both writing and drawing are thought to improve item-specific processing and subsequent retrieval, the mechanisms underlying their benefits may differ. The added step of personally re-representing the to-be-remembered information by transforming or linking the information to a tangible visual referent oneself may be a critical component as to why performing drawing is the most beneficial to later recall performance, and why it is able to further facilitate memory when performed rather than observed. Our study shows that drawing is an effective tool that can be used to optimize learning across a variety of contexts.

Chapter 4

Experiment 3a: Reinstating a visual percept enhances memory more than generating novel representations

The results from Experiment 2 suggest that actively creating one's own drawing confers a larger memory benefit. What is next to consider is what mechanism accounts for this benefit. One possibility is that drawing enhances memory by establishing personally relevant links between the to-be-remembered information and a visual representation. This account of the drawing benefit aligns with classic work by Hintzman, (1970) which demonstrated that repeated engagement with the same item strengthens an existing memory trace. Alternatively, drawing may evoke deep levels of semantic elaboration to re-represent verbal semantic information into a picture. This alternate account aligns with classic work from Slamecka and Graf (1978), demonstrating that producing/generating information during encoding enhances memory retention. Experiment 3 was designed to contrast these accounts by examining whether memory is enhanced by repeatedly engaging with, and further strengthening, well-established links to the same visual representation, or by self-generating multiple novel representations of the target item.

Strengthening an Engram

Coined by Richard Semon in (1904), the term “engram” refers to an enduring modification in the physical neural substrate of the brain when encoding a stimulus. That is, an engram is the physical representation of a memory in the brain, formed by a network of

neurons whose connections change when an item or experience is learned (Hebb, 1949; Josselyn & Frankland, 2018). Engrams can be strengthened in multiple ways. Two robust ways in which an engram can be strengthened are through *repetition* and *self-generation* (Bertsch et al., 2007; Hintzman, 1970; Hintzman & Block, 1971; Reagh & Yassa, 2014; Slamecka & Graf, 1978). Repetition and self-generation of information are proposed to enhance memory in distinct ways that are candidate accounts to explain the benefit of drawing on memory.

One way in which drawing may benefit memory is through the repetition of information both across and within modalities. Through the act of drawing, the target information is encoded via multiple modalities that create multiple, redundant, representations (Wammes et al., 2019; semantic, motoric, visual). These multiple representations can be thought of as ‘repetitions’ of the target information, with each repetition leading to a strengthening of corresponding neural traces. The process of drawing can also involve micro-repetitions (e.g., revisiting features as you sketch to check for correspondence between the created image and internally generated visual representation). This self-evaluation may function as internally guided rehearsal, ultimately making the engram easier to reactivate later. Thus, drawing may benefit memory through these various types of repetitions.

Drawing as an encoding technique also requires transforming a target – that is, generating an alternative representation. For example, when the task is to draw a word, one

must first engage in deep semantic analysis to transform the verbal information into a visual representation. It is this visual representation that is then acted upon. As suggested by Slamecka & Graf's early work (1978), creation of one's own exemplars enhances memory. It is, therefore, possible that this process of transformation may be the driving factor behind the drawing benefit. The following experiment sought to contrast these accounts of the drawing benefit. First, we describe each account in greater detail, and then we present predictions from each.

Repetition

One of the most robust findings within the field of memory is that the repetition of encoding events enhances later memory performance (Ebbinghaus, 1885; Hintzman, 1970; Hintzman & Block, 1971). Studies examining the effect of repetition on memory show that merely repeating the experience of a stimulus strengthens its memory representation (Ebbinghaus, 1885). This memory benefit from repeated encoding events is often referred to as the *repetition effect* (Ebbinghaus, 1885; Hintzman, 1970; Hintzman & Block, 1971). This has been shown to occur for both episodic (Cabeza & Jacques, 2007) and semantic memory types (Elward & Vargha-Khadem, 2018).

While there is some debate about the exact mechanisms underlying the repetition effect, there is a general consensus that each repetition or new exposure of a similar event or stimulus results in reactivation and changes to the original memory trace (Nadel & Moscovitch, 1997). The reactivation of an event or stimulus establishes a similar trace (Nadel

& Moscovitch, 1997; Yassa & Reagh, 2013) whereby the overlapping elements are assumed to be strengthened with each repeated encoding event in a “Hebbian manner” (for review, see Reagh & Yassa, 2014; Yassa & Reagh, 2013). For example, when participants were shown pictures of common objects once or three times, they were more likely to recognize or correctly identify items that were repeatedly presented compared to those with one single exposure (Reagh & Yassa, 2014).

In the current study, we aimed to assess whether repeating one’s original drawing results in a greater memory benefit. Such a finding would suggest that the links between the semantic meaning of a word and its associated visual referent formed during the first drawing could be further strengthened when given a second opportunity to encode those same connections again.

Novel Self-Generation

It has also been demonstrated that there is a reliable memory benefit from generating all or part of a to-be-remembered word in comparison to simply reading it (Jacoby, 1978; Slamecka & Graf, 1978). The Generation effect is a well-known phenomenon in cognitive psychology that refers to the finding that people remember information better when they actively generate it themselves, rather than simply reading or hearing it. For example, studies have shown that simply reading a word pair such as “bread – butter” results in worse memory compared to when one actively generates the pair. For example, after seeing the word “bread – b_____”, one must fill in “butter” as the logical pairing. The standard account for this effect

is that generating information forces you to think more deeply about it and to make more mental connections (semantic links, associations) to related information. Such semantic elaboration is reminiscent of the levels of processing framework, which suggest that thinking more deeply about to-be-remembered items improves later recollection (Craik & Lockhart, 1972). This deep elaborative process, engaged when generating line drawings, may underlie its benefit to memory.

The *generation effect* has been demonstrated regardless of how memory is assessed (i.e. on tests of recognition, cued recall, and free recall; for review, see Bertsch et al., 2007; McCurdy et al., 2020). In addition, the generation effect has been shown across a variety of different experimental designs (within-subjects, between-subjects; for review, see Bertsch et al., 2007; McCurdy et al., 2020). Of note, the generation effect only occurs for meaningful stimuli, and no benefit occurs for nonwords which lack meaning (Gardiner & Hampton, 1985; McElroy & Slamecka, 1982). This suggests that to observe a generation effect, one must think about the semantic or physical characteristics of the item being generated. Self-generation enhances memory by improving both item-specific details and relationships between items, leading to stronger overall encoding through deeper and more varied processing (McCurdy et al., 2020).

In the current study, we aimed to assess whether generating multiple new drawings would further augment the drawing benefit. If generating multiple new drawings results in a greater memory benefit, this would suggest that self-generation or transforming to-be-

remembered words into many semantic exemplars is a critical component underlying the drawing benefit.

Current Study

We aimed to determine whether creating a strong visual percept to a target word, or generating multiple novel representations of the target, was more critical in accounting for the memory benefit. If creating tangible links between a word and a visual sensory referent is a critical component underlying the drawing benefit, we would expect an even greater benefit from re-drawing one's initial sketch, as the fidelity of the representation would be enhanced. In contrast, if elaborative generation of exemplars is the critical component underlying the drawing benefit, creating multiple distinct drawings to represent the to-be-remembered word should confer a larger benefit.

Participants were asked to encode a set of visually presented words by either writing or drawing a sketch depicting each one. On each of 48 study trials, participants were shown an encoding prompt (intermixed and within-subject) to either Draw, Write, Repeat Write or Repeat Draw (12 of each type) a target word shown underneath. For Repeat Write trials, participants in the Trace group were instructed to trace their original written production, while those in the Transform group were asked to re-write the target word but in a different style (e.g. block letter, cursive) than they did previously. For Repeat Draw trials, participants in the Trace group were instructed to trace their previous drawing onto translucent paper with their original production underneath while those in the Transform group were asked to

generate a new sketch of the target that differed from their previous one. If the drawing benefit depends primarily on strengthening links between a word and a visual sensory referent, then repeatedly redrawing the same image should produce a greater memory benefit due to increased representational strength. However, if the benefit depends on elaborative generation, then creating multiple distinct representations of the target word should lead to better memory performance because of the increased elaborative processing required for each new generation. Thus, comparing whether transforming or tracing during the secondary encoding event confers a greater mnemonic benefit will determine what mechanism is most critical to the drawing benefit.

Materials and Methods

Ethical clearance to conduct this study was granted by the University of Waterloo Human Research Ethics Board (REB# 46275).

Participants

A total of 108 participants (90 females; 16 males, 2 prefer not to say; $M_{\text{age}} = 21.32$, $SD_{\text{age}} = 5.24$) enrolled in a psychology course at the University of Waterloo took part in this experiment and received course credit as remuneration for 45 min of their time. The Mill Hill Vocabulary Scale (MHVS; Raven, 1983; Raven & Raven, 2003), was used to ascertain English Proficiency as part of the inclusion criteria. No participants were excluded based on this criterion (all participants achieved scores greater than our criterion of 30%). Participants were randomly assigned to one of the two repetition groups (Trace or Transform).

Word List

A word list was generated using the English Lexicon Project (ELP) which includes descriptive characteristics, including word length, type of word, and the number of syllables. From the ELP (Balota et al., 2007), 48 words were selected. Words included in our stimulus set had a maximum of two syllables, six letters, and were of medium frequency ($M = 2.89$, $SD = 0.61$; Balota et al., 2007). All words selected did not have varying UK/USA spellings.

Procedure

Participants were recruited for the study using an online participant management software (Sona Systems, n.d). At the beginning of the study, informed consent was collected and a demographic questionnaire was administered. Participants were not informed about the later memory test. Participants were told that researchers were interested in examining which technique was best for learning words. Participants completed the study in a group setting, and the group size ranged from 2 to 5 participants. Task instructions and words were presented on a 5' x 5' screen at the front of the classroom presentation using Qualtrics (Qualtrics, Provo, UT, 2022). Participants were all seated so that they were in the same row and at 2.5 meters from the screen.

Participants were given three sheets of 8½ x 11-inch grid paper and three sheets of 8½ x 11-inch translucent tracing paper. One sheet of grid paper and tracing paper were allocated for the Practice Session. Before the Study phase for the experiment, there was a Practice Session in which a practice word was presented alongside each of the 4 prompts (described below), one at a time. Once participants finished the Practice Session, they were presented

with a screen reminding them of the prompt instructions. No recall test was administered for the Practice session words. Participants were asked if they had any questions before beginning the Study phase of the experiment.

Study Phase. Participants were instructed to use one of the remaining grid papers for all their writings and the other for all their drawings. There were a total of 24 boxes on each of the two sheets of grid paper. In this way, there was a unique box for each of the 48 target words that was to be encoded, half written and half drawn (see Figure 6). The tracing paper was provided for all the Repeat Write and Repeat Draw trials.

Figure 6

Sample Section of Grid Paper Provided During Encoding for Write and Draw Trials, for Experiment 3a

Writing Grid Paper					Drawing Grid Paper				
	w	x	y	z		d	e	f	g
1					1				
2					2				
3					3				
4					4				
5					5				
6					6				

On each of the 48 study trials, participants were shown a prompt (DRAW, WRITE, REPEAT WRITE or REPEAT DRAW) along with a target word. Prompts were presented within-subjects and intermixed in a single encoding phase. That is, participants were presented with 12 DRAW prompts, 12 WRITE prompts, 12 REPEAT DRAW prompts and 12 REPEAT WRITE prompts in a random order during the encoding phase. The prompt appeared at the top of the computer screen, in orange font (Verdana 86-point) on a white background. The target word appeared in the middle of the screen, in black font (Verdana 70-point). Participants were given 10 seconds to perform each trial, using their sheet of grid paper. Each trial ended with an auditory tone that signaled that the next word/prompt would appear (see Figure 7).

Figure 7

Sample Write and Draw Encoding Trial, for Experiment 3a

Write	Draw
WRITE cat	DRAW craze

For the WRITE trials, participants were instructed to write the word repeatedly until they heard the auditory tone. For the DRAW trials, participants were instructed to DRAW a visual depiction of the meaning of the target word, and to continue to add details to their drawing until the next trial appeared. For the REPEAT WRITE trials, target words were presented to the participants a second time: During the subsequent presentation of the target word (e.g. annual) in the same encoding phase, the target would be presented with a REPEAT WRITE prompt (e.g. REPEAT WRITE - annual), indicating that the participant was to re-write the previously presented target a second time, on the tracing paper provided (the exact way in which they were to re-write it was a function of condition, see below). Similarly, for REPEAT DRAW trials, the target word was presented to the participant twice: During the first instantiation, the target word was presented with a DRAW prompt (e.g. DRAW - doll). During a subsequent presentation, the target word was presented alongside a REPEAT DRAW prompt (e.g. REPEAT DRAW - doll), indicating that the participant was to re-draw the target word a second time using the tracing paper provided (again, the exact way in which they were to re-draw it was a function of condition). The location of the square in which they produced the first instantiation of their writings or drawing of the target word was provided, so that they could look back at their previous writing and drawings with minimal search time (e.g. see square W2; see Figure 8). The maximum number of intervening trials between repeated targets was 47, and the minimum was 0.

Figure 8

Sample Repeat Write and Repeat Draw Encoding Trials, for Experiment 3a

Repeat Write	Repeat Draw
REPEAT WRITE see square W2 annual	REPEAT DRAW see square E2 doll

Participants were randomly assigned to one of the two Repeat type Groups: Trace or Transform.

Trace Group. For the Trace Group, participants were asked to trace their previous writings exactly on the translucent tracing provided when prompted on REPEAT WRITE trials. Similarly, when prompted to REPEAT DRAW, they were asked to trace their previous drawings onto the translucent tracing paper provided.

Transform Group. In contrast, those in the Transform group were instructed on REPEAT WRITE trials to write the target word on the tracing paper using a different style than they previously did. For example, participants were shown examples of styles (cursive, block letter writing) but could use any style of their choosing. For the REPEAT

DRAW trials, those in the Transform group were told to create a different image from the one that they previously drew.

After encoding all 48 words, the researcher collected all the grid and tracing papers from the participants. In order to assess memory, following the presentation of all 48 target words, participants were given a blank piece of 8½ x 11-inch paper. They were given five minutes to recall as many words as they could remember and asked to write these down. Finally, participants were given 5 minutes to complete Set A of the Mill Hill Vocabulary Scale (Raven, 1983).

Results

The number of words recalled was tabulated separately for each Encoding Type (Write, Draw), and Instantiation of target (First, Second), separately for each Group (Transform, Trace). See Table 4 for means. We calculated proportion recall by dividing the number of words correctly recalled in each condition by 12 and analyzed these data in a 2 (Encoding Type) x 2 (Instantiation) x 2 (Group) mixed ANOVA, with the first 2 factors being within- and the last a between-subject factor.

Table 4

Mean Number (and Standard Error) of Words Recalled Following Each Encoding Strategy by Instantiation and Group Type, for Experiment 3a

Group	Write	Draw	Repeat Write	Repeat Draw
Transform	0.45 (0.10)	2.10 (0.20)	1.51 (0.16)	3.76 (0.19)

Tracing	0.72 (0.12)	1.77 (0.17)	1.72 (0.15)	3.99 (0.21)
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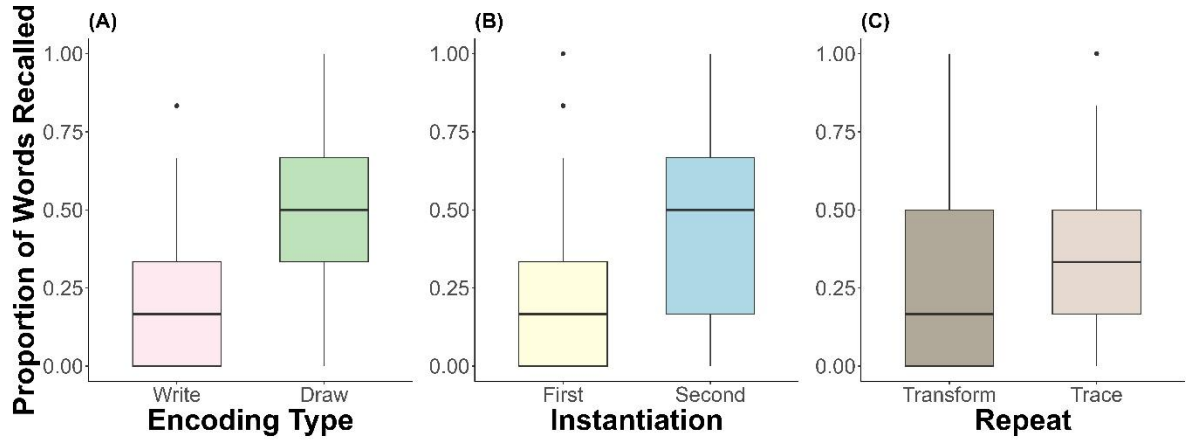
There was a main effect of Encoding Type, $F(1, 106) = 390.61$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = 0.79$. As expected, a greater proportion of words drawn at encoding were recalled relative to those written, $t(107) = 12.65$, $SE = 0.02$, $p < .001$, $d = 1.22$ (see Figure 9). This replicates the standard 'drawing effect', a robust and reliable finding within the memory literature (Fernandes et al., 2018a; Wammes et al., 2016; Wammes, Roberts, et al., 2018).

In addition, there was a significant main effect of Instantiation, $F(1, 106) = 446.27$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = 0.80$ (see Figure 9). That is, a greater proportion of repeatedly encoded words were recalled in comparison to words that were only encoded once, $t(107) = 21.18$, $SE = 0.01$, $p < .001$, $d = 2.02$, replicating the well-known repetition effect (Benjamin & Tullis, 2010; Ebbinghaus, 1885; D. Hebb, 1961; Hintzman, 2004, 2010). There was also a significant main effect of the between-subjects variable Group, $F(1, 106) = 6.47$, $MSE = 0.07$, $p = .012$, $\eta_p^2 = 0.06$, such that participants in the Tracing Group recalled a significantly greater proportion of words in comparison to the Transform Group, $t(106) = 2.54$, $SE = 0.02$, $p = .006$, $d = 0.49$ (see Figure 9). This finding suggests there is a greater benefit from copying the original representation than from creating multiple novel representations for the target word. As it has been previously demonstrated that encoding multiple times increases the strength of a memory (Bink et al., 1999; Bower, 1996; Bower & Winzenz, 1969; Ozubko et al., 2014), the current findings suggest that reinforcing the link between a target word and

percept enhances memory more in comparison to generating multiple exemplars of the target for both written and drawn words. That is, encoding by writing or drawing both benefit from repetition. However, it is also possible that strengthening an already existing memory representation was more beneficial because it was more difficult to come up with an entirely new way of representing the to-be-remembered word. We addressed this potential explanation in a follow-up study and discuss those results below.

Figure 9

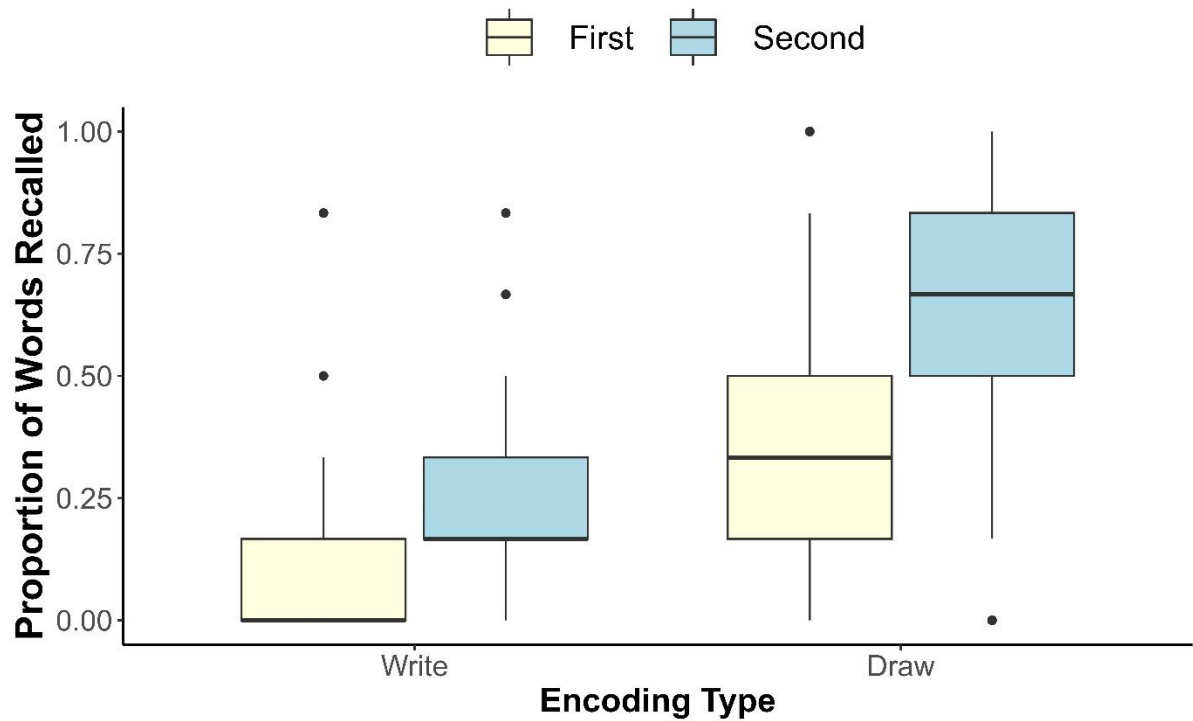
Proportion of Words Recalled as a Function of Encoding Type (Panel A), Instantiation (Panel B), and Repeat Group (Panel C)



Finally, there was also a significant Encoding Type X Instantiation interaction, $F(1,106) = 42.01$, $MSE = 0.00$, $p < .001$, $\eta_p^2 = 0.28$. This interaction was largely driven by a larger magnitude increase in the proportion of words recalled when the targets were drawn twice in comparison to written twice, $t(107) = 6.52$, $SE = 0.2$, $p < .001$, $d = 0.24$. That is, repeated encoding events were more beneficial when the encoding technique used was drawing in comparison to writing (See Figure 10).

Figure 10

Proportion of Words Recalled at Each Instantiation for Each Encoding Type



Discussion

In Experiment 3a, we replicated the well-known repetition effect (Hintzman, 1970; Hintzman & Block, 1971). In addition, our findings show that drawn words benefited from repetition more than written words. These findings suggest that the drawing benefit is better explained by a repetition-based strengthening account than by a self-generation account. Specifically, re-drawing one's own picture likely reactivates and strengthens the memory trace for a target, improving later retrieval (Nadel & Moscovitch, 1997; Reagh & Yassa,

2014; Yassa & Reagh, 2013). Thus, the mnemonic benefit of drawing enhances memory to the degree that it strengthens a given visual percept.

One possible alternative explanation for these results is that it may be more difficult to come up with an entirely new way of representing the to-be-remembered word. This is a particular concern for words drawn at encoding. That is, the drawing that an individual first generates is likely the most representative exemplar of the to-be-remembered item.

Therefore, generating a second visual representation for the exact same word may have been much more difficult. In fact, previous work has shown that when drawing concrete words, more prototypical images lead to better subsequent memory performance (Roberts & Wammes, 2021). As such, difficulty coming up with an entirely new way of representing the target word could explain why this type of repetition was less beneficial to memory. In Experiment 3b, we addressed this alternative ‘task-difficulty-based’ account of our results. We asked a set of naïve participants to assess the detailedness and representativeness of the first and second transformed drawings. We then compared these ratings to assess whether there were differences in the quality of the first and second drawings created.

Experiment 3b: Does the complexity and representativeness of the drawings impact memory?

We examined whether the enhanced memory observed in the Trace relative to Transform group was due to increased task demands, or level of difficulty, for the latter group. This was specifically a concern for the drawing condition as participants would have to generate a completely new and unique representation of a target word (for the Transform group), which was likely more cognitively demanding than simply tracing their first sketch. Put another way, it is possible that the Tracing group experienced a benefit because tracing is simply an easier task than generating a new exemplar. We gathered ratings of the quality and representativeness of drawings created on the first versus second encoding trials, for those in the Transform group. If participants in the Transform group experienced difficulty generating a new, unique visual representation on repeat trials, the quality and representativeness of their second drawings should be reduced.

Methods

Participants

All participants included in Experiment 3b were screened through the University of Waterloo's SONA system (Sona Systems, n.d) to ensure that they had not participated in Experiment 3a. This was done to ensure that participants were not rating their own drawings and were also naïve to the previous task and study. A total of 182 naïve participants (151 females; 31 males; $M_{\text{age}} = 20.50$, $SD_{\text{age}} = 4.41$), enrolled in a psychology course at the University of Waterloo were recruited for this phase of the study. They received course credit

as remuneration for 30 mins of their time. Participants were recruited until each drawing from the initial experiment had at least 10 ratings of representativeness and detailedness. On average, each line drawing was given 12.29 ratings (Min = 10; Max = 14).

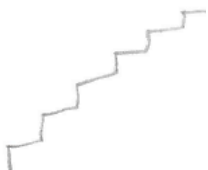
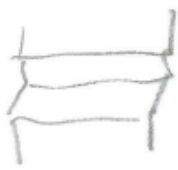
Materials

Pictures and Ratings

The drawings included in this experiment were created by participants in Experiment 3a (see Figure 11 for samples). Specifically, the line drawings from participants in the Transform Group were scanned, uploaded, and presented to raters. A total of 1,575-line drawings were rated.

Figure 11

Sample of First and Second Instantiations of Drawings During Encoding, From Participants in the Transform Group, From Experiment 3a

Stairs		Risk		Egg	
1 st Instantiation	2 nd Instantiation	1 st Instantiation	2 nd Instantiation	1 st Instantiation	2 nd Instantiation
					

Procedure

Participants signed up for the study through self-selection using an online participant management software (Sona Systems, n.d). Informed consent, a demographic questionnaire, stimulus presentation, and retrieval response recording were administered using Qualtrics (Qualtrics, Provo, UT, 2022). Participants were told that they would be rating the representativeness and detailedness of 100-line drawings. Two questions asking about the representativeness and detailedness of the drawings were presented alongside the to-be-rated line drawing. First, participants were asked to rate “How representative is this image of the word [WORD]? (i.e. is this image a good representation of the word)”. They would then indicate their rating on a 5-point Likert scale (1 = Very bad; 5 = Very good). Next, they were asked to rate “How detailed is this image of the word [WORD]? (i.e. how complex of a representation is this image)”. Again, they would indicate their rating on a 5-point Likert scale (1 = Very simple; 5 = Very detailed).

Results and Discussion of Experiment 3b

The average rating for level of detail for each target was tabulated. See Table 5 for means. Data were analyzed in a Univariate ANOVA. There was a main effect of Instantiation, $F(1, 1571) = 102.42$, $MSE = 0.29$, $p < .001$, $\eta_p^2 = 0.06$, such that ratings were higher for the first relative to second instantiation trials, $t(1117.04) = 9.72$, $SE = 0.03$, $p < .001$, $d = 0.50$. The average representativeness rating for each drawing was also tabulated. See Table 5 for means. There was again a main effect of Instantiation, $F(1, 1571) = 160.84$, $MSE = 0.59$, $p < .001$, $\eta_p^2 = 0.09$. As with the ratings of level of detail, the representativeness

ratings for the first relative to second instantiations were higher, $t(1144.10) = 11.99$, $SE = 0.04$, $p < .001$, $d = 0.62$.

Table 5

Mean (and Standard Error) of Participants' Ratings of Detailedness and Representativeness for Each Instantiation, for Experiment 3b

	Instantiation	
	1	2
Detail Rating	2.85 (0.02)	2.56 (0.02)
Representativeness Rating	3.32 (0.03)	2.80 (0.03)

Correlation with *Memory Performance*. An item-level correlation analysis was conducted on participants' ratings of representativeness and detailedness of the drawings generated in Experiment 3a. Memory performance did not correlate with representativeness, $r(1375) = .01, p = .852$, or detailedness, $r(1375) = .03, p = .285$, ratings of the drawings. In addition, a multiple regression analysis was used to determine whether the representativeness and detailedness ratings significantly predicted memory recall. Both were non-significant predictors: $R^2 = .004, F(2, 1372) = 2.62, p = 0.07$. Thus, although the images generated in the Transform group on repetition trials were indeed of lower quality, this does not appear to explain the reduced benefit observed in this group relative to the Trace group.

Discussion of Experiment 3a and 3b

In Experiment 3a, during the second encoding trials, participants either traced their first writings or drawings, or they generated words in a different style or created a new sketch. The goal was to determine whether strengthening a visual percept via repetition of the exact same line production (in the tracing group) or generating multiple novel related ones

(in the Transform group), further boosted memory. The former manipulation enhanced memory of the target words in comparison to the latter, for both writing and drawing trial types. In line with the mere repetition effect (Ebbinghaus, 1885; Hintzman, 1970), the results from Experiment 3a demonstrate that encoding a target item twice results in better memory than encoding it only once. The novel finding from Experiment 3a is that repetition of the same visual percept benefited memory more than generating related exemplars of the target item. This suggests that repetition of a visual percept is a better account for the drawing effect.

Our findings are also in line with previous work showing that drawing semantically related information can result in increased false alarms in recognition memory (Meade, Klein, et al., 2020). In that study, participants were presented with lists of categorised/semantically related words. Such lists typically induce high false alarm rates to semantically related but non-target lures on a recognition test (Meade, Klein, et al., 2020). Meade and colleagues (2020) found that drawing not only enhanced one's ability to recognize previously encoded words, but also led to higher rates of false alarms. Others have suggested that higher false alarm rates indicate a weaker memory trace (Banks, 1970; Clark & Gronlund, 1996; Dobbins et al., 2000). In a similar manner, in Experiment 3a, participants in the Transform group were asked to create multiple distinct pictures (for repeat draw trials) depicting the same word. That is, these pictures were of the same target items and therefore semantically related to one another. Consequently, the creation of multiple novel, but related

visual representations may have inadvertently boosted gist-based memory and reduced item-specific memory of targets, accounting for the poorer memory in this group compared to the Trace group. Although participants were specifically instructed to generate a completely novel drawing the second encoding event, further in-depth analysis of the images themselves is required to determine how distinct the images were.

Interaction of Encoding Type and Instantiation

Experiment 3a showed there was also a larger magnitude benefit for drawing twice in comparison to writing twice. That finding is in line with evidence from previous studies suggesting that representations of repeated experiences are better integrated with one another in long-term memory (Benjamin & Tullis, 2010; Hintzman, 2010; Moscovitch et al., 2006; Nadel & Moscovitch, 1997; Yassa & Reagh, 2013). The use of drawing combines information from multiple modalities (Roberts et al., 2024; Wammes et al., 2019). Critically, engaging in drawing integrates information from more modalities than writing does (Forrin et al., 2012; Roberts et al., 2024; Sadoski et al., 1997; Wammes et al., 2019). Both written and drawn items benefit from repetition, but drawn items benefit more because they include more features (like visual details), giving more connections that can be reinforced each time they are revisited (Moscovitch et al., 2006; Nadel & Moscovitch, 1997; Yassa & Reagh, 2013).

Experiment 3b addressed a possible alternative explanation, that generating a different exemplar was just harder and reduced memory performance for those in the ‘Transform’ group. We ruled out this alternative explanation because we showed that while

quality ratings of detailedness and representativeness were higher for the first than the second encoding trials, these did not correlate with, nor predict memory recall. Thus, task difficulty demands do not appear to explain why performance was lower in the ‘Transform’ relative to ‘Tracing’ group. The implications of these findings in terms of explaining the mechanism of action for the memory benefit are discussed further in the General Discussion, along with a proposed model for how drawing benefits memory.

Conclusion

Here, we showed that strengthening an already existing link between the conceptual meaning of a target word and its visual percept (through repetition) provides a greater memory benefit in comparison to generating multiple semantically related exemplars (transformation). We also showed that there was a larger magnitude benefit for drawing twice in comparison to writing twice. Our study suggests that establishing and strengthening a single exemplar is more beneficial for memory, particularly for words drawn at encoding.

Chapter 5

Experiment 4: Which encoding techniques facilitate comprehension?

Throughout this thesis, I have demonstrated that drawing is an effective memory encoding technique. It is the best encoding technique for younger, middle-aged, and older adults when compared to reading aloud, writing, and silently reading (Tran & Fernandes, 2023a). Drawing can also improve memory for concrete and abstract word types (Tran & Fernandes, 2023a, 2024a). Previous work has also demonstrated that the use of drawing can even improve memory for academic terms and their definitions (Wammes et al., 2017). If the use of drawing can benefit memory for concepts and ideas requiring some degree of abstraction (Tran & Fernandes, 2023a; Wammes et al., 2017), this raises the possibility that encoding techniques could also benefit performance on other cognitive tasks. In Experiment 4, we examine whether drawing as an encoding technique could also improve reading comprehension.

Remembering requires that one retain discrete units of information (e.g., recalling a word from a studied list). Studies have demonstrated that encoding techniques exist that can effectively boost retention. Comprehension involves integration, abstraction, understanding, and the application of discrete units of learned information, in novel ways or in new scenarios (e.g., using a word correctly in a sentence; Basaraba et al., 2013; Bransford & Johnson, 1972; Diakidoy et al., 2011). Regardless of their different end goals, remembering and comprehension both begin with a common process: encoding. Encoding is the process by which we perceive, acquire, and learn information (Baddeley et al., 2014; McDermott &

Roediger, 2018; Melton, 1963). This parallel between remembering and comprehension suggests techniques designed to enhance memory may similarly enhance comprehension. The current study aimed to examine whether encoding techniques (production and drawing) known to benefit memory, can also improve comprehension. In addition, if these memory encoding techniques can improve comprehension, we sought to determine whether improvements would be comparable in size to that of paraphrasing, a technique known to benefit comprehension (Hagaman et al., 2012, 2016; Hans, 2017; Hua et al., 2014).

Factors affecting comprehension

Past work has shown that memory and comprehension are inextricably linked. According to a review by Just and Carpenter (1992), engaging in comprehension not only involves generating a coherent sequence of information (from memory), but also using this information by either applying or integrating it with additional information. The retrieval of partial information, such as content previously learned about a topic, is often required during comprehension, particularly when given longer or more complex texts (Just & Carpenter, 1992). That is, when engaging in comprehension, one must retrieve learned words, phrases, or sentences and integrate them with new information. In addition, comprehension also requires the storage of themes within a text and contextual information from surrounding sentences. Once such higher-level representation of the information is established (e.g. theme of the text), lower-level information is often forgotten (e.g. how the sentence was structured; Huey, 1908; Jarvella, 1971; Sachs, 1967). High-level information such as context is then used to integrate new and relevant incoming text (Sharkey & Mitchell, 1985). Because

relating information is an intrinsic part of comprehension, the ability to retain content over time while processing new content is crucial. Given this, Just and Carpenter proposed that comprehension is constrained by an individual's working memory capacity to hold multiple interpretations of the given information, as well as store intermediate and final interpretations as they construct and integrate ideas (Just & Carpenter, 1992).

A common measure of working memory within the comprehension literature is reading span, defined as the number of sentences one can read while accurately remembering the last word of each sentence at later recall (Daneman & Carpenter, 1980). A reading span task requires that the reader simultaneously process the text and store the final words of each sentence (Daneman & Carpenter, 1980). In a sample of university students, the average reading span ranged from two sentences to five sentences, and was highly correlated with comprehension (Daneman & Hannon, 2007). In a variety of studies using different comprehension tasks, the largest differences between participants characterized as having high and low-span were observed on longer and structurally complex texts, whereby high-span readers were both faster at reading, and more accurate on a later comprehension test (Daneman & Carpenter, 1980; Just et al., 1982; King & Just, 1991). These results suggest that working memory, or the ability to hold multiple pieces of previously learned information, for integration with newly learned information, is highly related to comprehension. Similarly, Hua and Keenan (2014) found that when memory for text was high, there were no differences in comprehension scores between those who were identified as "good" and "poor" comprehenders. Thus, memory for content contributes to, and possibly

underlies, the comprehension of information. The findings from these various studies suggest that high working memory capacity facilitates the ability to hold and integrate multiple pieces of information at the same time, thus facilitating comprehension. That is, it seems that one's ability to comprehend is linked to one's memory capabilities. As such, we reasoned that encoding techniques known to improve memory may also improve comprehension.

Memory encoding techniques to improve comprehension

Importantly for the current study, continuously reading a word aloud (production; Putnam et al., 2014) has been shown to boost memory for abstract words (Tran & Fernandes, 2023a), as well as text passages (Ozubko et al., 2012), suggesting it could be effective in improving comprehension of text passages that require some degree of abstraction. In contrast, recent work suggests that the use of production does not improve performance on evaluative comprehension-type questions that do not assess verbatim memory (literal comprehension; Roberts et al., 2023). Specifically, in a series of four experiments, Roberts and colleagues gave participants university-level text passages and asked them to read half of the passages aloud and the other half silently. Participants then answered five multiple-choice questions for each of the 10 passages, that either assessed comprehension based on information directly available in the text (literal comprehension questions) or assessed comprehension based on inferences that could be derived from the passage (evaluative comprehension questions). Literal comprehension questions are those that require one to recall exactly what was stated in the text (Basaraba et al., 2013). Inferential comprehension questions are those that require connecting ideas within the text, similar to propositional logic

statements (1. A grizzly is a bear, 2. A bear is a mammal, 3. A grizzly bear is a mammal; Basaraba et al., 2013). Evaluative comprehension questions are those that require that one use information acquired earlier and apply it to a novel situation (evaluative comprehension; Basaraba et al., 2013). They found a consistent production benefit on literal comprehension questions, but not evaluative ones.

A possible explanation as to why production did not improve performance on comprehension-based evaluative questions (Roberts et al., 2023) may lie in its mechanism of action. Both distinctiveness and strength-based accounts have been proposed to account for the production benefit (MacLeod & Bodner, 2017). According to a distinctiveness account, the production of a word aloud provides more unique speech and sound information. Distinctiveness has been the dominant account of the production effect as the benefit does not emerge in between-subject designs, nor when assessed using pure-lists, likely due to the lack of a relatively “less salient” comparator trial types such as silently reading (MacLeod et al., 2010). However, in Fawcett (2013) , a production effect was demonstrated in a between-subject design, in line with the other account of production effects. According to a strength-based account, reading aloud enhances a word’s fluency and familiarity, making it more familiar at retrieval (MacLeod & Bodner, 2017). Similarly, while computational accounts have largely focused on, and support, a distinctiveness account of the production benefit (MINERVA2; Jamieson et al., 2016; Retrieving Effectively from Memory; Kelly et al., 2022, 2024; Revised Feature Model; Saint-Aubin et al., 2021), modelling of the corollaries and constraints of a strength-based account also aligns with results from behavioural data

(Jamieson et al., 2016; Kelly et al., 2022, 2024). Given this, it makes sense that Roberts and colleagues (2023) failed to find any benefit of production on evaluative comprehension.

Drawing also has been shown to boost memory for abstract words (Roberts & Wammes, 2021; Tran & Fernandes, 2023a), emotional words (Tran & Fernandes, 2023b), autobiographical events (Tran et al., 2022), and academic terms and their definitions (Wammes et al., 2017). This last finding suggests that drawing may be particularly effective in improving memory for concepts and ideas requiring some degree of abstraction. Previous work has also suggested that drawing requires the creation of a personal and unique representation of to-be-remembered information during the study phase, and this may contribute importantly to its beneficial effect on memory (Fernandes et al., 2018). Relatedly, the drawing benefit has been proposed to arise from the integration of multiple representations: verbal, semantic, and pictorial (Fernandes et al., 2018; Wammes et al., 2019). Given this, drawing may be particularly able to enhance evaluative comprehension, more so than production.

In addition, it has also been shown that reading aloud confers a similar benefit for concrete and abstract words whereas drawing confers a greater benefit for concrete words in comparison to abstract ones (Tran & Fernandes, 2023a). As the advantage that is often observed for concrete words on a memory test is likely derived from engagement of semantic-based processing, it would seem that drawing requires one to think about the meaning of the word, whereas reading aloud does not. In line with the notion that production has a different mechanism of action, its benefit is maintained and similar in magnitude for

words and non-words that have no associated meaning (MacLeod et al., 2010). This suggests that reading aloud confers a memory benefit by invoking perceptually-based, rather than a semantically-based mechanism. In contrast, the drawing benefit seems to be dependent on a semantically-based mechanism (Tran & Fernandes, 2023a, 2024a). Given these differences, the two memory encoding techniques may have different effects on comprehension.

The efficacy of various encoding techniques has been concurrently studied within the realm of comprehension and education. These techniques are often referred to as learning strategies. Relevant to the current study, like drawing, paraphrasing is an effective strategy for notetaking (Bui et al., 2013; Bui & Myerson, 2014; Kiewra, 1985; Kiewra & Benton, 1988; Williams & Eggert, 2002). When paraphrasing the user must rephrase, elaborate upon, and transform content into their own words (Best et al., 2005; Graesser et al., 1994; Magliano et al., 2011). This means that paraphrasing requires that one understands the text well enough to transform the information into their own words (Best et al., 2005; Hans, 2017). In addition, the user must think deeply about the meaning of the text in order to transform the information (Graesser et al., 1994; Magliano et al., 2011; Wammes et al., 2017). Therefore, paraphrasing, like drawing, allows the reader to personalize the information and describe the information using more familiar language (Hagaman et al., 2016; McNamara, 2004). Paraphrasing has already been demonstrated to aid recall of terms and their definitions (Wammes et al., 2017), as well as comprehension of main ideas (Ellis & Graves, 1990; Hagaman et al., 2016; Hagaman & Reid, 2008). As such paraphrasing as an encoding technique serves as a useful comparator in the current study.

Current Study

In the current study, we compared the effectiveness of three encoding techniques known to benefit memory (production, drawing, paraphrasing), but with different proposed underlying mechanisms (e.g. distinctiveness/strength-based, multimodal processing, transformation). More specifically, we aimed to compare the encoding techniques to a baseline condition of silently reading the materials. Silently reading was chosen as a baseline condition because it is one of the most commonplace methods used to encode new information, particularly in educational settings (Frost, 1991; Perfetti et al., 1988). Silently reading is often considered to be a more impoverished or non-elaborative encoding task (Jonker et al., 2019). It has also been shown to benefit the retrieval of relational information in shorter lists in comparison to drawing (Jonker et al., 2019). Given that we were assessing comprehension of terms and their definition, which likely require relational processing, silent reading was selected to be the baseline for comparison with our treatment conditions of Reading aloud, Drawing, and Paraphrasing. Because these encoding techniques are purported to have somewhat different underlying mechanisms of actions, they may differentially benefit performance on an evaluative comprehension test that requires the application of learned information to novel scenarios.

We assessed the benefit of these various encoding techniques, relative to silent reading, on a test of evaluative comprehension of printed texts. We predicted that while paraphrasing and drawing would likely result in higher comprehension scores, production would result in similar performance to silently reading. This is because both drawing and

paraphrasing requires one to transform the given information, either to create an image representing the information (Fernandes et al., 2018a; Wammes et al., 2019) or to re-generate the information in their own words (Best et al., 2005; Graesser et al., 1994; Magliano et al., 2011). Both of these techniques not only require the user to think deeply about the given information, but also require them to personally re-represent the information, making it more familiar and personally relevant. In addition, previous work also has shown that while production can benefit memory for long-form text passages (Ozubko et al., 2012), it is not necessarily beneficial to performance on more evaluative types of comprehension questions (e.g. Roberts et al., 2023). We also reasoned that because drawing and paraphrasing both facilitate the formation of memory representations, critical working memory resources (Just & Carpenter, 1992) could more efficiently be devoted to integrating or linking concepts across sentences within a passage, ultimately enhancing evaluative comprehension.

Previous literature indicates that the ability to hold, represent, and integrate discrete information over time is critical for successful comprehension. If the use of production, drawing, and paraphrasing differentially benefit comprehension test performance, it would suggest that the way in which these encoding techniques benefit memory differs. In addition, it would reveal what underlying mechanisms are particularly effective at enhancing both the quantity of what we remember and the quality of our understanding.

Materials and Methods

Participants

A total of 66 participants (37 females; 25 males; 4 preferred not to say), aged 17 to 25-years-old ($M = 20.36$; $SD = 2.08$), with a mean of 15.35 ($SD = 2.32$) years of education were recruited from the University of Waterloo, and received course credit in psychology courses for taking part in the study. Participants were randomly assigned to 1 of 3 encoding groups (production, drawing, paraphrasing), each consisting of twenty-two participants. A G* Power calculation (version 3.1.9.7) based on the effect size from a related study comparing the comprehension benefit between reading aloud and silently (Roberts et al., 2023) revealed a total target sample size of 60 participants was needed to provide 80% power to detect group differences. The Mill Hill vocabulary scale was used to ensure that all participants included in the analysis met the inclusion criteria of being fluent in the English language. All participants scored above 30% (a score of 10 out of 32) on the Mill Hill Vocabulary Scale (Raven, 1983), indicating English literacy (10 – 24; $M = 15.01$, $SD = 3.85$).

Materials

Terms and Definitions. Twenty term-definition pairs from various subject areas were provided by Wammes and colleagues (2017). These terms consisted of concepts from university textbooks spanning seven subject areas: Astronomy, Biology, Chemistry, Earth Sciences, Engineering, Physics, and Psychology (see Figure 12 for samples and <https://osf.io/gbc3m> for a full list). The terms were 5-14 letters ($M = 9.50$, $SD = 2.52$) and 1-5 syllables ($M = 3.35$, $SD = 1.04$). Each associated definition was 9-28 words ($M = 17.85$, $SD = 4.28$).

Figure 12

Sample of Terms and Their Definitions, for Experiment 4

<i>rhizoid</i>	<i>Root-like threads that help anchor the plant to the ground. They do not absorb nutrients and water.</i>
<i>transpiration</i>	<i>The evaporation of water from the surface of leaves and stems. This process is a necessary part of photosynthesis and respiration.</i>

Comprehension Test. Comprehension was assessed using 20 multiple-choice questions (see Figure 13 for a sample and <https://osf.io/gbc3m> for the full list). The comprehension test was presented on Qualtrics (Qualtrics, Provo, UT, 2022). The order of the questions was randomized for each participant, and one question was presented per page. The question appeared at the top center of the Qualtrics form in size 13.5 Georgia font. The possible multiple-choice answers were presented in size 10 Georgia font. The four possible answers were displayed below the question, with two options listed in each of the two columns. For each question, four possible answers were listed: the correct term, a semantically related lure, and two other terms that were previously presented. Each question required the participant to use the information from the given definition provided in the study phase, and apply it to a novel scenario. Participants were instructed to skip to the next question if they did not have an answer to the current question.

Figure 13

Sample of a Term and Its Associated Evaluative Comprehension Question, for Experiment 4

<i>Rhizoid</i>	<i>Blake was reorganizing the garden bed. He found that certain more established flowers were difficult to remove. He had to dig deep and wide to remove the entirety of the plant. This plant likely has a density of?</i>
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☐ *Rhizoid* → *Correct Answer*

☐ *Spore* → *Familiarity Lure*

☐ *Aridisol* → *Familiarity Lure*

☐ *Stalk* → *Semantically Related*

Note: Here the term, definition, correct answer, and lure types are shown for illustrative purposes. These are not shown on the actual test.

Procedure

Randomly intermixed and counter-balanced term and definition pairings were presented, one at a time, during the study phase. In each of the 3 groups of participants, all 20 terms and their corresponding definitions were presented. Depending on group assignment, participants performed one of the 3 encoding techniques (production, draw, or paraphrase) for half of the trials (10) and silently read the term/definition for the other half (10). On all trials, the prompt and to-be-remembered term and definition pairings were shown simultaneously for 15 seconds, followed by a 500-millisecond auditory tone indicating the end of the trial. The encoding prompt (Read aloud/ Paraphrase/ Draw or Read silently) was presented in size 60, purple Verdana font, with placement aligned centrally at 25% from the top of the screen. The term and definition pairings were presented simultaneously in size 30, black, Consolas font with placement aligned 65% from the top of the screen. During the study phase, participants in the Draw group were asked to draw a picture of the definition, using a pencil and a notepad (10.1m cm x 15.20cm). Participants were instructed to allocate a single page for each word and to flip to a blank page once they heard the auditory tone indicating the end of the trial. They were told to add detail to their sketch until the next trial. The Paraphrasing group was asked to reiterate the definition in their own words and write it out on the provided notepad. They were told to add detail to their paraphrased summary until the next trial. Figure 14 shows samples from the Drawing and Paraphrasing groups. The Production group was asked to repeatedly read the term and its definition aloud at a comfortable speaking pace. They were told to repeat their reading until the next trial. The

researcher ensured compliance with encoding task instructions. Each participant was given a practice study phase using their group-specific encoding technique, and another to practice silently reading, using unique term and definition pairings not from the experimental stimuli set. After the study phase, the notepads from those in the Drawing and Paraphrasing groups were removed by the researcher.

After all twenty of the term and definition pairings were presented, regardless of Group, there was a 15-second filled delay during which participants counted backward by threes from 99 to reduce recency effects in subsequent memory recall. Stimulus presentation was conducted using E-Prime 3.0 (Psychology Software Tools, Pittsburgh, PA). Following the study phase, participants in each group were asked to answer the 20 evaluative comprehension questions sequentially and the Mill Hill Vocabulary Scale on Qualtrics (Raven, 1983).

Figure 14

Sample of Output From Different Participants for the To-Be-Encoded Term 'Transpiration', for Experiment 4

Paraphrase		
Transpiration - required for photosynthesis.	transpiration: plants breathing	Transpiration: evaporation from leaves
Draw		
		

Results

Participants' comprehension was assessed by tabulating the number of correct selections on the multiple-choice test, separately for each Group and Strategy type (see Table 6 for means). Sphericity was not violated in any of the analyses.

Table 6

Mean (and Standard Deviation) of the Number of Correct Selections on the Multiple-Choice Comprehension Test, for Experiment 4

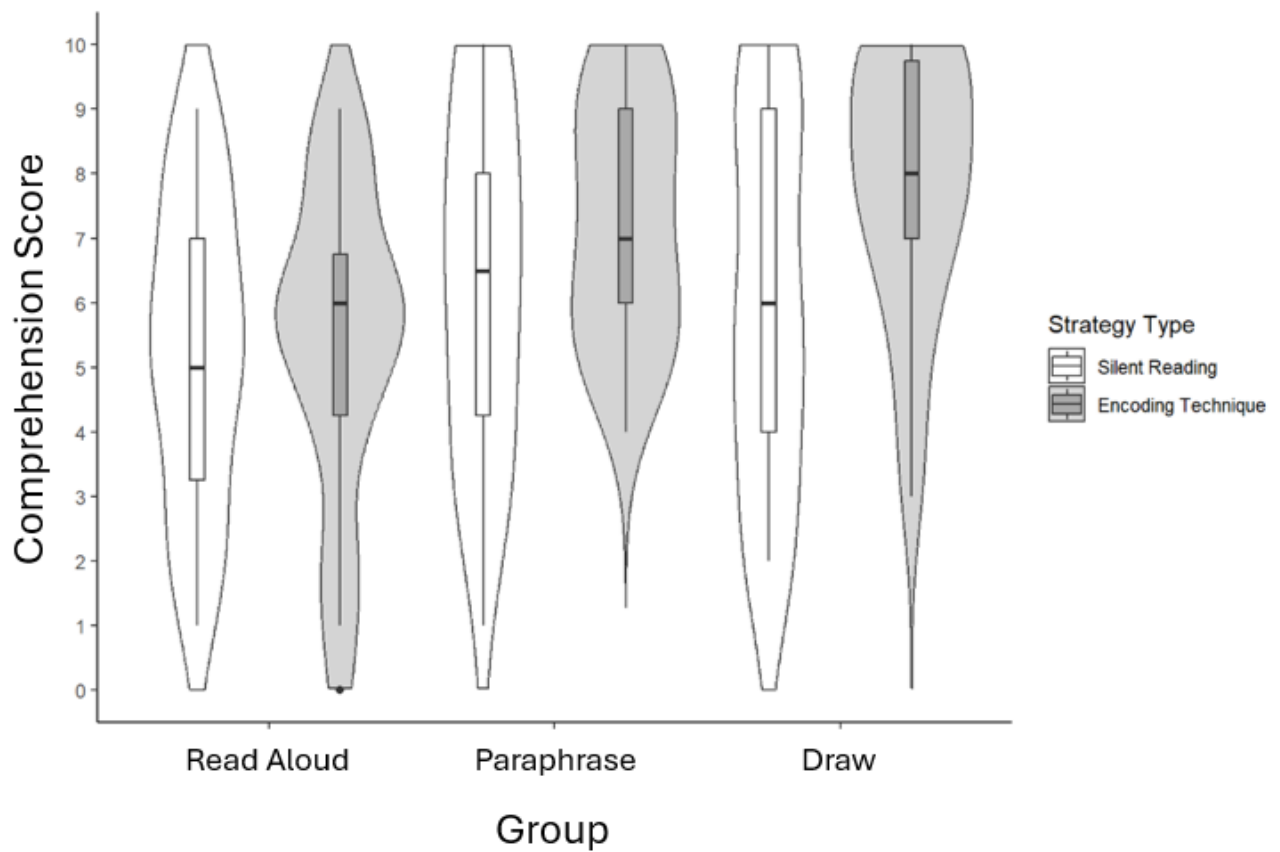
	Group		
	Production	Paraphrase	Drawing
Encoding technique	5.41 (2.46)	7.23 (1.88)	7.81 (2.04)
Silent reading	5.27 (2.39)	6.27 (2.71)	6.05 (2.87)

Data were analyzed in a 2 Strategy type (Silent reading and Encoding technique) X 3 Group (Read Aloud, Paraphrase, and Draw) mixed ANOVA with the first being a within- and the second being a between-subject factor. There was a main effect of Strategy type, $F(1,63) = 19.59$, $MSE = 1.54$, $p < .001$, $\eta_p^2 = 0.24$, such that comprehension scores were higher when an Encoding technique was used rather than Silent reading. There was also a main effect of Group, $F(2,63) = 3.29$, $MSE = 5.08$, $p = .04$, $\eta_p^2 = 0.09$. There was a significant difference in comprehension score depending on what Encoding technique was used, $F(2,63) = 3.29$, $MSE = 5.08$, $p = .044$, $\eta_p^2 = 0.09$. The use of Drawing, $t(42) = 3.54$, $p < .001$, $d = 1.07$, and Paraphrasing, $t(42) = 2.76$, $p = .004$, $d = 0.83$, conferred greater benefits to comprehension scores in comparison to Production. There was no significant difference in comprehension scores when comparing Paraphrasing and Drawing $t(42) = 1.00$, $p = .323$, $d = 0.30$. This was qualified by a significant Strategy type X Group interaction, $F(2,63) = 4.80$, $MSE = 1.54$, $p = .012$, $\eta_p^2 = 0.13$.

To explore the interaction, we examined the effect of Strategy type separately for each level of Group. For the Production group, a paired t-test showed no significant difference in comprehension performance following the Silent reading and the Encoding technique of production, $t(21) = 0.31$, $SE = 0.45$, $p = .76$, $d = 0.06$. For the Paraphrase group, the paired t-test showed there was better comprehension performance for trial types using the Encoding technique of paraphrasing relative to Silent reading $t(21) = 2.67$, $SE = 0.36$, $p = .007$, $d = 0.57$. For the Draw group, the paired t-test showed there was better comprehension performance for trial types using the Encoding technique of draw relative to Silent reading $t(21) = 5.89$, $SE = 0.30$, $p < .001$, $d = 1.25$ (see Figure 15). Notably, the Groups did not differ in terms of comprehension performance following the Silent reading Strategy type, $F(2, 63) = 0.85$, $p = .43$, $\eta_p^2 = 0.03$.

Figure 15

Comprehension Scores (Out of 10) for Each Encoding Technique and the Corresponding Silent Read Conditions, for Experiment 4



Discussion

We compared the effectiveness of different encoding techniques (production, drawing, paraphrasing) in improving comprehension test performance, compared to silently reading. Different mechanisms of action have been proposed to account for the memory benefit conferred by production, drawing, and paraphrasing: Distinctiveness or strength for production (MacLeod et al., 2010), integration of multi-modal representations for drawing

(Wammes et al., 2016) and personalisation for paraphrasing (Ellis & Graves, 1990; Ellis & Lenz, 1987; Hagaman et al., 2012; Hans, 2017; Hua et al., 2014). We hypothesized that these techniques may also differentially benefit performance on an evaluative comprehension test. As predicted, we found that the use of paraphrasing and drawing resulted in better comprehension performance relative to silently reading. In contrast, reading texts aloud as an encoding strategy, relative to silently reading, led to similar levels of comprehension performance.

Our results replicate previous findings showing that paraphrasing confers a greater benefit to comprehension performance than does silently reading (Ellis & Graves, 1990). Past studies have shown that participants who use paraphrasing are likely to recall more text (Hagaman et al., 2016), correctly identify the main ideas (Ellis & Graves, 1990; Glover et al., 1981; Hagaman & Reid, 2008), and correctly respond to short answer questions (Hagaman et al., 2016; Hagaman & Reid, 2008) about the studied text. One possible component that makes paraphrasing beneficial on assessments of evaluative comprehension is that it requires that the user understands the meaning of information well enough to reiterate and transform the text into sentences that the user generates. In line with this explanation, it has been previously demonstrated that deeper levels of processing, and self-generation of information during encoding enhance subsequent memory retrieval (Craig & Lockhart, 1972; Slamecka & Graf, 1978). Another component that could be contributing to the observed comprehension boost is that conveying key information from the text in one's own words likely personalizes the information, making it self-referential (Hagaman et al., 2012; Hans, 2017; Hua et al.,

2014). Previous studies have demonstrated that when information is associated with oneself, it is consistently better remembered (Rogers et al., 1977) due to enhanced relational and item-specific processing (Symons & Johnson, 1997).

Our findings also demonstrate that, like paraphrasing, drawing also benefits comprehension performance. Given that drawing led to comprehension performance that was similar to that following paraphrasing, and that both encoding techniques led to better performance than silently reading, our results highlight that drawing is an effective means of enhancing comprehension. In a similar manner to paraphrasing, the use of drawing requires that one re-represents the meaning of the information into a personally unique image that is generated by the user (Fernandes et al., 2018). Our work suggests that personally transforming or re-representing the meaning of the text, either verbally or pictorially, may underlie not only benefits to memory but to comprehension as well.

Finally, our results suggest that production may be more beneficial for verbatim memory rather than the application of knowledge. Such a conclusion aligns with recent work by Roberts and colleagues (2023) who similarly found that production does not benefit performance on a test of evaluative comprehension. The results from the current study suggest that this may be because production does not require the user to personally re-represent or transform the meaning conveyed by the text. As production did not significantly enhance evaluative comprehension in our study this would further suggest that semantic processing of the material during encoding is needed to confer a benefit to comprehension.

The lack of a benefit of production on comprehension test performance is also in line

with previous work showing that production is equally effective in boosting memory for non-words as for words (MacLeod et al., 2010). In fact, when comparing the magnitude of benefit from production on memory for word and non-word stimuli, MacLeod and colleagues (2010) found no significant differences. That is, items that hold no semantic meaning similarly benefited from being produced as did actual words (MacLeod et al., 2010). This suggests production benefits arise due to perceptual- rather than semantically-mediated mechanisms. In line with this, recent work from our lab also showed that producing words at encoding did not confer a differential benefit to concrete and abstract words (Tran & Fernandes, 2023). Such findings suggest that the production benefit is not semantically, but rather is perceptually, based. Given this, production offers no benefit to memory on tests that assess understanding of the meaning of information. That is, production likely enhances the perceptual representation of the material, but this does not facilitate performance on an evaluative comprehension test that demands understanding the meaning of the information.

Conclusions

Here, we showed that drawing and paraphrasing, as encoding techniques, were similarly able to boost evaluative comprehension test performance, but production failed to do so. In contrast to production, both paraphrasing and drawing are techniques that require semantic elaboration and/or transformation of the to-be-learned information, suggesting this as a likely mechanism of action. Drawing and paraphrasing are effective encoding techniques that not only boost the quantity of what one retains in memory, but also elevate the quality of information that is encoded.

Chapter 6

General Discussion

“Of all the hand-held tools that have been invented, the sort that makes traces on a surface especially noteworthy – the stylus, brush, pen, pencil, crayon, or marker. The movement of the tool over the surface is both felt and seen... The seeing of a progressive record of the movement of the tool is lasting. There is a track or trail of the movement like the afterimage of a firebrand whirled in the darkness except permanent, a stroke, stripe, or streak, in short, a trace.” (Gibson, 1978, 229-230)

Since prehistoric sketches on cave walls, drawings have been used as a tool to convey and preserve information. Today, drawings can be sketched out quickly onto a napkin, receipt, coffee sleeve, or in a note-taking application on a smartphone. Recently, researchers have become increasingly interested in examining how drawing as an encoding tool shapes what we remember and learn (Bainbridge et al., 2025; Fernandes et al., 2018b; Jonker et al., 2019; Meade et al., 2020; Tran & Fernandes, 2024b; Wammes et al., 2016). The overarching goal of my PhD dissertation was to determine whether drawing can enhance not only the quantity of information remembered, but also the quality of information remembered. In addition, this dissertation also aimed to further disentangle the possible mechanisms underlying the drawing benefit.

Summary of thesis

In Experiment 1, I compared various encoding techniques: silently reading, reading aloud, writing and drawing. Previous evidence suggests that although these techniques can each improve memory, they may do so through different mechanisms. I observed a concreteness benefit for every encoding technique, except reading-aloud. This finding provides further evidence that some encoding techniques are semantically based and influenced by the meaning of the word (silently reading, writing, and drawing), whereas others rely on perceptual distinctiveness (reading aloud). I also determined that the use of drawing was the most beneficial encoding technique overall. Importantly, I also showed that the magnitude of the drawing benefit was smaller for older adults than middle-aged adults, and smaller for middle-aged adults than for younger adults. This pattern is consistent with reported age-related deficits in generating imagery or integrating it with motoric processes. Despite this age-related reduction in the drawing benefit, concrete words that were drawn during encoding were better retained than abstract words, regardless of age, suggesting the degree to which a target word can be visualized remains a driving factor. The robustness of the benefit suggests that drawing can facilitate formation of age-invariant visuospatial representations that ultimately enhance memory.

In Experiment 2, we examined the mechanistic differences in these techniques by comparing memory performance when participants wrote and drew words themselves versus

when they observed someone else writing and drawing (Tran & Fernandes, under review). Overall, drawing at encoding benefited memory more than writing or reading words, regardless of whether it was performed or observed in-person or online. This finding is consistent with common-coding-theory which suggests that perceiving an action activates some of the same motoric processes in the brain involved in performing that action. However, the magnitude of the drawing benefit was greatest when performed rather than observed, suggesting an additional role of personal relevance, in transforming the target information and creating one's own drawing in enhancing memory.

In Experiment 3a, we contrasted a semantic elaboration account for the benefit (i.e. creating multiple drawings linked to the target word) versus a strengthening of visuo-perceptual representation account (i.e. repeating the same image of the target word multiple times). The first account was derived based on Slamecka and Graf's (1978) suggestion that self-generation of target information enhances retention. The second account was derived based on Hintzman's (1970) suggestion that simple repetition drives retention of information. Here, we asked participants to engage with to-be-remembered words twice, using the encoding technique of either drawing or writing words at encoding. Importantly, during the second encoding event, we manipulated whether participants needed to generate a different visual representation or simply repeat their initial sketch. As expected, encoding words twice versus once boosted the proportion of words recalled, regardless of encoding technique, though drawing twice was more beneficial to memory than was writing. We also found that tracing the exact same representation of the word (whether drawn or written) enhanced

memory performance more so than creating a novel drawing or writing of the target. These findings suggest that additional semantic elaboration or generation of multiple exemplars does not account for the drawing benefit. Rather, strengthening the link between a word and a visual sensory referent matters more in enhancing retention.

In Experiment 3b, the representativeness and detailedness of line drawings from Experiment 3a were rated by naïve participants. Here, we showed that while the original drawings were more representative and detailed relative to subsequent drawings of the target, these factors did not correlate with, nor predict, memory performance. Given this, it is unlikely that increased task-difficulty in generating novel drawings of the target, relative to re-tracing an initial drawing, can explain why it led to poorer memory. Instead, results favour the simpler explanation that the degree to which a visual percept is established and enhanced determines memorability.

In Experiment 4, we extended the conditions under which drawing conferred a benefit to comprehension. Specifically, we examined whether drawing led to a deeper level of understanding of the target material. Here we compared whether encoding techniques known to benefit memory (drawing and reading aloud), also enhanced comprehension of new information: terms and their definitions. Drawing as a way to encode and learn this new information benefitted performance on a test of comprehension more so than did reading the information aloud, with performance in line with that conferred from paraphrasing. This demonstrates that drawing not only improves the quantity of the information that can be remembered but also deepens the quality of what is understood. Better comprehension

following drawing of target information also provides converging evidence with Experiment 1 which showed that drawing can benefit memory even for abstract information. Once again, these findings underscore that it is the fact that drawing creates a visual percept of to-be-remembered information, and this results in a broader representation than simple verbal coding. Thus, creating and strengthening this additional visual code has been demonstrated here in this thesis to underlie the benefit of drawing to memory and cognition.

In this dissertation, I have demonstrated that drawing is a powerful encoding technique, conferring the greatest memory benefit when compared to silently reading, reading aloud, and writing. This pattern held for different word types and across the adult lifespan in Experiment 1, it was further strengthened by personal relevance of the production in Experiment 2, and also by repetition, particularly of the visual percept in Experiment 3. In Experiment 4, I also showed that the use of drawing could even improve reading comprehension, a cognitive task that demands a greater degree of abstraction. Together, these findings demonstrate that drawing is useful for improving not only the quantity, but also the quality of information that is remembered.

Creating A Strong Visuo-Perceptual Representation

As in the current dissertation, past research in cognitive psychology consistently shows that creating strong visual representations enhances memory. According to Paivio's dual coding theory (1963), information encoded both verbally and visually is more likely to be remembered because it is stored in two interconnected systems, providing multiple retrieval pathways. Experimental studies support this idea: participants instructed to form

mental images of target words recalled significantly more items than those who rely on verbal rehearsal alone (Bower, 1972; Paivio, 1979). Similarly, words that are intrinsically more imaginable and readily evoke a mental image are better remembered (Richardson, 1975). In addition, the well-established picture superiority effect demonstrates that images are more memorable than words across a wide range of tasks, as they are encoded more richly and often generate both visual and verbal representations (Paivio & Csapo, 1973; Rissenberg & Glanzer, 1986; Shepard, 1967; Standing, 1973). Together, these findings indicate that it is the visual representation that strengthens encoding and improves both recall and recognition.

Experiments 1, 2, and 3 showed that the user's ability to personally create a link between a visual-perceptual representation and the semantic meaning of a target word is critical to the drawing benefit. Further, our findings support the idea that if the drawing benefit arises from the formation of strong links between a word's meaning and a sensory referent, concrete words should benefit more than abstract ones since concrete words more readily evoke real-world sensory experiences and spontaneous imagery (Paivio, 1990; Paivio et al., 1994). Finally, once there is a well-established link between a sensory referent and the semantic information of the to-be-remembered item, strengthening the existing engram is more beneficial than broadening the network of associated links.

Creating a model of memory

Within the field of memory, the mnemonic benefit of repetition is a reliable finding (Ebbinghaus, 1885; Hintzman, 1970; Hintzman & Block, 1971). This repetition effect is thought to occur because each repetition results in reactivation of the original memory trace (Nadel & Moscovitch, 1997). In this dissertation, I also demonstrated that the repetitive use of encoding techniques can further enhance memory. That is, copying one's writings verbatim and drawings exactly resulted in the greatest benefit to memory. Therefore, the best way to enhance memory is to strengthen an already established memory trace by reactivating all previous elements during the second encoding event. This is particularly true for images compared to words as drawing a second time conferred a larger memory benefit than writing twice.

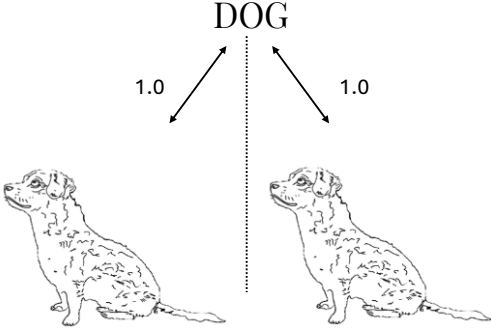
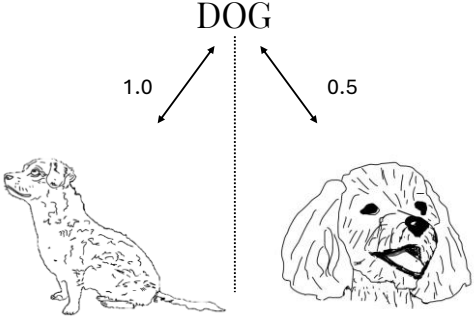
In the case of trace drawing, the original image that the individual previously generated is copied exactly. Therefore, the totality of the existing memory trace is reactivated and strengthened as the elements of the first and second instantiations overlap completely. I propose the following model of memory. We could assign a base memory trace strength of 1.00 to the initial drawing encoding event (See Figure 16). When tracing the original image, the user is reactivating all the elements that comprise the initial encoding event, strengthening the entire original memory trace. A memory trace strength of 2.00 could be assigned to traced items, as the same memory trace is activated twice. In contrast, creating multiple novel writings and drawings inherently means that there will be some differences between each iteration. This means that the elements present during the first and second

encoding events will not maximally overlap. There will be less depth of encoding and a wider breadth of elements linked to the to-be-remembered item, possibly diminishing memory strength. As there is only a partial reactivation of the original memory trace, we can assign a value of 0.50 to memory trace strength added through transformation (See Figure 16). As such, transformation may broaden the network of associations linked to the target item, however, it does not strengthen the original traces to the same degree and would be given a memory trace strength of 1.50. There is still an additional memory benefit, but not to the degree of items that were traced during the second encoding event. More broadly, these findings suggest that memory is strongest when encoding conditions repeatedly reactivate

and reinforce an existing cell assembly used to create the memory trace, rather than adding new associations to an already established representation.

Figure 16

Model of Memory Trace Strength in the Trace and Transform Groups

Group			
Trace		Transform	
			
1 st Instantiation	2 nd Instantiation	1 st Instantiation	2 nd Instantiation
Trace Strength: 2.0 (All features overlap)		Trace Strength: 1.5 (Only some overlapping features)	

This model seems to account for past published work. In a related line of experiment we demonstrated that the memory benefit from drawing was additive with the well known emotional enhancement effect on memory (Tran & Fernandes, 2023b). Specifically, it is well known that emotional words tend to be better remembered than non-emotional ones. If emotional words are then drawn, rather than simply written, at encoding (as they were in this study), these words were better remembered. In this model, we could then assign a memory trace strength of 2.00 to negative and positive valence words and 1.00 to neutral words. The

additional weighting for the emotional words represents another way in which a target item can be strengthened – here by the stimulus characteristics themselves, rather than repetition of the target.

As another example, Experiment 1 of this dissertation showed that the mnemonic benefit for drawing declines as we age. Applying my model, we could assign a memory trace strength value of 1.00, 0.75, and 0.50 to young, middle-aged and older adults, respectively. The reduced weighting represents the attenuation of the drawing benefit as the user ages due to either decline in one's ability to engage in imagery (Dirkx & Craik, 1992) or to integrate multiple representations effectively (de Dieuleveult et al., 2017). In this example, the value of the trace strength goes down because the engram itself is less well-established, accounting for the reduced benefit of drawing to memory. In future streams of research, this model could be more formally tested using computational modelling.

Limitations and Future Directions

As the aim of this dissertation was to disentangle possible mechanisms underlying the drawing benefit, I opted to use only nouns or declarative sentences. That is, all stimuli used in the current work referred to a subject (person, place, or thing) or conveyed a fact. However, these stimuli do not encompass all the critical information individuals may want to remember in their daily lives. To extend on my program of research, there are several future studies that can examine the generalizability of the drawing benefit to a variety of stimuli. For example, verbs carry information about actions, events, and associations. Previous

studies have also shown that the processing of nouns and verbs are dissociated (Cappa & Perani, 2003; Tyler et al., 2004), and as such encoding techniques may interact with word type. One such ongoing study examined whether the drawing benefit generalizes to verbs and scenes. Preliminary findings indicate that drawing versus acting out the meaning of the word differentially improved memory for different types of verbs (Tran, Muraki, Fernandes, Pexman, in prep). This finding suggests that drawing as an encoding technique can benefit action memory and could potentially be extended to a sequence of actions or could be used to remember the quickest route to a new location, extending the work to the spatial memory domain.

Another type of information that is critical for individuals to remember is the context in which items exist or actions are occurring in. Scene memory is necessary for navigating one's day-to-day life and can even become critical when testifying as an eyewitness. Future work can involve drawing or writing scenes of a staged museum tour viewed in virtual reality. The findings from these ongoing studies could reveal how beneficial drawing can be for preserving the depth and the rich contextual details of an individual's everyday memory.

Finally, future research could also examine more complex materials and the benefits of drawing in educational contexts. As drawing is arguably not as disruptive in classroom settings as other encoding techniques (e.g., reading aloud or enactment), it could be a useful tool at various education levels. Drawings are already often used in a variety of subjects, including chemistry (Lewis Structures), math (Euclidean geometry), physics (Feynman

Diagrams), and biology (phylogenetic trees). However, these drawings differ from those in the current dissertation as they typically convey some type of association rather than a fact. Such drawings are likely still beneficial, as previous work has shown that converting abstract information into a concrete visual aid that enhances remembering and understanding (Tran & Fernandes, 2023a, 2024a). However, the benefits of these drawings compared to other forms of encoding have yet to be quantified, particularly relative to other means of learning this information (e.g., silently reading or writing). In addition, examining whether drawing can benefit learning in these other domains could demonstrate how drawing supports other cognitive tasks, such as problem solving in mathematics and physics.

Lastly, although the role of motivation was briefly explored in Experiment 2, future studies should more thoroughly examine whether motivation interacts with the drawing benefit. As reviewed in Experiment 2, motivation, or the drive one has to direct behaviours towards acquiring new information, has been shown to facilitate memory performance and is associated with better learning performance (Astleitner & Wiesner, 2004; Duan et al., 2020; Gruber et al., 2014; Loewenstein, 1994; Ryan & Deci, 2000; Robbins et al., 2004; Sachs, 2001; Sankaran & Bui, 2001; Weiner, 1990; Yin & Yuan, 2021). In all the studies within this dissertation, there was some type of compensation provided for participation. This could explain why Experiment 2 showed no difference in motivation between the learning contexts (online, observing and performing) That is, we would have predicted lower motivation in the online context as online settings often lack social presence, which can reduce students' motivation to engage with the material (Cui et al., 2013; Garrison & Cleveland-Innes, 2005;

Inoue, 2007; Mykota & Duncan, 2007). Further work could first administer a more thorough motivation inventory, such as the Motivated Strategies for Learning Questionnaire (MSLQ-SF; Pintrich et al., 1993). This questionnaire has been validated to assess the learner's motivation to engage with learning strategies and educational materials. Further, a more naturalistic paradigm could be used, whereby the study could be embedded in an introductory psychology class spanning two semesters. Written or drawn assignments could be given to students throughout the course, and then later assessed during quizzes. Embedding the experimental paradigm in a course would allow students to be more naturally motivated by their desire to pass a required course. In addition, having the paradigm span approximately eight months would also help reduce the novelty of drawing as an encoding technique, and possibly minimize any potential differences that could exist due to writing being a more commonly used encoding technique than drawing.

Concluding Remarks

Over the course of this dissertation, I have contributed to the fields of memory and learning by demonstrating the robustness of drawing as an encoding technique that improves both the quantity and quality of information individuals remember. Across four experiments, I demonstrated that the use of drawing improved memory more than other mnemonic techniques, including silently reading, reading aloud and writing. This effect was observed across different word types and across the human lifespan. These studies pinpoint a key mechanism underlying the drawing benefit: the creation of a meaningful link between the

semantic content of the to-be-remembered information and a concrete visual representation. Importantly, further strengthening this link through repetition, rather than broadening the network associated with target information (by creating multiple exemplars), improves one's memory to a greater extent. Finally, I also showed that drawing can benefit cognitive tasks beyond memory, enhancing one's understanding and comprehension of information. In this way, drawing is a means of connecting abstract information to a more concrete representation or code. Together, these findings position the use of drawing as a practical learning strategy with applications and relevance in educational realms and everyday contexts.

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