Enhancing Memory by Enactment: Does Meaning Underlie the Advantage of Producing or Observing an Action?

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Enactment is an encoding strategy in which performing an action depicting a word (relative to reading) enhances its memorability. Precisely how this motor activity aids recall is unclear. In our Experiments, we investigated whether actions needed to convey meaningful information about the verbal target to confer a memory benefit. In Experiment 1 (Chapter 2), participants were asked to either a) enact, b) perform unrelated motoric gestures, or c) passively read forty-five visually-presented action verbs shown sequentially, and intermixed during encoding, in a within-subjects design. We found that enacted words were recalled significantly better than words read or gestured at encoding. In Experiment 2 (Chapter 2), to control for ambiguity in gesture initiation, participants were specifically instructed to write target words in the air on "unrelated gesture" encoding trials. Results were similar to Experiment 1. In Experiment 3, we aimed to replicate the results of Experiment 2 using an online platform to be able to video record the onset time of actions initiated in response to verbal targets, as a measure of action planning. Chapter 2 experiments showed 1) that meaningful or task-related action produced at encoding is critical to the enactment effect, and that 2) planning of meaningful actions may also contribute to the memory performance. In Experiment 4 (Chapter 3), we asked whether the performed action needed to be semantically relevant, and whether it needed to be performed by the subject (relative to observing the action of an experimenter), to confer a memory benefit. As in our previous experiments, the semantic relevance of actions to items was found to be important for the memory benefit. Importantly, the magnitude of the enactment benefit was greater when participants performed rather than observed the actions of a researcher. Results from Chapter 3 suggest that a social presence may contribute to the magnitude of past reported effects of action observation. Overall, this thesis shows that (1) semantic relevance of actions produced at encoding is critical for the observed memory boost, and (2) planning of task-relevant actions highlights another key component by which enactment benefit memory.

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Table of Contents

List of Figures

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Chapter 1: General Introduction

1.1 The Importance of Multimodal Encoding to Memory

Memory is an important faculty of human cognition that enables us to carry out our day-to-day tasks. Intact memory is crucial for successful learning in the classroom, when navigating a route, and during socialization with friends and family. Given its critical role in our daily lives, it is desirable to understand how we might better learn and retrieve new information. To this end, researchers have explored the utility of several encoding strategies that serve to enhance the initial registration of information in long-term memory, distinct from the act of retrieval. For example, prior work has explored the mnemonic benefits of repetition (Hintzman & Block, 1971), associative information (verbal; e.g., Treat, Poon, Fozard & Popkin, 1978; or visual, e.g., Paivio, 1971), deep semantic processing (Craik & Lockhart, 1972), generative processing (Slamecka & Graf, 1978), verbal production (MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010), and the drawing of to-be-remembered items (Wammes, Jonker, & Fernandes., 2016). Other forms of memory enhancement techniques involve the use of visual imagery, such as the method of loci (Bower, 1970), or rely on the benefit gained from sensory touch in the form of haptic feedback (Reales & Ballesteros, 1999; Lederman, Klatzky, Chataway & Summers, 1990). The common thread among these encoding strategies is that they require participants to actively engage with the target material, through the use of multiple sensory modalities (e.g. visual, motor, auditory). For instance, drawing out to-be remembered words at encoding has been shown to improve memory recall relative to simply reading these words, as this strategy entails the use of motor, elaborative, and pictorial/imagistic processes (Wammes et al., 2016; 2019). Information processing via multiple sensory modalities is predicted to promote a diversity of processing, which may facilitate creation of distinct ways of representing the to-be-remembered information (visual, verbal, motor) (Wammes et al., 2016). In light of these findings, the objective of this thesis was to explore the underlying mechanism of the memory benefit gained from a motoric encoding strategy referred to as the *enactment effect* (Engelkamp & Krumnacker, 1980).

Researchers have previously understood hand movements produced by people during speech to primarily aid speech comprehension between the speaker and the listener (Novack & Goldin-Meadow, 2017). However, an increasing number of studies suggest that these actions are also capable of influencing the memory of the enactor (Novack & Goldin-Meadow, 2017; Yap et al., 2011). These findings date back to research from the early 1980s, when Engelkamp and Krumnacker (1980), Cohen (1981), and Saltz and Donnenwerth-Nolan (1981), independently initiated a series of experiments to show that studying target phrases using representative actions could confer a memory benefit. The primary design of these experiments required participants to remember verb – noun phrases such as, “lift the pen” or “pour the coffee”, either by performing a representative action depicting the verbal command (subject-performed task; SPT) or by simply listening to or reading the verbal target phrase (verbal task). Findings from these early studies revealed a benefit to subsequent recall memory performance when participants enacted the phrases relative to the verbal task (coined as the *enactment effect* by Engelkamp & Krumnacker, 1980). This consistent finding has since been observed with different to-be-remembered materials (e.g., action verbs, actions performed with imaginary objects and real objects), in distinct samples of participants (young and older adults, Alzheimer patients), with different test formats (cued recall, recognition), and regardless of whether the memory test was incidental or intentional (Cohen, 1989; Engelkamp, 1997; Engelkamp & Zimmer, 1985, 1989).

Engelkamp and Zimmer (1984, 1985) suggested that enacting a verbal command (relative to simply reading it) results in creation of a supplementary motor memory trace that improves item-specific processing because participants perform an action that is unique to each command. They define item-specific processing as better conceptual processing of target items (Mohr et al., 1989). Enacting a phrase that contains both a verb and a noun ("open the book") is theorized to lead to a motoric representation[1] that is distinctive to the action involving the verb ("open") and the noun ("book") contained in the verbal item (Engelkamp & Zimmer, 1984, 1985). In Engelkamp's view, the valuable aspect of overtly carrying out a representative action during encoding is that the motor components of the action now become part of the episodic memory trace for the to-be-remembered verbal command (Zimmer et al., 2001). In a sense, this account is a dual-coding one (see Paivio, 1971). Enactment boosts memory because the encoding strategy establishes a motor trace in addition to the verbal representation of the item; thus, creating two (verbal and motor) rather than one (verbal) memory representations of the to-be-remembered information (Backman et al., 1986; Engelkamp, 1984, 1985; Masumoto et al., 2006; Mohr et al., 1989).

Moreover, Engelkamp and Zimmer (1984, 1985) argued that while both verbal and motor

[1] A motoric representation for an action is created by cell assemblies (group of neurons), which distinctly interact to facilitate the execution of that action (Wolpert et al., 1998). These memory representations, which follow a specific pattern of activation for every action performed, are then replayed to execute similar movements in different (e.g., swinging a bat in practice or during a game) situations.

representations enhance memory formation by contributing to conceptual processing, it is the motor one that substantially improves retention. Although they suggested that an additional motor program may underlie the enactment effect, they did not explain the specific characteristics of the performed action that they believed were necessary for enhanced memory. Hence, one of the objectives of this thesis was to determine the type of motor activity that aids memory, to provide a mechanistic explanation as to how a supplementary action contributes to the enactment effect. In doing so, this thesis will serve to broaden our understanding of actions not only as a communicative aid, but also as an encoding strategy capable of influencing memory through semantics.

1.2 The Role of Semantic Relatedness of the Encoding Strategy to Recall

Previous research investigating the cognitive mechanism underlying the enactment effect has suggested that the mnemonic benefit from action during encoding relies on the level of association formed between motor and verbal representations (Feyereisen, 2006; Liu & Wang, 2018; Zimmer & Engelkamp, 2003). That is, a motor and a verbal memory representation must share or convey the same semantic information to generate a boost to later memorability (Macedonia, Muller, & Friederici, 2011; Zimmer & Engelkamp, 2003). Liu and Wang (2018) provided evidence for this claim in Experiment 3 of their study. They instructed participants, during encoding, to mimic a related action performed by an experimenter that was matched to a verbal command (High level of association between the verbal item and action), to imitate the use of a sign language when encoding a target phrase (Low level of association; participants would not be able to interpret the motor information and associate with the verbal phrase if they did not know sign language), or to only observe the verbal information without actions (Verbal task). Recall performance revealed a graded effect of motoric actions, such that poorer subsequent memory was observed for phrases that were signed by the participants (low association) relative to phrases that were matched with a symbolic action (high association). Performance was the poorest in the baseline verbal task.

Research by Meade and colleagues (2019) also suggests a role for semantic relatedness between the encoding strategy and the target item in facilitating memory performance. These researchers investigated the influence of encoding strategies such as writing out to-be-remembered words versus drawing a picture of them, or doodling during encoding. Their goal was to highlight the importance of the semantic contribution of the encoding strategy to subsequent benefits to memory. In their study, participants were asked write out to-be-remembered words, to draw a picture of these words, or doodle – make drawings that were semantically unrelated to the to-be-remembered words during encoding. In a later memory test, participants showed poorer free recall for words that had been encoded with free-form doodling compared to words that were drawn or written, with drawing resulting in the best memory performance. Their work showed that creating semantically related drawings of words (defined as drawing a picture illustrating the word) during encoding improved subsequent free-recall performance, relative to creating unrelated doodles to target words (defined as freely drawing patterns or images semantically unrelated to the target). These results suggest that semantic processing of the to-be-remembered information may be critical to integrate the various memory representations (motor, verbal, visual) established by an encoding technique (Pulvermuller, 2005; Russ et al., 2003). In Chapter 2 we examined whether a motor action created during encoding needed to be semantically relevant to the to-be-remembered target item, to confer a memory benefit.

1.3 The Contribution of Planned Actions to the Enactment Benefit

The work of Ratner and Foley (1994, 2020) highlights another plausible reason why the execution of meaningful actions might confer a memory benefit to the participant. They stress the importance of intentional planning when enacting action phrases. That is, the level of effort, or self-planning, engaged by the performer in producing an action is believed to be a critical factor underlying the memory benefit. In their 'Activity Memory Framework', Ratner and Foley (1994) suggest that the performer enacting the action is a goal-directed agent; self-planned and executed movements that are related to the information (i.e., that meet the goal of the verbal target) contained in verbal commands improve memory because enactment serves as a means to engage in goal-directed activity (Ratner & Foley, 1994, 2020; Zimmer et al., 2001). For example, generating meaningful actions requires the appropriate appraisal of the verbal material to infer its meaning, selection of the correct action to represent the to-be-remembered item, and execution of that action. Thus, the contribution of semantic information to action memory may serve to enrich one's memory for the verbal material as a result of actively recruiting, planning, and executing the correct motor sequence. In chapter 2 of this thesis (Experiment 3), we calculated the onset time to initiate the prompted encoding task to the target word as a proxy for the time taken to plan and execute an action. We hypothesized that performing a semantically related action would take significantly longer to initiate relative to an unrelated gesture, because the former movement requires planning of a task-related action to the verbal command. If planning of task-related actions (selection and execution of a specific action) is longer relative to the time taken to initiate an unrelated gesture, our findings would suggest that it is precisely the planning of meaningful actions that enhances memory. If, however, the planning time between enactment and unrelated gesturing does not significantly differ relative to read (baseline), then our results would imply that the preparation time taken to select and execute an action is not a critical factor underlying the enactment effect.

1.4 The Impact of Social Presence to the Memory Benefit Gained from Action Observation

Prior studies have also shown that observing an experimenter perform a representative action to a verbal target (Experimenter-performed task; EPT) confers a memory benefit similar in magnitude to that from self-enactment of words (Cohen, 1981, 1983). It has been suggested that action execution and action perception may share similar processing areas in the brain, such that seeing an experimenter perform a representative action to a word activates similar motor areas in the participant, via a mirror-neuron mechanism (Chandrasekharan et al., 2009). What is unknown, however, is whether the effect of observing actions generated by an experimenter online, rather than in-person, is similarly beneficial. All past studies to date have been conducted with the participant and experimenter in the same physical room. Thus, another aim of this thesis (chapter 3) was to explore the moderating role of social presence underlying the magnitude of the memory benefit gained from an experimenter-performed task. Answering this question is especially important during the current COVID-19 pandemic because students must often learn new information by observing teachers in a video lecture where social presence is reduced compared to traditional classroom in-person learning. In many cases, this involves observing teachers demonstrate key concepts and terms through the use of arm and hand movements to aid explanation. In Chapter 3, we examined whether observing actions to target words, in pre-recorded videos, confers a memory benefit similar in magnitude to that found following a SPT (participant enacting verbal targets), and in past reports of a memory benefit following EPT.

Chapter 2: The Importance of Integrating Meaning into Action during Encoding

The goal in chapter 2 was to determine whether a semantically related action is vital to the enactment effect, as suggested by past research (Cook et al., 2012; Feyereisen, 2006; Macedonia et al., 2011; So et al., 2012; Zimmer & Engelkamp, 2003). To this end, we manipulated the semantic overlap between the target words and the concurrently performed action produced by the participant during encoding, in order to determine whether the encoding strategy must relate to the meaning of the to-be-remembered word to confer a memory benefit. In Experiment 1, our aim was to replicate the findings from previous research demonstrating the mnemonic benefit of the enactment-based SPT effect relative to a verbal task (Backman et al., 1986; Cohen, 1981; Engelkamp & Zimmer, 1984, 1985, 1989), and to determine whether the performance of any distinctive action, even if semantically unrelated, was sufficient to aid recall. For the semantically unrelated actions, participants were to execute an action with their hand and arms that was not in any way a depiction of the meaning of the target word (i.e.: participants were free to select and perform any action they deemed was unrelated to the word).

In Experiment 2, we sought to reduce the level of ambiguity in initiating an unrelated gesture by providing participants with an explicit instruction to pretend to write verbal targets in air for the unrelated gesture trials. Although the act of writing target words in air is related to the orthography of words, the actions performed can not be considered central to action semantics generally associated with the word. That is, the participant is only executing an action representative of the structure of the word (*hammer)*, but not the meaning we associate with the word. While the enactment of the word *hammer* while viewing the word *hammer* would allow the participant to use the visual word form and action semantics (the actions habitually associated with the word) to benefit memory. To determine whether the semantic meaning of the actions is vital for the enactment effect, we contrasted the enactment of words (*hammer*; make pounding action condition) with an action that is less habitually related to the target, such as writing out the spelling of target words cursively in the air. In line with previous studies comparing the memory benefit of meaningful and non-meaningful gestures, in our study we have defined non-representational gestures as hand movements that do not convey the semantics of the accompanying verbal commands (Cohen & Otterbein, 1992; Cook et al., 2011; Feyereisen, 2006; So et al., 2012). In Experiment 2 we implemented 3 conditions to study the role of semantics to the enactment effect: a baseline condition where participants try to remember a visually presented word (verbal task; *hammer*), a centrally related action condition (enactment; visual word hammer plus pounding-of-a-hammer action), and a gesture representative of the surface level structure of words but unrelated to meaning of the word (visual word hammer plus gesturing how one would write out the orthography of the presented word). Our key prediction was that combining the visually presented word with an action that is centrally related to the semantics of that word, would provide better support for one's memory than a condition in which the actions are only obliquely related to the word in terms of orthography but unrelated on the basis of semantics. In fact because reading and gesturing of target words so heavily rely on orthography of the words, one might expect these conditions to be equivalent in terms of recall.

In Experiment 3, we measured the onset time of action initiated during both enact and gesture trials as an indirect measure of planning requirements; the goal here was to assess whether planning time differed across encoding trial types (particularly enact and gesture trial), and whether this was the key factor accounting for differences in how much each encoding type benefitted subsequent memory performance. To our knowledge, past research examining the mechanism of enactment has not quantitatively differentiated the onset time of action execution for movements that vary in semantic content (i.e.: related versus semantically unrelated actions). The overall objective of our experiments in Chapter 2 was to investigate which characteristic of performed actions at encoding, facilitate memory performance.

Consistent with the research of Ratner and Foley (1994, 2020), that emphasizes the importance of self- planning and goal-oriented actions in generating the enactment effect, we predicted that planning and execution of task-related actions that convey meaning in line with that of the to-be-remembered information, would aid memory relative to task-unrelated actions. This is because enactment of words requires one to not only process the orthographic structure of words but also infer the meaning of the word to plan and execute a symbolic action (Zimmer et al., 2001). In contrast, engaging in motor activity that is unrelated to target items was predicted to diminish memory performance relative to those enacted, as these actions would not be goal-directed[2]. We also hypothesized that enacted words would confer a boost to memory, relative to words simply read during encoding, as suggested by past work in enactment (see Cohen, 1989, for review; Engelkamp & Zimmer, 1984, 1985). Finally, performing task-unrelated actions to encode target words, relative to reading verbal items, was predicted to result in comparable memory performance. Here, we predicted that the memory benefit, presumably conferred by engagement of a supplementary motor trace during the enactment of words (Masumoto et al.,

[2] The gesture utilized in Experiments 2 and 3 (writing words in air) would entail some level of planning to select the correct the movements to produce the orthographic structure of words, but not planning of an action representing the semantics of the word.

2006; Pulvermuller, 2005; Russ et al., 2003), would be absent when the performed action conveyed no meaning about the verbal target. As such, we reasoned that for both of these trial types (unrelated action and read), participants would have to rely solely on the verbal representation evoked by conceptual or phonological processing of target items to aid recall (Lesch & Pollatsek, 1998).

2.1 Experiment 1: Comparing the Mnemonic Benefit of Encoding Techniques (Enact, Unrelated Gesture, and Read) to Recall

The objective of this experiment was to determine whether the motoric representation engaged during encoding needed to be semantically relevant to the target item, to confer a memory benefit. In other words, we examined whether the meaningfulness of the actions produced at the time of encoding was important to observe the enactment effect. It may be that any engagement of the motoric system confers a benefit to memory. Because previous work (e.g: Engelkamp & Zimmer, 1984, 1985; Mohr et al.,1989) has suggested that enactment improves memory by forming a supplementary motor trace that is unique to each target, we aimed to investigate whether memory was improved with the performance of *any* distinctive action. If movement alone is sufficient in producing the enactment effect, then unrelated gestures that do not represent the meaning of a target item, but are unique to each item, should also enhance memory. If however, the benefit of enactment arises due to item-specific movement that is semantically related to the target, then unrelated gestures should not benefit memory.

Participants were asked to either a) enact, b) perform unrelated motoric gestures, or c) passively read, forty-five visually-presented action verbs shown sequentially, and intermixed during encoding, in a within-subjects design. When prompted to enact the word, participants were to perform an action that was semantically related (meaningful) to the target word. When prompted to perform a gesture as the encoding strategy, participants were to engage in a motor action with their hand and arms that was not in any way a depiction of the meaning of the target word (i.e.: participants were free to select and perform any action they deemed was unrelated to the word)[3]. For the read trial types, participants silently read the words presented on the computer screen. Following the encoding phase, memory was assessed by asking participants to write out words they recalled. We predicted a main effect of encoding strategy with enacted words yielding the best performance. Unrelated gesturing was hypothesized to diminish recall performance relative to enactment, as the motoric encoding would a) be task- or goal-irrelevant, and b) would not allow for creation of a semantically-relevant motoric representation, both of which have been suggested as critical for enactment to benefit memory (Ratner & Foley, 1994). Put another way, both the unrelated gesture and read trial types were predicted to result in similarly poorer recall performances, compared to enacted ones, as these encoding strategies limit the creation of a supplementary motor trace that is semantically related to the target.

2.1.1 Method

2.1.1.1 Participants

After conducting a power analysis using G*Power software (version 3.1), a sample size of 27 participants or greater was deemed necessary to have 80% power to detect a medium effect size (η_p^2 = 0.06) with an alpha level of 0.05 (Field, 2005). In all experiments, we aimed to collect

[3] Participants were also instructed to produce a different unrelated action each time to prevent repetition of actions.

data from 30 participants after excluding data from those who scored below 30% on the Mill Hill Vocabulary Scale (MHVS), indicating poor English language competency (Raven, 1958). Participants were excluded on the basis of linguistic proficiency to allow us to reliably interpret variability in memory performance as a function of trial type (experimental manipulation), and not as a result of language difficulties. Thirty-three undergraduate students from the University of Waterloo successfully participated for a partial course credit. Data from 3 participants were excluded based on their poor performance on the MHVS. The final sample included 30 undergraduate students (6 males), with ages ranging from 17 to 22 (*M* = 19.37, *SD* = 1.45). The University of Waterloo Research Ethics Board approved all study procedures. Written informed consent was obtained from all participants.

2.1.1.2 Materials

Forty-five action verbs were selected (e.g. throw, chop) from the Max Planck Institute for Psycholinguistics WebCelex (see Appendix). Action verbs ranged in frequency from 1 to 464 (*M* = 70.04, *SD* = 99.69) based on the Frequency Analysis of English Usage (Francis et al., 1985), varied in length from 3 to 7 letters (*M* = 4.60, *SD* = .96), and had either one or two syllables (*M* = 1.13, *SD* = .34).

2.1.1.3 Procedure

E-Prime (Psychology software Tool, Pittsburgh, PA) was used for stimulus presentation. Each participant was tested individually and viewed their own independent randomization of target words and encoding trial types. Participants studied forty-five action verbs (15 enacted, 15 gestured, 15 read) one at a time, with trial type intermixed. The order of trial type (enact, gesture, read) was counterbalanced across participants based on a Latin Square Design (Preece &

Freeman, 1983), resulting in six different possibilities in the order of trial presentation. The duration of the experiment for each participant was approximately 10 minutes (not including the completion of the MHVS).

For each trial, a fixation cross was centrally presented for 500 msecs, followed by a prompt presented for 1 sec (font size: 16, colour: black, font style: Courier New), specifying participants to either ‘enact’, ‘gesture’, or ‘read’ the target item on the screen. The action verb (target item) was then centrally presented on the screen for 4500 msecs (font size: 16, colour: green, font style: Courier New), during which time the participant enacted, gestured, or read the item. Each item from the stimulus list was presented only once to the participant. We verbally reminded participants, prior to beginning the encoding phase, to perform the action, or repeatedly read, for the entire time a target word was presented on the screen. Following the encoding phase, participants were instructed to count backwards from 190, by 3s out loud, for 20 secs, to prevent recency effects in their subsequent recall. During the recall phase, participants were given 60 secs to write down, on a sheet of paper, as many words as they could recall from the encoding phase. Following the recall phase, participants completed Set A of the MHVS (Raven, 1958).

2.1.2 Results

The dependent variable of number of words recalled was analyzed using a one-way repeated measures ANOVA, with Encoding Strategy as within-subject factor (see Figure 1 for means).The skewness and kurtosis values for enact, gesture, and read scores all fell within the normality assumptions as per Kline (1998); $|\text{skewness}| < 3$ and $|\text{kurtosis}| < 10$. Standardized z-scores were computed for each trial type indicated above to screen for outliers. Any z-score greater than 2 or below -2 standard deviation units from the mean was considered to be an outlier (Bini, Bertaccini, & Bacci, 2009). Data from 1 participant were excluded on this basis, [4] thus the reported analyses consist of data from 29 participants. Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 1.18$, $p = .554$. There was a significant main effect of Encoding Strategy, $F(2, 56) = 80.14$, $MSE = 1.85$, $p < .001$, $\eta^2_p = .74$. Bonferroni-corrected paired sample t-tests revealed that words enacted during encoding were recalled significantly better than words gestured, $t(28) = 9.10$, $SE = 0.37$, $p < .001$, or silently read, $t(28) = 10.79$, $SE = 0.38$, $p < .001$. No significant difference in recall performance was found between words gestured or read during encoding, $t(28) = 1.51$, $SE = 0.32$, $p = .143$ .We note that 27 of our 30 participants (including the outlier) showed memory boosts of enactment in this reported direction. For the remaining 3 participants, 1 recalled an equal number of words across enacted and gestured trial types, 1 recalled more words gestured, and the other recalled more words read compared to enacted and gestured.

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[4] The pattern of reported results did not change with the inclusion of the outlier.

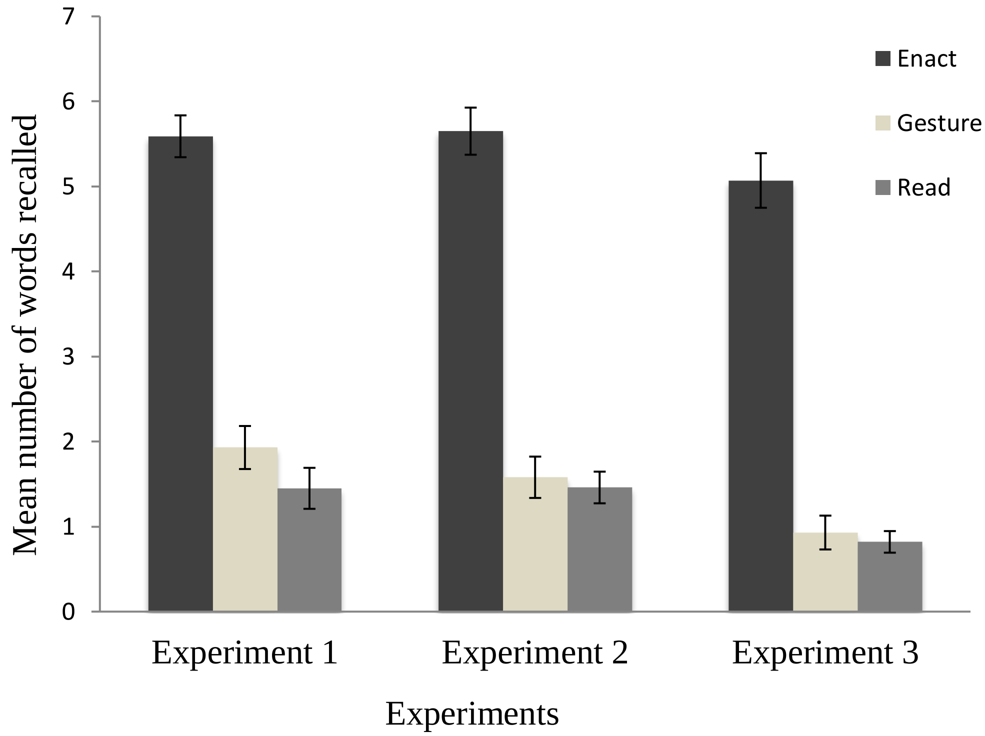

Figure 1. Mean number of words recalled following each encoding trial type in each Experiment. Error bars represent standard error of the means.

2.1.3 Discussion

Performance on the recall test was in line with previous research showing better memory for words that were enacted relative to words merely heard or read at encoding (Cohen, 1981; Engelkamp & Krumnacker, 1980; Engelkamp & Zimmer, 1984, 1985, 1989). More importantly, words enacted during encoding were recalled significantly better in comparison to words encoded using unrelated gestures (i.e. participants independently selected and performed any action they deemed was unrelated to the word). Such a pattern suggests that meaningful or task-related action is critical to observe an enactment benefit. Consistent with the findings of Meade et al. (2019), we propose that semantic processing of target words is critical to enable integration of the different memory representations (motor, verbal) established during encoding for a given item.

Our results indicate that simply engaging in any overt motoric activity will not enhance memory. Meaningful action is crucial to observe an enactment benefit. We interpret the findings as support for our suggestion that executing unrelated motoric gestures, as an encoding strategy, does not lead to the integration of the motor and verbal representations of the to-be-remembered word to aid memory (Masumoto et al., 2006; Pulvermuller, 2005).

A limitation of Experiment 1, however, is that on the gesture trial type, participants were asked to freely determine any unrelated gesture to perform at encoding. It may be that memory performance was reduced because it took participants longer to determine an action, and initiate it, and/or there was greater ambiguity associated with generating an action in this trial type, thereby limiting total encoding time of the target items. In the next experiment we sought to reduce the ambiguity associated with generating an unrelated gesture.

2.2 Experiment 2: Conceptual Replication of Experiment 1 to Control for Ambiguity in Gesture Initiation

One may argue that the planning required to initiate actions that are semantically related, on enactment trials, may be quicker than for initiating gestures that are unrelated. During unrelated gesture trials, participants would need to first generate possible actions that are semantically unrelated to the target, and then select which to perform. For enactment trials, there would be no need to generate alternative actions, or decide which action to perform. Thus, the cognitive requirements and planning time, required for unrelated gesture and enactment trials may differ, accounting for the difference in their benefit to subsequent memory performance. To overcome this limitation, in Experiment 2 we devised an unrelated gesture trial in which the need to generate options for actions was eliminated, and the need to decide which unrelated action to perform was also eliminated. To this end, we changed the unrelated gesture trials in Experiment 2 to be one in which participants were instructed to pretend to write target words in air. Providing a specific instruction on how to encode the word would reduce ambiguity in terms of what action to carry out for this trial type, while maintaining the requirement to produce a unique motoric action on each trial. At the same time, the gestures performed would be motorically unrelated to the semantics of the verbal commands (relative to enactment), but still capture the orthographic structure of word forms[5]. The instructions for enactment and read trial types did not change from Experiment 1. We hypothesized a replication of the enactment benefit, with better memory performance compared to when targets were simply read. We also predicted that although the new unrelated gesture trials would still involve motor engagement, the lack of semantic relatedness of the action to the target word would mean that memory would not gain the enhancement offered from enactment trials: recall would still be significantly poorer in unrelated gesture relative to enactment trials, and would not differ significantly from read trials.

[5] For example, in our day-to-day lives, we may have made pounding actions when talking about having to hammer a nail, however it is likely that we have never spontaneously made the actions associated with writing the word *hammer* in the air. Although we are capable of activating the motor programs that allow us to reproduce the orthography of the presented words, this is not something we habitually do and is therefore only weakly semantically related to the target words.

2.2.1 Method

2.2.1.1 Participants

Based on the power calculation computed for Experiment 1, we collected data from 30 participants; one was excluded for scoring below 30% on MHVS, indicating poor English language competency (Raven, 1958). As a result of the COVID-19 pandemic, we were not able to collect data from an additional participant. Thus, we report data from 29 undergraduate students (2 males), with ages ranging from 18 to 48 ($M = 21.03$, $SD = 5.79$), from the University of Waterloo who completed the experiment in person, for a partial course credit. The University of Waterloo Research Ethics Board approved all study procedures. Written informed consent was obtained from all participants.

2.2.1.2 Materials

The same action verbs that were used as target words in Experiment 1, were again used in this experiment (see Appendix).

2.2.1.3 Procedure

During the encoding phase, participants were instructed to enact (perform a related hand movement), gesture (pretend to write the target word in air), or read (simply read the verb silently) target words. The remaining procedures were identical to that used in Experiment 1.

2.2.2 Results

Recall data were analyzed using a repeated-measures ANOVA, with Encoding Strategy as the within-subject factor (see Figure 1 for means). The skewness and kurtosis values for enact, gesture, and read scores all fell within the normality assumptions as per Kline (1998); |skewness|

< 3 and |kurtosis| < 10. Standardized z-scores were computed for each trial type indicated above to screen for outliers. Any z-score greater than or less than 2 units of standard deviation from the mean was considered to be an outlier, resulting in exclusion of 3 participants from the final analyses (Bini, Bertaccini, & Bacci, 2009) [6]. Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 2.14$, $p = .344$. There was a significant main effect of Encoding Strategy, $F(2, 50) = 109.79$, $MSE = 1.35$, $p < .001$, $\eta^2_p = .82$. Bonferroni-corrected paired sample t-tests revealed that enacted words were recalled significantly better than gestured words, $t(25) = 11.63$, $SE = 0.35$, $p < .001$, and better than those silently read, $t(25) = 15.42$, $SE = 0.27$, $p < .001$. No significant difference in recall performance was found between gesture and read trial types, $t(25) = 0.34$, $SE = 0.34$, $p = .736$. We note that 26 of our 29 participants (including the outliers) showed memory effects in this reported direction. For the remaining 3 participants, 1 recalled more words read at encoding relative to words enacted and gestured, 1 recalled an equal number of words across enacted and read trial types, and 1 recalled more words gestured compared to words enacted and read.

2.2.3 Discussion

In Experiment 2, we replicated our pattern of findings from Experiment 1. Higher recall scores were observed for words enacted relative to gestured via handwriting in air, or read at encoding. These results provide compelling evidence that meaningful actions are a critical component to the enactment effect. The unrelated hand gestures performed by participants in this experiment were unique to each item, but motorically did not convey the meaning of the target

[6] The pattern of results does not change with the inclusion of the outliers.

words. The instruction to write target words in air during the unrelated gesture trials not only allowed us to vary the semantic relatedness of actions executed by participants, but also reduced ambiguity in participants' decision about what gesture to perform.

Further, Iani and colleagues (2018) suggest that a mental model for a given item may consist of both declarative knowledge (a set of concepts or underlying assumptions associated with an item; e.g.: "knowing that an object is a cup"), and procedural information pertaining to the action associated with the item (e.g.: "how to grasp a cup?"). The unrelated gesture used in Experiment 2 does not motorically convey the action represented by a target word, however these gestures do represent the surface-level features of the verbal material (i.e.: word form). Thus, we take the findings of Experiment 2 as evidence that actions need to convey both procedural and declarative knowledge (Iani et al., 2018) about the verbal material to enhance memory, and simply representing the word form is not sufficient to generate the enactment effect.

Given the replicability of our findings, we suggest that the effect of enactment is not simply a result of item-specific motor engagement, but action that is both specific and semantically related to the to-be-remembered item. A limitation of this experiment, however, was that we had no measurable indication of the "preparation time" engaged by the participant to initiate a related or an unrelated action. The work of Ratner and Foley (1994, 2020) purports that the level of effort or self-planning taken on by the participant is one of the critical factors contributing to the enactment effect. They suggest that a key purpose of performing actions is that it serves as a goal-directed action for the enactor, and planning is a critical feature underlying goal-oriented actions. When initiating a related hand movement that is representative of the activity contained in the target word (e.g. “knock”), planning of this action is believed to be the key factor leading to the enactment benefit to memory by their account. In our next experiment, we sought to determine if there were quantifiable differences in the onset time of action initiated during enactment (related action), gesturing (unrelated action; handwriting target item in air), and read trials during encoding of target words.

2.3 Experiment 3: Examining Differences in Preparation Time across Encoding Techniques to Assess the Role of Planning to the Enactment Benefit

In Experiment 1, during the unrelated gesture trials, participants freely engaged in any gesture they deemed to be semantically unrelated to the to-be-remembered word during encoding. It may be that it took participants a longer time to generate potential actions, and then decide on one to execute, for gesture trials, compared to enactment trials. Because unrelated gesture production arguably demanded greater processing time, it may have constrained the total time participants spent encoding the target word. As a result, one may argue that the lower recall scores observed for the unrelated gesture trial was due to limited encoding time, as opposed to the semantic relevancy of the performed actions to target items. In an attempt to overcome these differences between unrelated gesture and enact trials, in Experiment 2, we instructed participants to pretend to write target items in air during gesture trials to reduce these additional processing demands. We again observed that performing an unrelated gesture during encoding of target words, relative to enacting them, hindered memory performance. In Experiment 3, we aimed to replicate the results of Experiment 2 using an online platform to be able to video record the onset time of presentation of the target on the screen, and when the participant initiated an action (on enact and unrelated gesture trials), or moved their lips when reading aloud during the read trials. By video-recording the actions/lip movements generated by participants, we were able to determine if there were any quantitative differences in the time it takes the participant to initiate a related action relative to reading or performing unrelated gestures. In this way, we could infer the "preparation time", or level of planning, engaged by the participant for each trial type, which others have suggested as an important component underlying the enactment effect (Ratner & Foley, 1994, 2020; Zimmer & Engelkamp, 1996).

In addition, we thought to examine whether individual differences in participants' motor production tendencies in their daily life might influenced their recall scores. There are several studies suggesting that motor movements (gesturing) not only play an important role in facilitating speech comprehension between the speaker and listener, but also supports aspects of cognitive functioning such as, memory, lexical retrieval, and language acquisition (see Novack & Goldin-Meadow, 2017, for review). However, there is very little research investigating the potential influence of such individual differences in motor production and perception of gestures, to memory performance. Given this, in experiment 3 a secondary goal was to investigate whether a frequent gesturer benefitted more from enactment compared to an infrequent one. We reasoned that participants who frequently gesture during their day-to-day conversations may gain a relatively greater enactment benefit. Work by Klooster and colleagues (2015) is in line with this prediction. They suggest that engagement of the procedural[7] memory system is a key mechanism by which gestures support memory and learning. Thus, a frequent gesturer who utilizes gestures to aid with lexical retrieval or speech comprehension in their daily life, may be able to use

[7] Procedural memory is defined as memory for *how* to execute a task. This memory system supports one's ability to acquire and perform skills, and form habits through prior experience.

related actions (enactments) as cues to retrieve target words during the experiment. Hence, it is plausible that frequent gesturing in everyday life confers an additional memory benefit following enactment that may have been obscured in Experiments 1 and 2, as we did not account for this individual difference. To examine this possibility, in Experiment 3 we administered the Brief Assessment of Gesture (BAG) scale created by Nagels and colleagues (2015) to assess if any individual differences in gesture production and perception in everyday life influenced the number of words recalled that were enacted at encoding.

2.3.1 Method

2.3.1.1 Participants

Thirty-one undergraduate students from the University of Waterloo successfully participated for a partial course credit. One participant was excluded from the final sample as they scored below our established cut-off of 30% on the MHVS, indicating poor English language competency (Raven, 1958). The final analysis included 30 undergraduate students (10 males), with ages ranging from 18 to 39 (*M* = 20.83, *SD* = 3.69). The University of Waterloo Research Ethics Board approved all study procedures. Informed consent was obtained electronically from all participants prior to study entry.

2.3.1.2 Materials

The same action verbs that were used as target words in Experiments 1 and 2, were again used in this experiment (see Appendix). The BAG self-report questionnaire (Nagels et al., 2015) contains 12 items that have to responded to on a 5-point Likert scale (1 = not agree, 5 = fully agree), and probes for both gesture usage and perception. Examples of statements used in the questionnaire are: “I usually gesture a lot when I talk to make myself understood better.” or “I like talking to people who gesture a lot when they talk". A higher sore on the BAG scale indicated that the participant that they habitually use more gestures and to pay more attention to gestures during a conversation relative to a participant with a lower score.

2.3.1.3 Procedure

This experiment was conducted remotely, via a video-call with the participant using Microsoft Teams. The target words in the experiment were presented using Microsoft PowerPoint via the screen sharing function on Microsoft Teams. As in our previous experiments, a fixation-cross was presented, followed by a prompt specifying participants to "enact", "gesture", or "read" target words. Forty-five action verbs intermixed by encoding type (enact, gesture, or read) were presented and participants were verbally instructed to repeatedly perform the action or read the words on the screen for the entire time the action verb was shown (no changes to the colour, font size, or timings from our previous experiments). Each item from the stimulus list was presented only once to the participant. As in Experiment 1, the order of trial type was counterbalanced across participants following a Latin Square Design (Preece & Freeman, 1983). The instructions provided in Experiment 2 for enact and unrelated gesture trial types remained the same in this experiment; the only difference was that participants were instructed to read aloud for read trials, to enable us to determine the onset time of lip movements. Each participant was tested individually and viewed their own independent randomization of words and encoding trial types. After the encoding phase, participants were instructed to count backwards from 190, by 3s out loud, for 20 secs. Participants were then given 60 secs to recall as many words as they could, from the study phase, by typing each word into the chat box within Microsoft Teams, which was then sent to the researcher by clicking "Enter" on their computer keyboard. Following recall, a Qualtrics web link to the MHVS and BAG was sent to the participant via the chat box within Microsoft Teams. The order of the administration of the two questionnaires was counterbalanced. The duration of the experiment for each participant was approximately 10 minutes (not including the completion of the MHVS and BAG).

2.3.2 Results: Main Effect of Encoding Strategy on Recall

The number of words recalled was analyzed using a one-way repeated measures ANOVA, with Encoding Strategy as within-subject factor (see Figure 1 for means). Skewness and kurtosis values for enact, gesture, and read scores all fell within the normality assumptions as per Kline (1998); |skewness| < 3 and |kurtosis| < 10. Standardized z-scores were computed for each trial type indicated above to screen for outliers. Any z-score greater than 2 or below -2 standard deviations from the mean was considered to be an outlier (Bini, Bertaccini, & Bacci, 2009). Two participants were detected as outliers; thus, the reported analyses consisted of 28 participants[8]. Mauchly's test indicated that the assumption of sphericity has been violated, $\chi^2(2) = 10.63$, $p = .005$, thus, a Greenhouse-Geisser correction was applied. There was a significant main effect of Encoding Strategy, $F(1.50, 40.43) = 92.06$, $MSE = 2.39$, $p < .001$, $\eta^2_p = .77$. Bonferroni-corrected paired sample t-tests revealed that words enacted during encoding were recalled significantly better than words gestured, $t(27) = 9.45$, $SE = 0.44$, $p < .001$, and read, $t(27) = 11.97$, $SE = 0.36$, $p < .001$, at encoding. No significant differences in recall performance between gesture and read trial types, $t(27) = 0.42$, $SE = 0.25$, $p = .676$. We note that 28 of the 30 participants followed this pattern. For the remaining 2 participants, 1 retrieved an equal number

[8] The pattern of results does not change with the inclusion of the outliers.

of words enacted and gestured, and the other recalled more words gestured relative to enact and read.

2.3.2.1 Results: Onset Time to Initiate Encoding Task

For each participant, we calculated the onset time to initiate the prompted encoding task to the target word for all forty-five words (15 words enacted, 15 words gestured, 15 words read). We accomplished this by computing the difference between onset of presentation of the target on the screen, and when the participant responded by initiating an action (enact or gesture), or moved their lips to read. Action onset was obtained by downloading an extension named Time (version 3.2) to VideoLan Client (VLC) media player (https://addons.videolan.org/p/1154032). It enabled us to retrieve the precise timing for when the stimulus (target word) was presented and onset time of a participant's initiation of action to target words (enact, unrelated gesture, read). The timings were obtained manually by a research assistant naïve as to the experiment's hypotheses. They scrolled through each of the videos. For example, if the target was presented at 4 mins, 53 secs, and 605 msecs (shown by the software as 04:53, 605), and the action was initiated at 4 mins, 55 secs, and 853 msecs, we calculated the time difference as a proxy of the time taken to plan and execute that action (2 secs and 248 msecs).

We examined these data using a one-way repeated measures ANOVA (see Figure 2 for means)[9]. Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 1.51$, $p = .471$. There was a significant main effect of Onset Time, $F(2, 52) = 49.23$, $MSE = 0.03$, $p < .001$, $\eta^2_p = .65$. Bonferroni-corrected paired sample t-tests revealed that the onset time

[9] Outliers greater than 2 or below -2 standard deviations of the mean were excluded from the reported data. The pattern of results does not change with the inclusion of the outliers.

for initiating unrelated motoric gestures to target words was significantly faster relative to enactment, $t(26) = 6.99$, $SE = 0.04$, $p < .001$. Lip movements were also initiated significantly faster compared to enactment, $t(26) = 8.94$, $SE = 0.05$, $p < .001$, and unrelated gestures, $t(26) = 3.59$, $SE = 0.05$, $p = .001$.

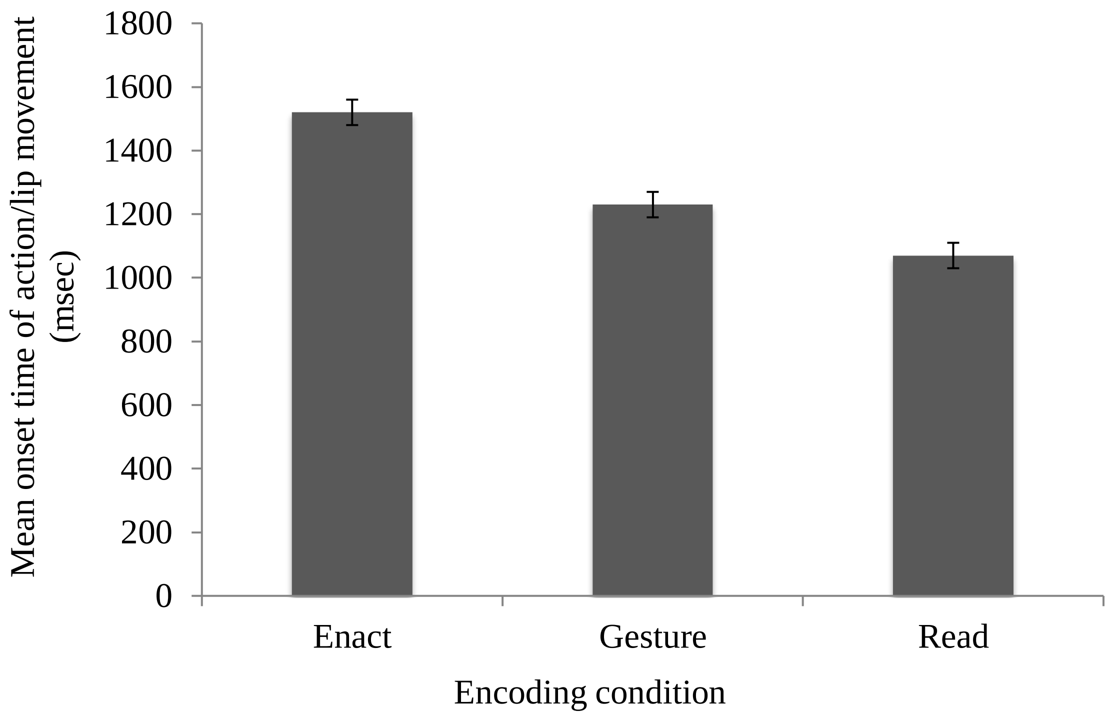

Figure 2. Mean onset time of action on Enact and Gesture trial types, and lip movement Read trials, in Experiment 3. Error bars represent standard error of the means.

2.3.2.2 Results: Individual Differences in Motor Production Tendencies

We derived the average score on the BAG scale, across all items as a comprehensive measure of a participant's gesture production and perception (items 4, 6, 9, and 11 were reverse coded as they were negatively framed in the questionnaire). A higher sore on the BAG scale indicated that the participant reported to use more gestures and to pay more attention to gestures during a conversation relative to a participant with a lower score. No significant relationship was observed between the BAG scores and the number of words recalled that were enacted, $r(26) = .22$, $p = .272$, at encoding[10].

2.3.3 Discussion

We replicated our findings from Experiment 2 even with remote data collection. Recall performance was significantly higher for words enacted at encoding compared to read or encoded using unrelated motoric gestures. These results suggest that integrating semantics with motoric activity is an important factor driving the enactment benefit.

Importantly, our results showed that it took participants measurably longer to initiate a semantically related action that was representative of the target item relative to initiating an unrelated action. It may be that when generating related actions, participants must first understand the meaning of the word, for example, “knock”, or “drive”, and then must call upon the appropriate visuo-kinesthetic motor engram[11] to initiate the pattern of actions associated with the verbal target (Rothi & Heilman, 1985). Participants likely rely on the information derived from the visuo-kinesthetic program to guide them in performing the action (Rothi & Heilman, 1985). However, when initiating an unrelated gesture, participants need not engage in such conceptual processing of the target word, as it was not necessary to generate a motor program that was representative of the verbal information. That is, when simply perceiving the word and

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[10] Outliers greater than 2 or below -2 standard deviations of the mean were excluded from the reported data. The pattern of results does not change with the inclusion of the outliers.

[11] Motor engrams are a set of memorized motor patterns used to execute a movement, which are stored in the motor areas of the brain (Monfils et al., 2005).

pretending to write target items in air during unrelated gesture trials, participants likely engaged in relatively limited semantic processing of the target, as indexed by the shorter onset time to initiate an unrelated action compared to enactment trials. An interesting aspect of our finding is that enactment still conferred a memory benefit at recall, even though initiating a related hand movement took, on average, longer compared to initiating an unrelated gesture. This suggests that planning of the appropriate action (selection and evaluation of an adequate action, and then recruiting the relevant motor program) may be a critical component influencing memory performance, as was suggested by Ratner and Foley (1994) as well as Zimmer and Engelkamp (1996). In our experiment, the movement onset time on read trials was significantly faster relative to enact and unrelated gesture trial types; we believe this was because participants did not need to execute any actions during this trial. As well, similar to executing unrelated gestures, in the read condition participants did not need to engage in elaborative processing of the target in order to generate a representative action; hence, the removal of action, and action planning, of the verbal target may explain the poorer memory observed for words read, relative to words enacted at encoding.

Further, neural evidence speaking to the importance of action planning in mediating action memory is highlighted in the work of Macedonia and colleagues (2011). These researchers compared learning of novel words coupled with meaningful and non-meaningful actions, and observed that meaningful actions representative of target words helped learners to retain the verbal material. After the learning phase, participants' brain activity was examined using fMRI while they performed a word recognition test. Macedonia and colleagues (2011) found that words encoded with meaningful gestures elicited bilateral activation of the pre-motor area, while words learned with meaningless actions generated a pattern of neural activity reflecting cognitive control (bilateral activation of the cuneus, left posterior cingulate gyrus, and left inferior frontal area). The involvement of the pre-motor area when recognizing words learned using meaningful actions lends further support for the notion that the perception, motor imagery, and planning involved in the execution of representative actions all serve to enrich/enhance the motoric trace (Macedonia et al., 2011).

We had also hypothesized that the benefit of enactment to recall performance may be greater in participants who frequently gesture in everyday life, relative to those who gesture very little. Klooster and colleagues (2015) suggest that the facilitory effect of gesturing on learning may be supported by a non-declarative memory system (i.e.: procedural memory); we reasoned this might have also allowed for an even greater enactment benefit to memory. However, our results revealed that responses to the BAG questionnaire did not significantly moderate the influence of the encoding strategy to later recall. This suggests that the enactment benefit is primarily a result of the type of motoric activity engaged by the participant at the time of encoding.

Chapter 3: The Influential Impact of Social Presence on the Magnitude of the Memory Boost Gained from Experimenter-performed Tasks

3.1 Enactment versus Observation: The Role of Item-specific and Item-relational Processing to Memory Performance

As discussed in chapter 2, the motor component of the enactment effect has been described as a critical modality underlying the memory boost, yet it is controversial whether the performer of the action is equally critical to the observed memory benefit. That is, is it necessary for one to perform a representative action to a verbal item (*subject-performed task*; SPT) to enhance memory, or is it sufficient to simply observe an action performed by an experimenter (*experimenter-performed task*; EPT) (Cohen, 1981). Past research shows that while EPT can boost memory compared to simply reading a target word, the strength of its effect relative to SPT is variable across published studies. Some (Cohen & Bean, 1983; Cohen, 1981, 1983; Cohen, Peterson, & Mantini-Atkinson, 1987;) found no difference between the magnitude of memory benefit provided by enactment versus observation, whereas others found a significant difference in size of the memory advantage for enactment over observation (Dick, Kean, & Sands, 1989; Engelkamp & Zimmer, 1983, 1985; Zimmer & Engelkamp, 1996). The discrepancy in the findings of prior studies has been primarily linked to the order in which the encoding trials were presented. Memory is better for SPT items when lists are intermixed across EPT and SPT tasks, as opposed to when these manipulations are performed in a blocked design; as well, the type of test used to assess memory matters, with recognition tests offering better support (higher hit rate) for SPTs and EPTs benefitting cued recall and recall (Engelkamp & Krumnacker, 1980;

Engelkamp & Zimmer, 1997; Golly-Haring & Engelkamp, 2003; Koriat, Ben-Zur, & Druch, 1991; Schult, Stulpnagel, & Steffens, 2014).

Schult and colleagues (2014) argue that the distinct type of conceptual processing (item-specific or relational processing) evoked by SPT and EPT is one reason as to why these changes to a study's methodology can differently impact memory. It is predicted that enactment (SPT) of actions forces participants to process task-relevant features of items because one has to conceptually think about the item in order to generate a representative action (Hunt & Einstein, 1981; Hunt & McDaniel, 1993; Schult et al., 2014). This draws attention to individual attributes or item-specific information, of a phrase's verb and object (e.x. "open the book"). Empirical support for the item-specific account of enactment is reflected in recognitions tests where self-performance of actions allows for better discrimination of target words from lures (Golly-Haring & Engelkamp, 2003; Koriat, Ben-Zur, & Druch, 1991). However, the benefit to item-specific processing conferred by enactment comes at the cost of a reduced understanding of relations among action phrases (i.e. item-relational processing), such as, the ordering of items into semantic categories. Conversely, an EPT task which eliminates the need to perform a unique action to each word, is believed to benefit item-relational processing at the cost of item-specific (Schult et al., 2014). For example, recall is higher (and better organized) for action sequences observed compared to enacted (Schult et al., 2014). Despite these conceptual distinctions underlying EPT and SPT, both tasks are believed to utilize the motor system to produce a memory benefit (Masumoto et al., 2006; Pulvermuller, 2005; Russ et al., 2003).

3.2 The Pivotal Role of the Motor System to the Beneficial Effect of Action for Memory

The notion that the enactment benefit to memory likely derives from the combined contribution of two separate memory representations (dual-code; motor and verbal) is a prominent one. Wammes and Fernandes (2017) showed behavioural evidence concerning the motoric contribution to the enactment effect. These researchers aimed to determine whether the enactment benefit is reduced under divided attention (relative to full attention) when a motor-based distractor task is introduced at recall. Previous fMRI research has shown that enactment at encoding invokes a motoric representation that is reinstated at recall to help participants retrieve the correct verbal items (Masumoto et al., 2006; Pulvermuller, 2005; Russ et al., 2003). If enactment aids recall by adding a separate motor representation to the processing of a target, then implementing a motor-based distractor task during retrieval, that overlaps with these processing demands should negatively influence memory at retrieval, as the availability of common processing resources would be limited or in competition. As predicted, Wammes and Fernandes (2017) observed a significant reduction to the enactment benefit to memory, when participants simultaneously performed a motor-based distractor task (tapping fingers) at recall. These results also support the findings of Zimmer and Engelkamp (1985) who suggested that participants may be relying on the motoric representation established during the enactment of words at encoding to facilitate later memory.

3.3 The Involvement of the Mirror-Neuron System in Experimenter-performed Tasks

Iani and Bucciarelli (2017, 2018) argue that actions observed during EPT at encoding could similarly aid in creation of a motoric representation of the word, by activating the observer's own motor system. This argument is supported by the "common coding theory" (Van der Wel, Sebanz., & Knoblich, 2013), which purports that action execution and action perception (observing the actions of others) may share similar brain areas. Seeing an experimenter perform a representative action activates similar motor and perceptual areas in the participant via mirror-neuron circuit (Chandrasekharan et al., 2009; Rizzolatti & Craighero, 2004; Hutchins et al., 2013; Tye-Murray et al., 2013; Van der Wel et al., 2013). Mirror-neurons are a particular type of visuomotor neurons that become active both when an individual executes an action and when they observe a similar motor act performed by another individual (Rizzolatti & Craighero, 2004). This class of neurons were originally discovered in the ventral pre-motor area (F5) of macaque monkeys, and have subsequently been reported in the inferior parietal lobule, including the lateral and ventral intraparietal areas, and in the dorsal premotor and primary motor cortex (Rizzolatti & Craighero, 2004). Sine their original discovery, several neurophysiological evidence suggest that the human motor system also has mirror properties, such that our ability to recognize and interpret the actions of others entails the involvement of our own motor system via the mirror neuron circuit (Cochin et al., 1998, 1999; Cohen-Seat et al., 1954; Fadiga et al, 1995). Indeed, this notion is supported by findings of Iani and colleagues (2018), whose work showed the involvement of the premotor cortex to the enactment benefit in participants who observed actions presented in EPTs. Thus, the memory benefit gained from observing the actions of others is predicted to be mediated by activation of the mirror neuron system, since EPTs are conducted with the experimenter and participant both physically present in the laboratory (Iani et al., 2018; Rizzolatti & Craighero, 2004).

3.4 Experiment 4

An important question regarding observed actions is whether the action must be semantically related to speech in order to provide a memory benefit. One kind of action that could be semantically unrelated to speech are gestures. Gestures are spontaneous hand movements that occur during speech (Novack & Meadow, 2017). Past research has distinguished between different gesture types based on the kind of information represented by the movement. Representational gestures, such as iconic or metaphoric gestures, are believed to reveal the meaning or the semantic content of ideas conveyed by a speaker (Novack & Meadow, 2017; McNeill, 1992).) On the other hand, non-representational or non-meaningful gestures such as, beat or deictic gestures do not convey the meaning of the accompanying speech (Novack & Meadow, 2017; So et al. 2012). Past research has only studied the impact of either observing or performing gestures that vary in semantic congruency to target words in lab based settings (Feyereisen, 2006; Kelly, McDevitt, & Esch, 2009; So et al. 2012). These studies did not directly examine the semantic relatedness of the encoding strategy to verbal targets, when actions are performed or observed through an online medium. The first goal of this next experiment was to determine the role of semantic relatedness.

A second goal of this experiment was to explore the importance of social presence. An important commonality among past studies of EPT is the physical presence of the researcher and the participant in the same room. Given this, we do not know whether the effect of observing enactment online, rather than in-person, would be similarly beneficial. Research examining the importance of social interaction in online learning indicates that the level of physical immediacy or social presence (e.x. measured by facial expression of the instructor, eye contact, posture, proximity) fostered by online platforms can be influential to student learning (Beege et al., 2020; Tseng et al., 2015; Woods & Baker, 2004). Answering whether observing actions online yields a memory benefit that is similar in magnitude to watching actions in-person is especially important during the current COVID-19 pandemic, because students must often learn new information from video lectures. Thus, one of the aims of chapter 3 was to examine the effect of observed actions on memory performance, specifically when observations were made through online videos. It may be that the reduced social presence of the researcher performing the action in the EPT condition reduces attention to the experimenter's enactments, limiting the beneficial effect on memory. Further, it is also plausible that the involvement of the mirror neuron system, predicted to be implicated in the memory benefit of EPT, may be attenuated in an online platform due to the reduced proximity between the enactor and the observer. Therefore, the online component of our study is critical to our understanding of how the learning environment (online vs. in-person) may influence the memory benefit conferred by actions.

The current experiment thus attempted to determine 1) whether observing someone else perform a representative action to target words (relative to enactment) in an online platform can still benefit memory, and 2) whether it matters if the observed action is semantically related to the to-be-remembered word, or if it is an unrelated hand gesture. We also sought to replicate the findings of Experiment 3 of this thesis pertaining to the onset time taken to generate meaningful and unrelated actions. Such a replication would provide strong evidence in favour of Ratner and

Foley's (1994; 2020) theory of intentional planning underlying the memory benefit conferred by enactment. Specifically, participants enacted, performed an unrelated gesture (instructed to write verbal targets in air), or read target items, depending on the cue (within-subjects; cue-type intermixed randomly), or watched videos of the experimenter carrying out these tasks (between-subjects). Memory was subsequently assessed in a written free-recall test. In line with findings from our own experiments in chapter 2, we predicted a main-effect of encoding strategy, such that actions conveying meaningful conceptual information about target words would significantly benefit recall more than words encoded by unrelated gesturing. In addition, the reduced proximity of the researcher and the participant in the online format of EPT was predicted to reduce the magnitude of the memory benefit gained from action observation relative to action execution.

3.4.1 Method

3.4.1.1 Participants

After conducting a power analysis using G*Power software (version 3.1), a sample size of 36 participants or greater was deemed necessary per task (EPT and SPT) to have 90% power to detect a medium effect size (h_p^2 = 0.06) with an alpha level of 0.05 (Field, 2005). We planned to remove participants who score below 30% on the Mill Hill Vocabulary Scale (MHVS), as the MHVS is an indicator for poor English language competency (Raven, 1958). The MHVS measures the ability of participants to reproduce verbal information previously learned (Raven, 1958). There are 33 questions in total on the scale, and each question in the MHVS requires participants to select a synonym for a word from six choices (see Appendix). Participants were excluded from analyses on the basis of linguistic proficiency to allow us to reliably interpret variability in memory performance as a function of trial type (experimental manipulation), and not as a result of language difficulties.

Eighty-six undergraduate students from the University of Waterloo successfully participated for a partial course credit. Data from 4 participants were excluded based on their poor performance on the MHVS. The final sample included eight-two (N=41 for SPT; N= 41 for EPT) undergraduate students (Male = 14; Female=68), with ages ranging from 17 to 22 (M = 19.37, SD = 1.45). The University of Waterloo Research Ethics Board approved all study procedures. Written informed consent was obtained from all participants.

3.4.1.2 Materials

Forty-five action verbs were selected (e.g. throw, chop) from the Max Planck Institute for Psycholinguistics WebCelex (see Appendix). Action verbs ranged in frequency from 1 to 464 (M = 70.04, SD = 99.69) based on the Frequency Analysis of English Usage (Francis et al., 1985), varied in length from 3 to 7 letters (M = 4.60, SD = .96), and had either one or two syllables (M = 1.13, SD = .34).

3.4.1.3 Procedure for Subject-performed Task

The procedure for the subject-performed task was identical to the procedure outlined in Experiment 3 of Chapter 2. Participants performed a related action, an unrelated gesture (write target words in air), or read verbs at encoding. Following encoding of forty-five words in total, participants were then given 60 secs to recall as many words as they could, from the study phase, by typing each word into the chat box within Microsoft Teams, which was then sent to the researcher by clicking “Enter” on their computer keyboard. The video call was recorded as in

Experiment 3 to obtain reaction time (action onset to each encoding task) to assess "preparation or planning time" taken to initiate an action for enact and gesture trials, and lip movements for the read trial type.

3.4.1.4 Procedure for Experimenter-performed Task

The presentation of each word and their corresponding encoding trial type was presented to participants via 4.5-second-long videos. Videos of each of the 45 words were created using Filmora (version 9.6.1.8; Wondershare, 2020), in which a research assistant was shown reading, enacting or gesturing (writing the word in the air). In each video, the research assistant performed one of three trial types (enact, gesturing, or read) twice for the corresponding word on the screen. The word and the label of trial type was specified to be 36-pt Times New Roman font on the top of the video (see Figure 3a, 3b, 3c).

First, the researcher initiated a video call with the participant on Microsoft Teams. After the call was accepted, a link to a Qualtrics questionnaire containing information and consent letter was sent via the chat box in Teams. Once consent was obtained, the researcher shared their computer screen displaying a PowerPoint presentation, the beginning of which contained instructions for the participant and information on what they would see. Once the participant understood the instructions, the researcher began the encoding phase.

For the encoding phase, videos of target words and encoding trial types were embedded in a PowerPoint presentation. Fifteen words (45 in total) were presented under each encoding trial type (enact, gesture, read). The order of trial presentation for the target words was counterbalanced across participants following a Latin Square Design (Preece & Freeman, 1983), producing six different versions of PowerPoints. Within each version of the PowerPoint, the trial types (enact, gesture, and read) were intermixed. Before each 4.5-second-long video, a fixation cross appeared for 500 milliseconds. The presentation of all 45 videos took 225 seconds. After presenting the videos, the participant was given a 20-second distractor task where they were asked to count backwards by three, out loud from 190. This task was meant to prevent recency effects in recall. Following this, a set of instructions for recall appeared as the last slide of the PowerPoint. The participant was then given 60 seconds to recall as many words as they could. The participant was instructed to type the recalled words into the Chat box in Teams and send them to the researcher. After recall, a Qualtrics link containing the Mill Hill Vocabulary Scale (MHVS) was sent to the participant via the chat. After the scale was completed, the video call ended. The entire session lasted approximately 15 minutes in total.

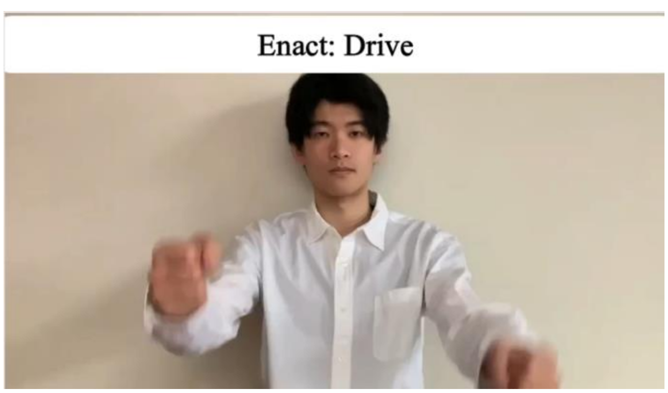

Figure 3a. Enact trial

Figure 3b. Unrelated gesture trial

Figure 3c. Read trial

3.4.2 Results: Main Effect of Encoding Strategy on Recall

We conducted a 2 X 3 mixed ANOVA, with Encoding Strategy as the within-subject variable consisting of three levels (enact, gesture, and read), and the between-subject variable as Task consisting of two levels (Experimenter-performed task or Subject-performed task). Skewness and kurtosis values for enact, gesture, and read for both tasks fell within the normality assumptions as per Kline (1998); $|skewness| < 3$ and $|kurtosis| < 10$. Standardized z-scores were computed for each trial type indicated above to screen for outliers. Any z-score greater than 2 or below -2 standard deviations from the mean was considered to be an outlier (Bini, Bertaccini, &

Bacci, 2009). We chose to only make exclusions based on participants' z-scores for the read trial type, and not based on enact and gesture trial types for both tasks, as read was treated as a baseline with which the other two encoding types were being compared. No outliers were detected, and a final sample size of 82 (N= 41 SPT; N=41 EPT) was retained for the analysis.

Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(2) = 16.41$, $p < .001$, thus, a Greenhouse-Geisser correction was applied. We observed a significant main effect of encoding strategy (see figure 4), such that both the performance and observation of semantically related actions ($M = 4.62$, $SD = 2.0$) resulted in greater recall of words, $F(1.67, 125.11) = 110.18$, $MSE = 271.21$, $p < .001$, $\eta^2_p = .60$, in comparison to when targets were encoded with unrelated gestures ($M = 1.53$, $SD = 1.25$) or read ($M = 1.58$, $SD = 1.17$). Bonferroni-corrected pairwise comparisons revealed that the unrelated gesture trial-type did not significantly increase recall compared to reading in both tasks (EPT and SPT), $p = 1.000$. There was no significant main effect of task (SPT vs. EPT), $F(1,75) = .001$, $MSE = .002$, $p = .971$, $\eta^2_p = .00$, to memory performance. However, we detected a significant Encoding Strategy X Task interaction, $F(1.67, 125.11) = 24.13$, $MSE = 59.38$, $p < .001$, $\eta^2_p = .24$, whereby self-performance of related actions (SPT) produced greater recall (M = 5.49, SD = 1.80) relative to observing an experimenter enact (M = 3.64, SD = 1.78) verbal targets (EPT), though the effect size was reduced for the EPT format: SPT provided a 57.75% boost to memory relative to the read trial type, whereas EPT provided only a 21.86% increase in recall relative to read.

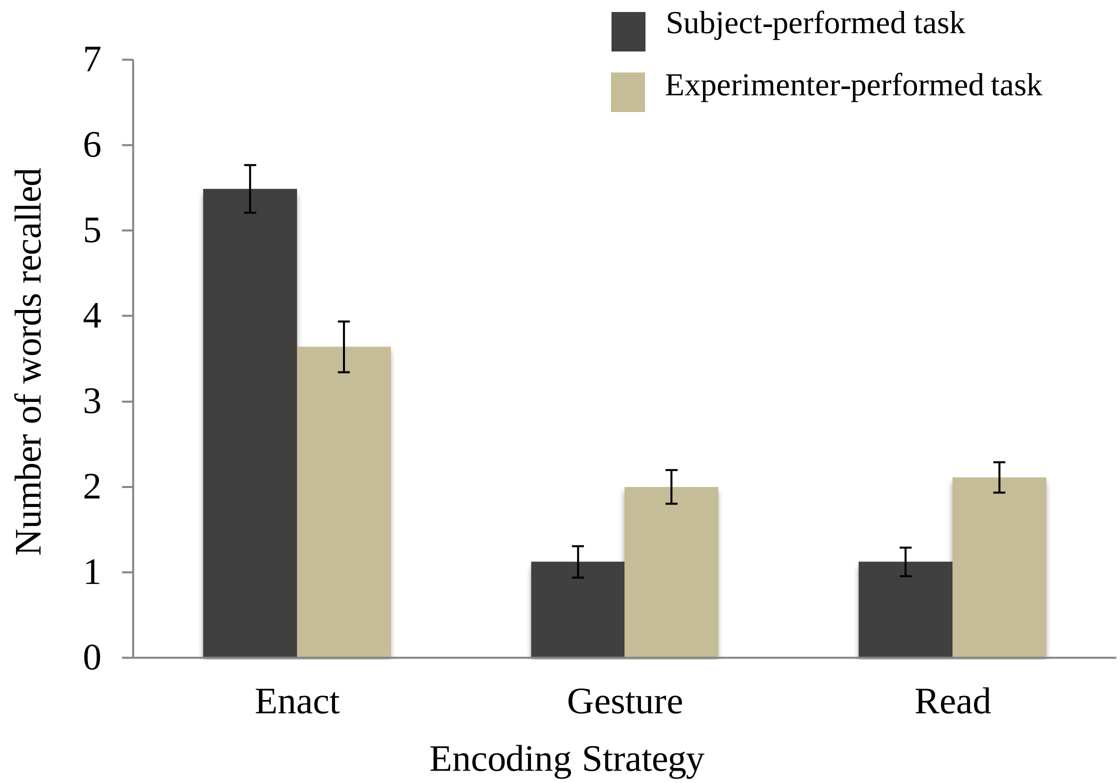

Figure 4. Mean number of words recalled following each encoding trial type, for each Task in Experiment 4. Error bars represent standard error of the means.

3.4.2.1 Recall: Onset Time to Initiate Encoding Task in the SPT Group

For each participant in the subject-performed task, we calculated the onset time to initiate the prompted encoding task to the target word for all forty-five words (15 words enacted, 15 words gestured, 15 words read). The methodology and the software program used to measure onset time of action in Experiment 3 of chapter 2 was also used in this study.

We examined these data using a one-way repeated measures ANOVA (see Figure 5 for means). Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 4.80$, $p = .091$. There was a significant main effect of Onset Time, $F(2, 80) = 67.39$, $MSE = 0.05$,

$p < .001$, $\eta^2_p = .63$. Bonferroni-corrected paired sample t-tests revealed that the onset time for initiating unrelated motoric gestures to target words was significantly faster relative to enactment, $t(40) = 9.88$, $SE = 0.04$, $p < .001$. Lip movements were also initiated significantly faster compared to enactment, $t(40) = 9.82$, $SE = 0.05$, $p < .001$, and unrelated gestures, $t(40) = 2.87$, $SE = 0.05$, $p = .006$.

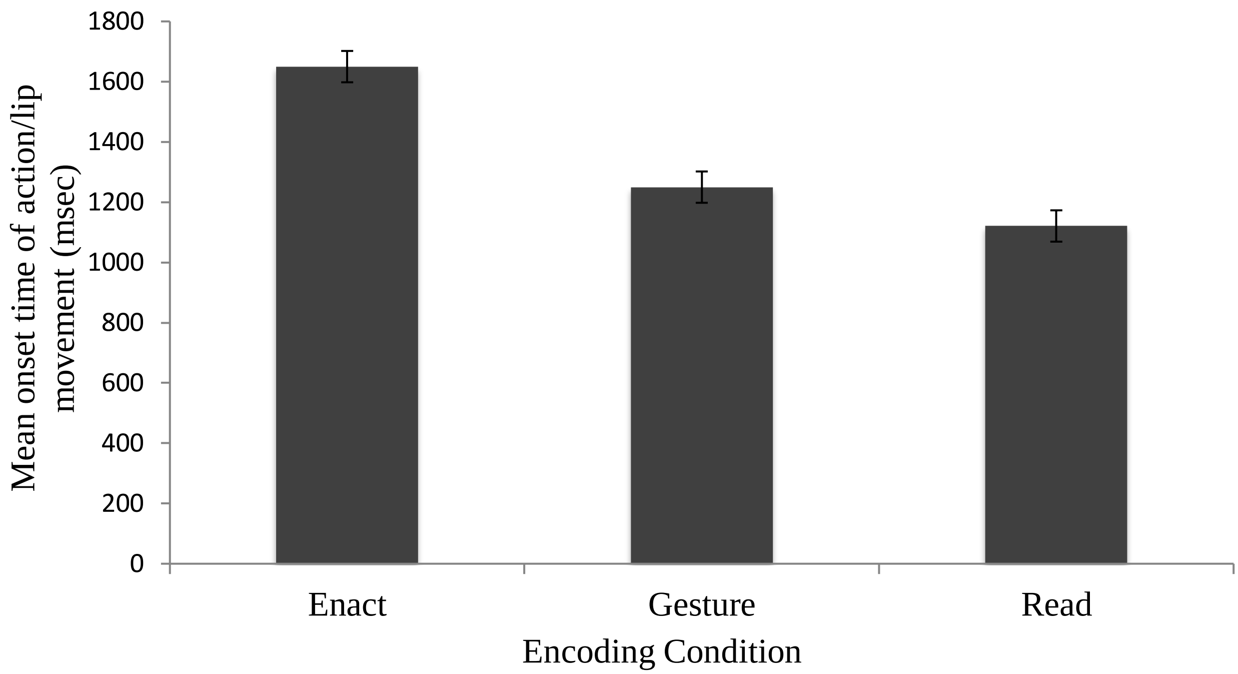

Figure 5. Mean onset time of action on Enact and Gesture trial types, and lip movement Read trials in Experiment 4. Error bars represent standard error of the means.

3.4.3 Discussion

As predicted we observed a significant main effect of encoding strategy, such that enacting a word at encoding significantly produced greater recall compared to unrelated gesturing and reading. There was no significant differences in recall for unrelated gesturing and read. In addition, as in Experiment 3 of this thesis, we found that participants took measurably longer to initiate an action on enactment relative to unrelated gesture trials. Further, initiating lip movements to read target words was significantly faster compared to enact and unrelated gesture trial types. That enactment conferred a memory benefit even with a longer onset time of action initiation is in line with claims that task-related action planning may serve as another mechanism underlying the enactment benefit (Ratner & Foley, 1994, 2020; Zimmer & Engelkamp, 1996).

Critical to this experiment, we also observed that performing a related action significantly ameliorates memory relative to participants who observed an experimenter perform meaningful actions concurrently to the presentation of target words. That we found a larger magnitude memory benefit from action execution (enact trial type in SPT) and online action observation (viewing enactment in EPT), is contrary to past findings. For example, the experiments conducted by Schult and colleagues (2014) comparing the effect of enactment and action observation on recall of single action items found no significant differences in the magnitude of the benefit across tasks. However, a recognition test did produce significant differences, whereby participants in the enactment condition recognized more actions correctly than participants in the observation condition. These findings highlight the very mechanisms by which enactment and action observation are predicted to benefit memory. Enactment is predicted to benefit memory for distinct items (supporting recognition test), while action observation is thought to enhance memory for relational processing among items in a word list (supporting recall of words) (Engelkamp & Zimmer, 1984, 1985; Zimmer et al., 2001). In our experiment, we employed a recall test when assessing the relative benefit of SPT and EPT to memory performance. Thus, we should have observed comparable memory for both SPT and EPT conditions. However, our findings run contrary to this prediction. We suggest that social presence may contribute to the magnitude of past reported benefits from EPT; watching a video of another person enacting without a social/physical presence, may limit engagement of the mirror-neuron mechanism (Shih et al., 2017) hypothesized to mediate the EPT effects (Iani & Bucciarelli, 2017; 2018).

Activation of the pre-motor cortex has been implicated in mediating the memory benefit conferred by action observation (Iani et al., 2018). The notion that our brain reflects the actions we observe is predicated on the involvement of the mirror neuron system (Rizzolatti & Craighero, 2004; Tye-Murray et al., 2013; Van der Wel et al., 2012). In experiment 4 of this thesis, we believe that the reduced proximity between the enactor and the observer may have attenuated the beneficial impact of the mirror neuron circuitry to memory performance. In fact, recent research investigating the impact of lectures delivered through online educational videos suggest that the level of social presence evoked by remote learning (measured by facial expression of the instructor, eye contact, posture, proximity) is critical to student's understanding and retention of material (Woods & Baker, 2004). It is plausible that in our study, the observations of actions through an online forum negatively impacted the memory benefit gained from experimenter-performed tasks. In summary, our study has shown that expressing meaningful actions is not only beneficial for language and communication, but also highly relevant to memory systems. Specifically, this study supports the use of semantically related actions, but not meaningless gestures, to enhance memory of target information. In addition, our results suggest that educational programs ought to be designed to promote a learning environment where learners feel closely connected to their peers and the instructors, to enhance social presence and in turn retention, when in-person learning is obstructed.

Chapter 4: General Discussion

4.1 Summary of Chapter 2: Semantic Relevance of Actions for Memory Performance

Enactment is an encoding strategy in which physically performing an action related to the to-be-remembered word enhances memory for that word. Specifying precisely how this motor activity aids memory was the focus of this thesis. We examined whether the action created during encoding needed to be semantically relevant to the to-be-remembered target item, to confer a memory benefit. Chapter 2 showed that performing semantically related compared to unrelated motoric gestures substantially enhanced the number of words later recalled. Moreover, our findings in Experiment 1 of Chapter 2 revealed no significant difference in recall between unrelated gesture and read trial types. In Experiment 2, we provided an explicit instruction to participants to “write target words in air” for the unrelated gesture encoding trials to reduce the level of ambiguity in initiating an unrelated action. We again observed a boost to memory after the enactment of action verbs at encoding, relative to unrelated gesturing. In Experiment 3 we replicated these results using a video-conferencing format for stimulus presentation and recall. Using this format also allowed us to show that participants took significantly longer to initiate an action on enactment relative to unrelated gesture trials. In addition, our results revealed that initiating lip movements to read target words was significantly faster compared to enacting and performing unrelated gesture trial types. The finding that enactment enhanced recall performance even with a longer onset time prior to initiating an action is in line with claims that task-related action planning may serve as another mechanism underlying the enactment benefit (Ratner & Foley, 1994, 2020; Zimmer & Engelkamp, 1996).

Given that unrelated actions did not produce the same memory benefit as that observed following enactment at encoding, we can infer that semantically related actions are essential to integrate the motor and verbal representations to enhance recall performance (Pulvermuller, 2005; Russ et al., 2003). When actions do not correspond to the meaning of target items, we believe participants must rely solely on the verbal representation to recall items at test. This claim is supported by our finding of no significant difference in recall performance between unrelated gesture and read trial types, in all three of our experiments. Further, it is likely that both enactment and self-performed gestures, during encoding, added a cognitive load as participants needed to both observe the word and perform an action (dual-task). However, only semantically related actions conferred a memory benefit; unrelated gestures did not. Thus, the dual-task or cognitive load requirement is unlikely to be driving the differential effect of each encoding manipulation. One may also argue that retrieval of enacted items may evoke thoughts about the meaning of items in the participant and thus benefit recall for enacted items relative to the other two encoding types (gesturing and reading). This argument, however, is a weak one since our manipulation was done only at encoding (i.e. participants did not retrieve items by enactment, or by gesturing, or verbally; written recall was conducted), and we employed a delayed memory test (not working memory). Importantly, all words in our stimulus list were action verbs and encoding trial types were intermixed, thus it is unlikely that participants would have chunked enacted items into semantic categories to aid recall.

4.2 Summary of Chapter 3: Is Social Presence Important for the Memory Benefit of Action Observation

In chapter 3, we investigated whether it was important for the semantically related action to be generated by oneself to confer a memory benefit, or was it sufficient to simply observe the action performed by another individual. As found in our previous experiments, meaningful actions are an essential component to the enactment effect. However, our results revealed that observing actions via online videos reduces the memory boost gained from meaningful actions, relative to performing them. We believe that observing actions in an online platform where there is physical distance between the enactor and observer attenuates the memory benefit gained from action observation.

In addition, we found that it took participants a significantly a longer time to initiate enactments relative to unrelated gestures and lip movements when reading target items. The replication of our onset time data suggests that planning is another critical mechanism supporting the enactment benefit to memory. Ratner and Foley (1994, 2020) suggest that enactment enhances memory due to the intentional planning that is required of the participant to select the correct motor program to execute an action. Our results further clarify the intentional planning account proposed by Ratner and Foley (1994, 2020). It is not planning of any action that boosts memory, but precisely the planning of a task-relevant action that represents the goal denoted by the action verb which supports recall performance. One could argue that unrelated gesturing (writing target words in air) also requires intentional planning as participants would have to select the appropriate motor acts to trace the word in air. In this instance, the unrelated gesture is a planned action that represents the surface level word form, but is not representative of the goal intended by the action. Thus, our findings suggest that planning of actions which elaborate on the goal are far more superior and critical to the enactment effect, than planning an action that captures the orthographic structure of words (Craik & Lockhart, 1972).

4.3 Implications for the Enactment Domain and Real-world Scenarios

If indeed enactment promotes the creation of two independent (verbal and motor) memory representations (Zimmer & Engelkamp, 1985), this thesis seeks to answer the question of what type of motoric activity benefits memory. Based on the results of our experiments, meaningful actions plays a central role in integrating the verbal information and the actions that are semantically linked to the word, thereby enhancing memory. Neuroimaging research has indicated a close link between the neural circuits dedicated to storing the verbal representation of an action verb and the semantically related motor programs associated with the actions conveyed by the words (Willems & Hagoort, 2007; Pulvermuller, 2005). Further, Russ and colleagues (2003) identified the inferior parietal lobule as a central region implicated in the enactment benefit; this brain area receives input from visual, motor, auditory, and somatosensory regions and may integrate related information represented in different modalities. Using functional Magnetic Resonance Imaging (fMRI), Russ and colleagues (2003) observed a specific pattern of activation in the parietal association cortex, namely the supramarginal gyrus (Brodmann area 40), during the retrieval of enacted items. Given this intricate relationship between language and motor areas of the brain, it is possible that meaningful actions performed in response to the to-be-remembered action verbs in our experiments contributed to the multimodal integration of verbal and motoric representations. Our results suggest that unrelated gestures, in contrast, do not lead to the same integration of motor and verbal representations of the to-be-remembered word. Thus, the most important finding from our thesis is that embedding meaning to the action produced at the time of encoding appears to underlie the memory benefit from enactment.

A finding such as this may be especially relevant to inform diagnostic assessments for those with apraxia, whose deficits transect language and motor areas of the brain (Gross & Grossman, 2008). Patients with ideomotor apraxia show impaired performance in executing planned motor acts despite intact sensory, motor, and language function (Heilman et al., 1982). Such patients primarily have the greatest difficulty in performing actions representative of verbal commands (Gross & Grossman, 2008). This deficit is comparable to participants enacting a target word in our experiments. Other research indicates that patients' inability to generate a related action to a verbal command may be a result of the disruption sustained to left frontal, parietal, and language regions (Wernicke's area) of the brain (Kareken et al., 1998). This is in line with findings from our research program, which suggest that generating a related action, that presumably establishes a motor trace representative of the meaning of action verbs, is a critical contributor to the enactment effect. Therefore, praxis assessments could further examine whether such patients struggle with inferring the meaning from a verbal command and translating the information to a motoric representation to be able to execute the appropriate action. These assessments would help researchers clarify the specific reason as to why apraxic patients struggle to perform representative actions; that is, does the deficit occur as a result of a motor impairment or due to concerns underlying language and perceptual regions of the brain responsible for inferring meaning from verbal commands to produce a symbolic action. We speculate that patients with apraxia would show deficits in recall compared to healthy individuals, since they would have deficits in the very procedures that convey the memory boost seen in the enact conditions of all the experiments presented here.

4.4 Limitations and Future Directions

Finally, it is important to note that our proposed mechanism for the enactment benefit is predicated on the assumption that it establishes a supplementary motor code, that when semantically related to the target word, allows for better later retrieval. An alternative account however, suggests that superior memory observed following enactment at encoding was due to better self-involvement by the participant to learn the word, as opposed to forming an independent motor trace (Kormi-Nouri et al., 1994). Kormi-Nouri and colleagues (1994) explain greater self-involvement in enactment as the performer having better self-awareness of what is encoded, when they themselves produce an action that captures the word read on the screen. In line with this reasoning, Kormi-Nouri et al. (1994) dismissed the view put forth by Engelkamp and Zimmer (1984, 1985) that enactment establishes an independent motor trace to benefit memory, and argued for the notion that enactment simply improves verbal episodic memory (enhancement of a single memory trace). We did not directly assess the role of self-involvement in mediating the enactment effect. However, further studies should examine this possibility as brain regions implicated in self-involvement (D'Argembeau et al., 2005) are distinct to those observed with motor-based processing of target items. Another limitation of this thesis is that we did not directly test if social presence is indeed important when assessing the memory benefits of action observation. Future research should directly compare the results of participants observing actions in the same physical room as the experimenter relative to those observed via online videos to delineate the differences in the magnitude of the memory benefit gained from both environments.

Further, there have been some neuropsychological studies investigating the neural regions implicated in enactment and its impact on memory performance by assessing stroke patients, but these studies have focused on specific patient groups (Ertelt et al., 2007; Knopf et al., 2005). Thus, little could be inferred about the relative contribution of distinct brain regions shown to be important for the enactment effect. For example, Masumoto et al. (2015) proposed that the enactment benefit that follows subject-performed actions is not simply due to activation of motor information about the timing and form of actions as mediated by the primary motor cortex (M1), but rather is a result of movement representations of the meaning of actions, mediated by the posterior parietal lobe. As a future direction, we aim to specify the underlying brain areas responsible for the memory benefit conferred by enactment. Existing literature suggests that the primary motor cortex may be responsible for the memory boost following SPT (Russ et al., 2003). The posterior parietal lobe has also been documented as an important area contributing to enhanced memory following SPT, as this region is thought to process movement representations pertaining to semantic and conceptual information, as well as movement imagery (Masumoto et al., 2006, 2015; Russ et al., 2003). We plan to document performance in a variety of participants who have sustained a stroke affecting various regions of the brain, to determine how their damaged regions impact memory performance following enacting and reading of target words. By assessing performance in a wide array of stroke patients, our work will not only offer a theoretical replication of prior work examining the neural basis of the enactment effect, but will also tease apart the relative contribution of different brain areas implicated in this encoding strategy.

4.5 Conclusion

Our study has shown that expressing meaningful actions is not only necessary for language and communication, but also highly relevant to memory systems. Our study also provides insights that inform our understanding of how intertwined memory systems are with motor and language areas of the brain. In conclusion, our experiments provide compelling evidence that performing semantically related actions, that convey declarative and procedural knowledge about the verbal material (Iani et al., 2018), rather than performing any action to verbal targets, accounts for the significant memory benefit conferred by enactment as an encoding strategy. Importantly, the benefit gained from semantically related actions may be determined by who is performing (participant or experimenter) the action, especially when actions are observed via online videos.

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Appendix

List of target items used in Experiments 1, 2 and 3.

Drive	Salute	Braid
Throw	Dig	Dribble
Type	Swim	Dive
Chop	Flick	Climb
Whisk	Juggle	Count
Applaud	Tap	Sweep
Comb	Wave	Row
Knock	Flex	Serve
Punch	Catch	Stroke
Knit	Tear	Honk
Stir	Paint	Stop
Greet	Drink	Wipe
Pour	Cut	Carry
Crawl	Hug	Snap
Eat	Hammer	Bend