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The Enactment Effect: A Systematic Review and Meta-Analysis of Behavioral, Neuroimaging, and Patient Studies

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The enactment effect is the phenomenon that physically performing an action represented by a word or phrase (e.g., clap, clap your hands) results in better memory than does simply reading it. We examined data from three different methodological approaches to provide a comprehensive review of the enactment effect across 145 behavioral, 7 neuroimaging, and 31 neurological patient studies. Boosts in memory performance following execution of a physical action were compared to those produced by reading words or phrases, by watching an experimenter perform actions, or by engaging in self-generated imagery. Across the behavioral studies, we employed random-effects meta-regression with robust variance estimation (RVE) to reveal an average enactment effect size of $g = 1.23$. Further meta-analyses revealed that variations in study design and comparison task reliably influence the size of the enactment effect, whereas four other experiment factors—test format, learning instruction type, retention interval, and the presence of objects during encoding—likely do not influence the effect. Neuroimaging studies demonstrated enactment-related activation to be prevalent in the motor cortex and inferior parietal lobule. Patient studies indicated that, regardless of whether impairments of memory (e.g., Alzheimer's) or of motor capability (e.g., Parkinson's) were present, patients were able to benefit from enactment. The findings of this systematic review and meta-analysis highlight two components accounting for the memory benefit from enactment: a primary mental contribution relating to planning the action and a secondary physical contribution of the action itself.

Public Significance Statement

The enactment effect is the finding that physically performing an action represented by a word or phrase leads to enhanced memory for that information relative to simply reading it. This review integrates evidence from behavioral, neuroimaging, and patient studies to highlight the utility of encoding multiple facets of an item or an event to enhance its retention. Enactment was found to be a reliable and effective mnemonic tool for both neurotypical and patient populations.

Keywords: enactment effect, subject-performed task, multimodal encoding, meta-analysis, systematic review

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Physically performing an action represented by a word or phrase leads to enhanced memory for that information relative to simply reading the word or phrase. This is the *enactment effect*. Why has this memory enhancing effect been of continuing interest to memory researchers for 6 decades? Put simply, only a few encoding techniques actually produce substantial benefits to remembering. In this exclusive group, the major ones are imagery (Paivio, 1971), level of processing (Craik & Lockhart, 1972), and generation (Slamecka & Graf, 1978), augmented by other "classic" techniques (e.g., rehearsal, Rundus, 1971; narrative chaining, Bower & Clark, 1969) and a few more recent ones (e.g., testing, Roediger & Karpicke, 2006; production, MacLeod et al., 2010; and drawing,

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Wammes et al., 2016). As we will show, enactment consistently provides a substantial benefit to memory, deserving its place on this list.

Historical Context

Since the dawn of empirical psychology, the relation between movement and memory has fascinated investigators. In 1896, Theodate Smith may have been the first to explore this connection. Her goal was to study the "motor element" of memory by instructing participants to learn a series of hand movements from the American Manual Alphabet (gestures that correspond with letters of the English language, often used by deaf individuals). Smith found that the inclusion of action at encoding led to a reduction in errors during subsequent recall. Smith (1896) was careful to note that a motor element was not entirely isolated in her study, "for though actual muscular movements were absent, the idea of movement was never entirely excluded" (p. 490).

In 1932, Jacobson used a string galvanometer to measure action potential signals coming from participants' arms when they were asked to imagine themselves performing an action. By 1948, Werner argued that perception and representation both depend on how objects can be physically responded to, thereby introducing the concept of affordance—that an object enables specific actions depending both on its form and on the constraints of human interaction (Gibson, 1966, 1979; see Greeno, 1994, for a review).

The earliest research linking purposeful action to memory enhancement began in 1964, when Asher first showed that participants learned verbal phrases in a second language faster when they performed associated actions, a result confirmed in subsequent studies (Asher, 1965, 1966, 1969; Asher & Price, 1967; Kunihira & Asher, 1965; Price, 1966). Perhaps most strikingly, Asher (1968) was contracted by the United States Office of Naval Research to compile a 21-experiment report on how best to learn spoken Russian during the height of the Cold War. Asher's proposed solution was his newly discovered encoding strategy: Performing actions related to learning content—or as Asher called it, the *total physical response method*.

In 1971, Saltz suggested that motor action interacts with other components of language and semantics to establish meaning (see also Dixon, 1979). Building on Piaget's (1962) view that children can use motor action to induce imagery, a collection of developmental studies explored action as a way to improve their memory even before children are old enough to perform mental imagery voluntarily (Guttentag & Ross, 1972; Levin, 1976; McCabe et al., 1974; Paris & Lindauer, 1976; Restum, 1978; Wolff et al., 1972; Wolff & Levin, 1972).

Finally, in 1980, Engelkamp & Krumnacker published the first study on what we now refer to as the more strictly defined and contemporary *enactment effect*. They showed that actually performing the action described by a word led to better memory for it than did hearing the word, imagining the associated action, or observing the action. Soon after, Saltz and Donnenwerth-Nolan (1981) compared memory performance following enactment, imagining, and reading by manipulating the interference present during retrieval. Because a motoric interference task influenced memory for enacted items, whereas a verbal interference task did not, they argued that representations in verbal and motoric memory were separate, unique modes of encoding. In the same year, Cohen (1981) began to popularize the benefit of enactment, writing about what he called "subject-performed tasks," and arguing that the encoding invoked by this procedure differed in several critical ways from that engaged when simply reading words. The foundation was thus established upon which 40 years of enactment research has since been built.

The enactment effect is very robust (and large, by psychology standards), but there is still ongoing debate concerning its underlying mechanisms. Since 2010, over 150 journal articles and books about the effect have been published. Numerous authors continue to explore the realm of enactment, investigating—as just two examples—the neural underpinnings of the effect (e.g., Leynes & McGowan, 2021; Ma et al., 2021) and its efficacy as a cognitive tool for various patient populations (e.g., Fantasia et al., 2020). Consider just a few recent research directions: Can those with learning disorders benefit from enactment (Li et al., 2020)? How does action interact with other phenomena such as the testing effect (Kubik et al., 2020)? Does working memory also benefit from enactment (Allen et al., 2020)? Does action memory enhance conceptual representations (Zhang & Wang, 2020)? And how might enactment integrate with emerging technologies such as virtual reality (for a review, see Tuena et al., 2019)?

At a time when pop culture interest in cognitive enhancement is high and research concerning multimodal encoding is on the rise, enactment serves as a critical tool not only to evaluate ways to improve memory in everyday life but also to delineate mechanisms of multifaceted cognition more generally. Given the continuing frequency of publications relating to the enactment effect, as well as its theoretical implications for broader mechanisms of memory, a systematic review and meta-analysis of this literature is certainly timely.

Theories of Enactment

The first 2 decades of enactment research culminated in several theories to explain the memory benefit of enactment, all of them focusing on the four main concepts shown in Table 1. Here, we also group each theory's relevance to the eight major research questions highlighted later (see Table 3). Initially, Cohen (1981) argued, by analogy to Paivio's (1969, 1971) dual coding theory, that motoric and verbal memory were functionally distinct from each other and that motoric memory, being more efficient than verbal memory, led to superior performance. Cohen (1983, 1985) based this idea primarily on observations that memory for enacted items demonstrated no primacy effect on serial-order memory tests, little to no age-related performance effects, and a resistance to levels-of-processing type manipulations (Cohen & Stewart, 1982).

Bäckman and Nilsson (1984, 1985) expanded on Cohen's (1981) hypothesis to argue that motor memory is superior to verbal memory because it facilitates multimodal encoding. In their view, the verbal component of action memory can be strategic, whereas the motor component cannot be (cf. Peterson & Mulligan, 2015). Enactment was seen as facilitating implicit encoding of object size, color, shape, and so on, as well as information regarding the action itself, which then combined with (potentially strategic) verbal memory to provide a richer multimodal memory. Intriguingly, in the autobiographical memory literature, actions in daily life tend to be among the most detailed types of memories for young adults (Levine et al., 2002), consistent with memory for actions being especially detailed and possibly incidentally encoded.

Table 1
Summary of Influential Theoretical Ideas of Mechanisms Underlying the Enactment Effect

Representative citation	Motoric encoding is critical	Multisensory integration is important	Action enhances conceptual integration	Enactment is (at least partially) nonstrategic
Bäckman and Nilsson (1985)	Yes	Yes	Yes	Yes
Cohen (1981)	Yes	No	No	Yes
Engelkamp (1998)	Yes	Yes	Yes	Yes
Helstrup (2004)	No	Yes	Yes	No
Kormi-Nouri (1995)	No	No	Yes	Yes
Perrig (1988)	No	No	Yes	Yes
Ratner and Foley (1994)	Yes	No	No	No
Saltz and Donnenwerth-Nolan (1981)	Yes	No	Yes	Yes
Relevant major research questions:	1, 5, 7, 8	1, 2, 4, 5, 7	2, 3, 4, 6, 7	3, 4, 5, 8

Note. Representative articles are listed alphabetically. Relevant major research questions are presented in Table 3.

Engelkamp and Zimmer (1983, 1985) agreed with Bäckman and Nilsson's (1985) multimodal encoding idea but argued instead that, rather than the key being sensorimotor details stemming from an object, motor activation during enactment is what leads to superior memory. Saltz and Donnenwerth-Nolan (1981) modified Engelkamp and Zimmer's account to state that despite motor imagery and verbal imagery being separate, they should theoretically result in equivalent performance, thus some additional factors had to be at work to explain the enactment benefit. One critical assumption tied all of these early theories together—that the enactment effect likely originated from nonstrategic (i.e., implicit) memory processes.

Other explanations followed. Perrig (1988) held that motor information could not be directly contributing to explicit memory performance (e.g., free recall) because raw movement information (e.g., muscle contraction) is unconscious. Instead, Perrig claimed that added conceptual information was what benefitted subject-performed task (SPT) explicit memory performance. The possibility remained open that "pure motor" effects (i.e., resulting from unconscious sensory and movement information) could still play a role in implicit uses of memory.

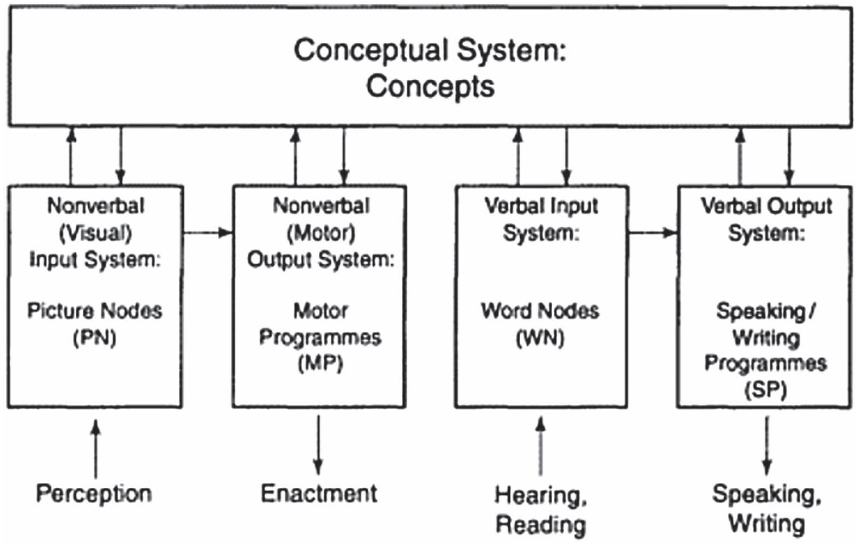
Helstrup (1986, 1987, 1989a), in contrast, argued that the enactment benefit was strategic and that new memory "laws" were not necessary to explain the benefit. Helstrup suggested that all memory events, including encoding and retrieval using enactment, were conscious learning strategies employed for the use of problem-solving in a given context. Critically, Helstrup theorized that changes in contextual factors within an experiment could alter the participant's chosen memory strategy and in turn the basic enactment effect. To illustrate, Helstrup (2004) successfully "brought back" the primacy effect for enacted items when the task was made more difficult by requiring faster actions from participants. Similarly, Ratner and Foley (1994) based their "activity memory framework" on the inherent goal-directed nature of actions. They posited that perceptual, motoric, and conceptual representations elicited by enactment are not merely elaborative, but rather further contribute to the actor's goals. The goals of the actor are therefore enhanced via prospective planning, outcomes of the action, relational structures such as those in multistep sequences, and retrospective evaluation of past activities (Foley & Ratner, 2001).

In keeping with these non-motor-centric views of enactment, Kormi-Nouri (1995) proposed his episodic integration theory. His core idea was that enactment benefits item-specific memory via greater self-involvement and understanding stemming from three levels of integration: (a) between-item integration where action phrases all become more strongly related, (b) within-item integration where a to-be-remembered verb and noun become more strongly associated, and (c) greater integration with the environment due to performing the action (subject–environment integration; Kormi-Nouri & Nilsson, 1998, 2001). Critically, Kormi-Nouri (1995) attributed no unique contribution to the motor system, arguing instead that enactment enhanced existing noun–verb conceptualizations by way of these three integrations.

Around the same time, the current leading account of enactment gained significant traction: This was the idea of enhanced item-specific processing via multimodal encoding (Engelkamp, 1998; Engelkamp & Zimmer, 1996, 1997). Engelkamp (2001) described this idea as a "system-oriented approach" whereby all episodic memory has a conceptual component (e.g., of the action sequence plan, intention, and/or object used), but that additional multimodal encoding can be invoked depending on the specific memory task, often having the benefit of improving memory. Thus, memory for read/spoken words would involve only verbal input/output systems in Engelkamp's multimodal theory, whereas enactment would implicate both of these systems plus a motor output system (see Figure 1). Essentially, enacted items benefit from the combination of conceptual knowledge with physical action, enhancing item-specific processing. Evidence of diminished item-relational processing for enacted items (e.g., Bäckman et al., 1986; Engelkamp, 1986; Engelkamp & Dehn, 2000; Steffens et al., 2003; Zimmer & Engelkamp, 1989a) could be due to a trade-off from this enhanced item-specific processing.

In sum, early theories assumed that the memory benefit was entirely nonstrategic and posited a version of dual coding—that memory for motor action was separable from verbal memory, and that two codes were better than one. Subsequent work suggested, however, that there was some effect of strategic encoding tied to the verbal and/or motor codes of an enacted memory. Then, the idea of rich multimodal encoding became dominant and for several years underwent an evolution of incremental additions and concessions as evidence accumulated. At the same time, other theories took a more holistic stance, downplaying any role of motor information and arguing instead that integration of a memory with one's goals, one's self, and one's environment was key. Eventually, multimodal memory theories were further developed to highlight aspects of enhanced item-specific encoding; these have remained the most popular explanations of the memory benefit that results from

Figure 1
Engelkamp's (1998) Multimodal Encoding Theory



Note. Figure 4.1 from Engelkamp's (1998) book depicting his idea of a system-oriented approach to multimodal encoding of episodic memory. All modality-specific subsystems have access to and are informed by an overarching conceptual system, but each may also act independently depending on the memory task. From *Memory for Actions*, by J. Engelkamp, 1998, Psychology Press/Taylor & Francis. Copyright 1998 by Psychology Press/Taylor & Francis. Reprinted with permission.

enactment. We will reconsider the two leading enactment theories later in this article, once all evidence has been thoroughly evaluated.

Goals of the Meta-Analytic Review

We had three primary aims in our meta-analytic review: (1) to create a detailed catalogue of enactment articles that will serve as a resource for future research to build upon; (2) to meta-analyze the existing behavioral literature on enactment, summarizing the efficacy and use of several theoretically significant study factors; and (3) to synthesize this behavioral work with that from neuroimaging and patient studies, offering further insight into both the neural correlates of enactment and its manifestation in various patient groups. With the intent of keeping terminology in this review consistent with past literature (e.g., Cohen, 1981; Nyberg, 1993), we define some common terms in Table 2.

We have chosen not to consider developmental or healthy aging-related questions; numerous studies have already examined enactment across the lifespan. In brief, early work found no developmental effects of SPTs on memory (Cohen & Stewart, 1982), while a more recent series of studies by Badinlou et al. (2017, 2018a, 2018b) found the effect in free and cued recall to be larger in older than in younger children, but this age difference was not evident with recognition testing (Badinlou et al., 2017). For reviews of enactment in children, see the continuing works of Ratner and Foley (Foley & Ratner, 2001; Ratner & Foley, 2020). The popularity of the "total physical response method" endures in publications of language learning in school-aged children (for a review, see Asher, 2009). Finally, the immense Betula cohort study offers an overview of enactment across adulthood (ages 35–90; Lövdén et al., 2002; Nilsson et al., 1997; Rönnlund et al., 2003).

We also note that there have been other, more selective reviews. Madan and Singhal (2012) examined the role of motor imagery in

Table 2
Common Tasks and Abbreviations Used in the Enactment Literature and Their Definitions

Task label	Abbreviation	Definition
Subject-performed task	SPT	Participants perform (enact) the actions themselves.
Experimenter-performed task	EPT	Participants view an experimenter (or another participant) performing the action, without doing any imitation or movement themselves.
Imagery task	IT	Participants imagine themselves performing the action, without seeing the action performed or performing the action themselves.
Verbal task	VT	Participants read or hear action words or phrases, without seeing an action performed or performing the action themselves.

Note. SPT is often what researchers refer to when describing "enactment"; the other three tasks typically serve as comparisons to SPT.

several facets of higher-level cognition, including memory, while Steffens et al. (2015) examined the role of other study factors on enactment, including number of study–test cycles, list structure and length, object-related actions versus self-related actions, and verbs versus action sentences. In contrast to these previous reviews, here we conduct a meta-analysis which includes an up-to-date systematic review, coupled with integration of neuroimaging publications and studies of various patient groups. Outside the realm of the enactment effect specifically, reviews (e.g., Halsband & Lange, 2006) and meta-analyses (e.g., Hardwick et al., 2013) of motor learning at the neural level serve as useful accompaniments to the present review when interpreting proposals for neural mechanisms of enactment. Here, our objective was to contextualize the enactment effect as a powerful multimodal encoding strategy, as well as to highlight similarities to other multifaceted mnemonic techniques in enhancing learning, memory, and patient outcomes. In so doing, we aimed to answer the eight major research questions outlined in Table 3. The first six of these are addressed immediately below and focus on the behavioral studies; the last two questions are answered later by integrating evidence from neuroimaging and patient studies.

Meta-Analytic Review of Behavioral Studies

There is a wide variety of approaches to the study of enactment. Some studies have used nonconventional versions of the typical enactment paradigm, such as allowing for reenactment at retrieval (e.g., Helstrup, 2005; Norris & West, 1993; Worthen & Wood, 2001); others have even explored enactment *only* at retrieval (e.g., Koriat et al., 1990). Other researchers opted to study the effects of enactment when altering word color (Bäckman et al., 1991) or word importance (Cohen, 1983), or varying level-of-processing (Zimmer & Engelkamp, 1999), or even combining enactment with other mnemonics such as the method of loci (Helstrup, 1989a). Such studies contribute to our understanding of enactment, but they vary so widely in methodology that any comparison of their results to those stemming from the more "standard" procedure would be fraught with difficulty. In this article, we have chosen to restrict the meta-analysis of behavioral studies to research fitting the standard enactment paradigm: a subject-performed task versus one of the three comparison tasks (verbal task [VT], experimenter-performed task [EPT], or imagery task [IT]) done at encoding, followed by a verbal retrieval test.

Table 3
The Eight Major Research Questions Addressed in the Systematic Review and Meta-Analysis

RQ#	Question
1	Does the form of enactment matter in determining whether a memory benefit will occur (i.e., real vs. imagined; performed vs. viewed)? How do the three most common comparison tasks (VT, EPT, and IT) relate to the classic enactment task (SPT)?
2	Does the enactment benefit manifest differently across free recall, cued recall, and recognition memory tests? How does enactment unfold at the time of retrieval?
3	Does the enactment effect occur regardless of experimental design (i.e., in both within-subject and between-subjects designs)? Does the size of the effect differ between designs?
4	Does intentionality of encoding matter for the enactment effect (i.e., does the effect occur under both intentional and incidental learning conditions)?
5	Does the inclusion of real objects in SPTs influence the size of the enactment effect?
6	Does enactment provide more robust, longer-lasting memories compared to simple verbal rehearsal?
7	What is the neural basis of the enactment effect?
8	Can enactment benefit the memory performance of various neurological patient groups? Do motor or memory impairments alter the efficacy of enactment?

Note. RQ = research question; VT = verbal task; EPT = experimenter-performed task; IT = imagery task; SPT = subject-performed task.

Method

Literature Search and Filtering Process

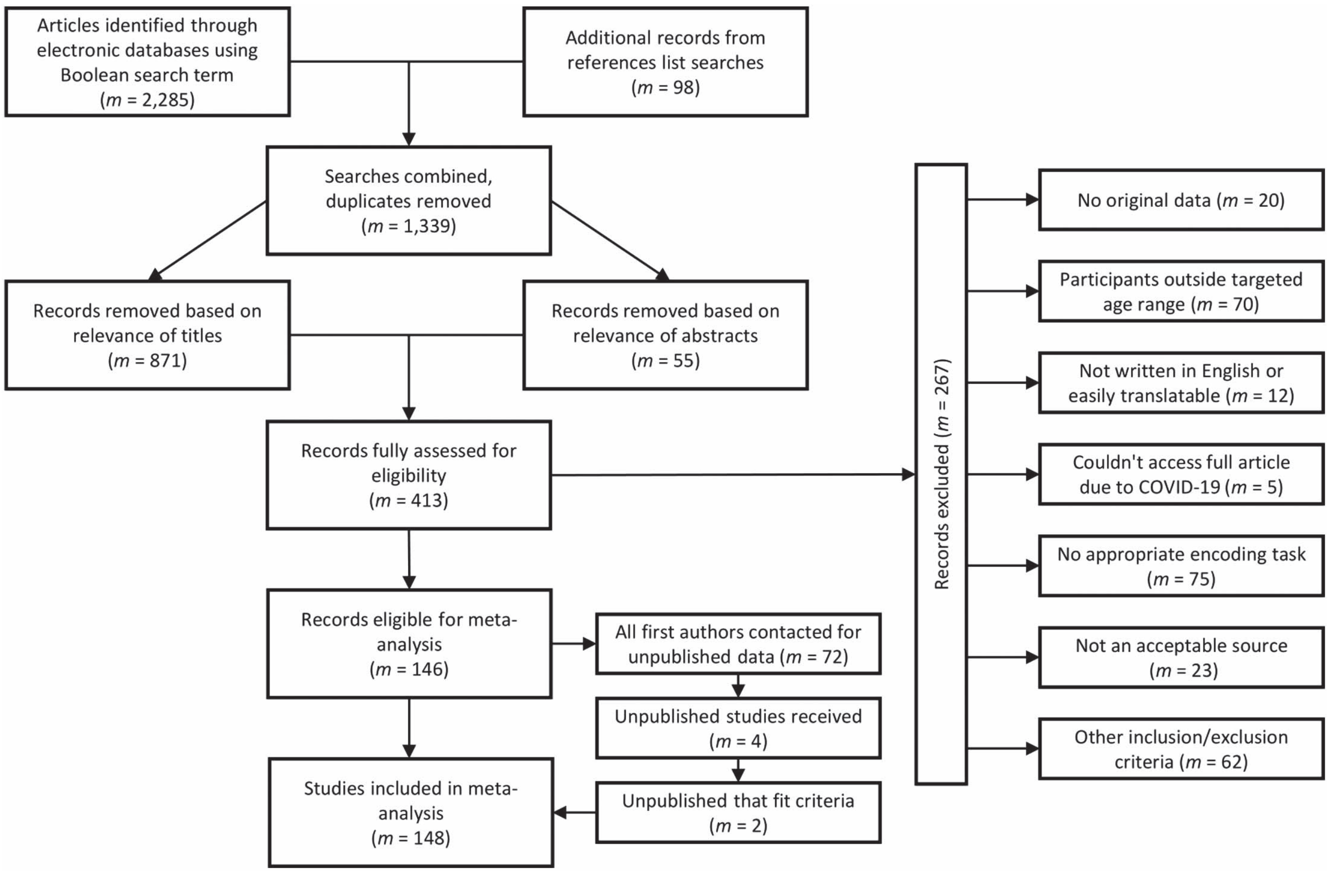
To obtain a comprehensive list of relevant studies, articles in this meta-analytic review were gathered via two different methods: database search and mining of reference lists. Our goal was to locate the entirety of the enactment literature, including peer-reviewed research articles, theses and dissertations, and unpublished data obtained through correspondence with authors. No date restrictions were made for any article during the literature search. The electronic database search was conducted on September 30, 2020, with mining of reference lists and correspondence with authors completed thereafter.

To begin the electronic literature sweep, we formed a standard Boolean search string that encompassed enactment and related subfields: ("enactment" OR "subject-performed task" OR "SPT") AND "memory."[1] We assumed that most relevant studies published after 1981 would have used the term "enactment" at some point. To cast a wide net, we used our search string in PsycINFO, PubMed, Scopus, Web of Science, and ProQuest Dissertations and Theses Global. Our second method was "backward snowballing" (Wohlin, 2014): Articles found by the first method were used to find additional articles by mining their reference lists. When a new study was found, that article in turn underwent the same process. Both search methods were applied for each of the three major sections of this review.

After all database searches and reference mining, we had well over two thousand hits. A graphical overview of our literature search and filtering process is presented in Figure 2. We first removed duplicates using the freely available Mendeley citation manager software, then proceeded to filter studies by relevance based on the content of their titles, then their abstracts. The latter two steps were conducted independently by the first author and two research assistants. When there was a disagreement among the three coders, careful discussion determined whether an article would be filtered out or would remain in the corpus (typically, we were liberal with inclusion on this step). Next, the first author evaluated the full-text content of the remaining articles both by their relevance (as in the previous steps) and using our preregistered inclusion/exclusion criteria. Inclusion criteria mandated that a source have original data, use a healthy adult sample with ages 18–60 years, be written

[1] The search term "action" was too broad and resulted in tens of thousands of search results in each database, rendering the search string impractical. Studies concerning gesturing were initially considered as well, but ultimately many of them did not match typical enactment experiment procedures closely enough to be included here (for a review of how gesturing affects learning and memory, see Cook & Fenn, 2017; for a recent meta-analysis on how gesturing affects comprehension, see Dargue et al., 2019).

Figure 2
Flowchart of the Literature Search and Study Filtering Process



Note. m = number of primary research studies.

in English or translatable using Google Translate, involve enactment and a comparison task during encoding, and assess episodic memory performance. Illustrations of exclusions include studies that used simple repetitive actions (e.g., button pressing), that assessed the effects of enactment performed only during retrieval, that included only expert groups, or that involved additional encoding/retrieval manipulations (e.g., dual tasking). See our files on the Open Science Framework (OSF) for more detailed article selection criteria.

After this in-depth filtering, 146 articles remained eligible for inclusion in the behavioral meta-analysis. In our final step, we emailed the first author of each remaining article to request unpublished data, experiments, or manuscripts. We received data from four unpublished studies, of which two met our inclusion criteria, resulting in a total of 148 studies in the meta-analysis.

Coding of the studies involved recording the study citation, its source "type" (journal article, book, dissertation, etc.), several sample demographics, all relevant study parameters (e.g., retrieval test format), and relevant statistics in raw format, as well as the results of the original significance testing found within each article. If available, we recorded raw means and standard deviations for the proportion of hits, false alarms, and memory accuracy/sensitivity scores (although only hit rate was analyzed here so as to equate metrics across all retrieval test formats). When these values were not available, we instead obtained them by converting from other presented metrics (most often, raw correct recall counts and standard errors). Conversions to standard deviations were done using the RevMan Excel workbook calculator available online (Drahota & Beller, 2021). When summary statistics in these articles were presented only in figures, we used the tool "WebPlotDigitizer" (Rohatgi, 2020) available online to create a digital matrix of the plot axes, allowing accurate extraction of the desired data. All full-text coding was performed by the first author and was conducted twice to ensure accurately recorded data.

Effect Size Calculation

Because we were interested in the size of the enactment effect across such a vast literature, we decided to use a standardized mean difference between SPT and its comparison task as the main measure of interest for each study. Hedges' g was favored over the more common Cohen's d due to the latter's relatively biased estimate of the population effect size in the case of small sample sizes. We first calculated Cohen's d from the available statistics, then applied an approximation of Hedges' (1981) small sample size correction factor to achieve a measure of Hedges' g (Borenstein et al., 2009). See our page on OSF for detailed descriptions of effect size calculations (including exact formulae used).

The enactment literature has often used both within-subject and between-subjects designs, so we required a way to equate the effect sizes of these two designs to make them comparable in the meta-analysis. Without correction, within-subject effect sizes would likely be systematically larger than between-subjects effect sizes due to inclusion of between-subjects sampling error in the latter case. Morris and DeShon (2002; see also Borenstein et al., 2009) recommend (1) converting the effect sizes into a common metric and then (2) assessing design as a potential moderator. Following this advice, we first calculated effect sizes d_{RM} and d_{IG}, representing Cohen's *d* for repeated measures and independent group designs, respectively. Then, we converted all d_{RM} values into d_{IG} values using equations supplied by Morris and DeShon (2002).[2] Converting effect sizes in the other direction would lead to systematically larger estimates of population effect sizes; our method should lead to more conservative estimates. We also did not want to record the reported effect size values presented in primary articles because effect size reporting is notoriously variable and mislabelling is prevalent (Cumming, 2012). Instead, to avoid this issue and to increase consistency, we calculated each effect size based on raw summary statistics where available (or on the results of hypothesis tests otherwise).[3]

In summary, we calculated effect sizes as available based on original study design, then converted every within-subject study effect size into a between-subjects variation called d_{IG}. Recent examples of this strategy in meta-analysis can be found in Pan and Rickard (2018) as well as in Shields et al. (2017). Because we first calculated d_{IG} from the available statistics, then converted to Hedges' *g*, our final effect size estimate could perhaps be more accurately described as g_{IG} to represent Hedges' *g* for an independent groups design. The specificity of effect size terminology is important, as identical effect size metrics are often used to describe very different concepts (see Goulet-Pelletier & Cousineau, 2018; Lakens, 2013). Nevertheless, we will refer to our effect size metric simply as Hedges' *g* because this metric is commonly understood to be used in between-subjects designs anyway, so it should already be familiar and allow for accurate interpretation (on the same scale as the more common Cohen's *d*).

Meta-Regression With Robust Variance Estimation

We chose to follow the Hedges and Olkin (1985) tradition of a random-effects meta-analysis designed to facilitate unconditional inferences (i.e., to make inferences about a population of studies larger than the set of observed studies, including studies that may not be identical to the ones observed). To do so, we conducted a meta-regression using a relatively new technique: robust variance estimation (RVE; Hedges et al., 2010; Tanner-Smith et al., 2016; Tanner-Smith & Tipton, 2014; Tipton & Pustejovsky, 2015), accomplished using the robumeta package (V. 2.0; Fisher et al., 2017) for R (V. 4.1.1; R Core Team, 2020). RVE accounts for nonindependent effect size contributions to the meta-analysis (i.e., multiple effect sizes from the same study, based on the same sample) without knowledge of within-study correlations.[4]

To use RVE, several parameters must be set. First, because we are using RVE to account for effect size dependencies that are primarily due to multiple experiments within a single article, we chose to use the correlated effects weight-type option within robumeta which accommodates for such dependencies of sampling error within a cluster (Tanner-Smith et al., 2016). The levels in our data set were therefore as follows: effect size estimates (Level 1), nested within individual experiments (Level 2), themselves contained within studies (Level 3). Next, due to the small number of research articles included in some analyses, we also used the available small sample size correction function within robumeta, as suggested by Tipton and Pustejovsky (2015). Then, between-study variance (tau-squared; τ^2) had to be estimated because we used random-effects meta-analysis. Doing so required setting ρ (rho) to an assumed constant correlation (Hedges et al., 2010); we used $\rho = .80$, as recommended by Tanner-Smith and Tipton (2014). However, as they point out, estimations of ρ only affect the precision of the estimates, not the validity of the confidence intervals, meaning that the cost of choosing an unsuitable value of ρ should be relatively unimportant. Indeed, varying the value of ρ from 0 to 1 led to no changes in any effect size estimates greater than an absolute value of 0.006. Finally, following the advice of many meta-analysis authors (Doncaster & Spake, 2018; Hedges, 1982; Hedges & Olkin, 1985; Hedges & Vevea, 1998; Marín-Martínez & Sánchez-Meca, 2010; Morris & DeShon, 2002), effect sizes were weighted by an approximation of the inverse variance method for random-effect models using the default weighted-least-squares estimation method in robumeta.

Our RVE meta-regression analysis consisted of three stages. First, we created an intercept-only model to determine the overall pooled enactment effect size (i.e., SPT vs. VT, IT, and EPT across all studies). Second, to assess the "classic" enactment effect size (only the effect of self-generated actions vs. a verbal task), we ran an intercept-only model with just SPT and VT data included (i.e., the

[2] To convert from d_{RM} to d_{IG}, a correlation from each within-subject study is required. However, because reporting of this correlation is very rare in the literature, we opted to use a standard correlation of $r = 0.5$ in this formula. When this specific correlation is used, the two effect size metrics become highly similar (Lakens, 2013). It is worth noting, however, that the removal of small sample bias is not as effective when applying Hedges' correction to effects based on d_{RM} (Cumming, 2012; Lakens, 2013).

[3] Although most studies provided raw means, many did not provide measures of variability like standard deviation (*SD*) or standard error (*SE*). For these studies, when possible, effect sizes were computed using the reported *t* or *F* values. However, even this was seldom possible because (a) test statistic values were not presented at all, (b) they were reported as "<1," (c) the statistic values were not reported for hit rate (our primary dependent variable), (d) the *F* values only represented broader main effects of encoding condition (across three or more levels), or (e) there was an interaction present. In these cases, we imputed standard deviations based on the average *SD* of each specific encoding task, calculated and applied separately for between-subjects and within-subject designs. For example, in a within-subject study using VT, we would impute the average *SD* for all VTs found in other within-subject studies.

[4] Traditionally, the problem of effect size dependency is solved rather unsatisfyingly either by picking a single most representative effect size from each study or by averaging across all effect sizes in a given study. Using RVE allows for multiple effect sizes to come from each study and even from the same sample. This method permits calculation of valid standard errors of point estimates, interval estimates, and significance testing without knowledge of dependent estimate correlations (Hedges et al., 2010). A recent simulation study found RVE to be on par with three-level meta-analyses (another approach to handling nonindependent effect sizes; Cheung, 2014, 2019). Both of these options lead to less bias than does the traditional method of averaging effect sizes to provide a single effect size contribution per study (Moeyaert et al., 2017).

"VT-only" model). Third, we formed intercept-less regression models for each experiment parameter variable fitted individually to determine which variables significantly moderated the size of the enactment effect, and whether each level of these moderators produced significant enactment effects. Finally, all variables were entered simultaneously into a "full" model; then, using a backward elimination strategy,[5] we trimmed down to a "final" model. The full model contained fewer overall studies (*m*) and effect sizes (*k*) because all moderators were entered simultaneously. Doing so necessitated that any missing moderator data disqualified an effect size from inclusion in the model (see Supplemental Appendix A for the number of entries with missing moderator data). The final model, on the other hand, included all of the effect sizes and studies because no data were missing in the remaining moderators.

During the third stage of our analysis, when moderator variables were entered into intercept-less regression models separately, we also enlisted the clubSandwich package (V. 0.5.3; Pustejovsky, 2021) for R to conduct omnibus *F* tests (Wald tests) to examine whether multiple related coefficients (i.e., the different levels of each moderator) differed from each other overall, while maintaining use of RVE. We then used the same package to conduct pairwise comparisons to assess whether the size of the enactment effect differed between specific levels of the moderators. Finally, to provide a better sense of heterogeneity in the data than that provided by τ^2 or I^2 alone, we used Formula 1 from IntHout et al. (2016) to form 95% prediction intervals around the meta-analytic effect size estimates.[6]

Assessment of Publication Bias and Data Structure

In any meta-analysis, it is important to assess the potential effects of publication bias and data structure in terms of normality and heterogeneity. To accomplish this, we used the metafor (V. 2.4-0; Viechtbauer, 2010) and PublicationBias (V. 2.2.0; Mathur & VanderWeele, 2020) packages for R. To analyze for any potential effects of publication bias, we turned to the traditional method of running Egger's regression and visually inspecting funnel plots. However, because these two methods have not been validated with the RVE technique, we enlisted new variants of these tests that do use robust statistics to account for nonindependent effects. Specifically, we used the "Egger Sandwich" function from Rodgers and Pustejovsky (2020). This function is a variation of the typical Egger's regression used to assess funnel plot asymmetry (Egger et al., 1997); the "sandwich" aspect refers to its use of cluster RVE methods called "sandwich estimators" that can handle data dependencies.

To accompany the Egger Sandwich regression statistic, we also created significance funnel plots (Mathur & VanderWeele, 2020) and publication-bias-corrected meta-regression estimates, both of which are also cluster-robust. The classic funnel plot has long suffered from misinterpretation (Terrin et al., 2005); significance funnel plots, on the other hand, still show the classic funnel pattern, but offer a regression line that denotes where studies with exactly $p = .05$ would lie. Studies to the right of the line therefore represent "affirmative" results that support the overall existence of an effect; those to the left are "nonaffirmative." This also allows for easy inspection of whether nonaffirmative studies have systematically lower effect size point estimates, which would be indicative of publication bias. To complement these funnel plots, we also include publication bias sensitivity plots and analyses that indicate what the average enactment effect size would be under varying levels of publication bias severity. Finally, to provide an overview of the structure of our data set, we also used metafor to create quantile–quantile (Q–Q) plots that allow for visual inspection of normality (although note that these plots could not be formed using cluster-robust methods). See our OSF repository for RVE-based forest plot graphs of the included behavioral and patient studies.

Next, we searched for statistical outliers in the data by using the metaoutliers() function from the altmeta (V. 3.3; Lin et al., 2021) package for R to calculate standardized residuals, identifying outlier data points as per the method described by Viechtbauer and Cheung (2010). Doing so revealed seven statistical outliers: five were positive effect sizes, two were negative effect sizes. All positive effect size outliers were studies that used VT as the comparison task, whereas the two negative effect size outliers used IT and EPT comparison tasks. There were no other obvious patterns of experiment moderators in the outlier data. We then reran all major analyses to assess whether any tests of statistical significance changed with the outliers removed; footnotes are used throughout the article to denote when this is the case. Because the pattern of results remained largely the same, we opted to retain the most data possible and kept outliers in the data set for the analyses presented below.

In summary, the robumeta and clubSandwich packages were used to conduct random-effects meta-regression with RVE, and the metafor and PublicationBias packages were used to assess publication bias. Our main results include an overall effect size across all of the data, an estimate of the "classic" enactment effect, individual moderator analyses, and multiple regression models that assess simultaneous moderator fit. For all analyses, positive effect sizes indicate better memory performance following enactment relative to a comparison task, whereas negative effect sizes indicate the opposite. Finally, 14 effects that were not derived from hit rates were excluded to allow for comparison across retrieval test formats, leaving 443 effects across 145 studies eligible for the meta-analysis.

Transparency and Openness

A listing of all studies captured in the literature search, tabulated separately for behavioral, neuroimaging, and patient studies, is available via the OSF: https://osf.io/f4ymv/. Our preregistered and updated coding guidelines and analysis plans are also listed there.[7] The raw data included in our meta-analyses of behavioral and

[5] In the backward elimination strategy to multiple regression, we started with the full model (all moderators entered simultaneously), then created subsequent "trimmed" models where moderators were removed one-by-one based on which had the highest omnibus *p*-value in the previous model. This process was repeated until a model was identified for which each remaining moderator was statistically significant at $p < .05$ (i.e., the "final" model). This is a recommended approach to multiple regression (Stahel, 2004) and has recently been demonstrated in numerous publications employing meta-regression (e.g., Pan & Rickard, 2018; Van den Bussche et al., 2009).

[6] J.E. Pustejovsky (personal communication, January 25, 2022) alerted us that while the τ^2 and *SE* values that can be used in this formula are based on RVE, the property of robustness does not extend to the prediction intervals they form if the working model was misspecified. Therefore, these intervals may not have the correct coverage.

[7] Certain aspects of the statistical plan found in our preregistration available on OSF differ slightly from the method that we employed in this article. Both the final and the preregistered analysis plans are available for comparison.

patient studies, the code used to conduct all analyses, and the resulting RVE-based forest plot graphs are also available on OSF. We followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009) guidelines and checklists when preparing the protocol, reporting our study selection process (see Figure 2), and writing the final report. Finally, highlighted brain regions from neuroimaging studies, including the *XYZ* coordinates used to form Figure 7, are also on OSF.

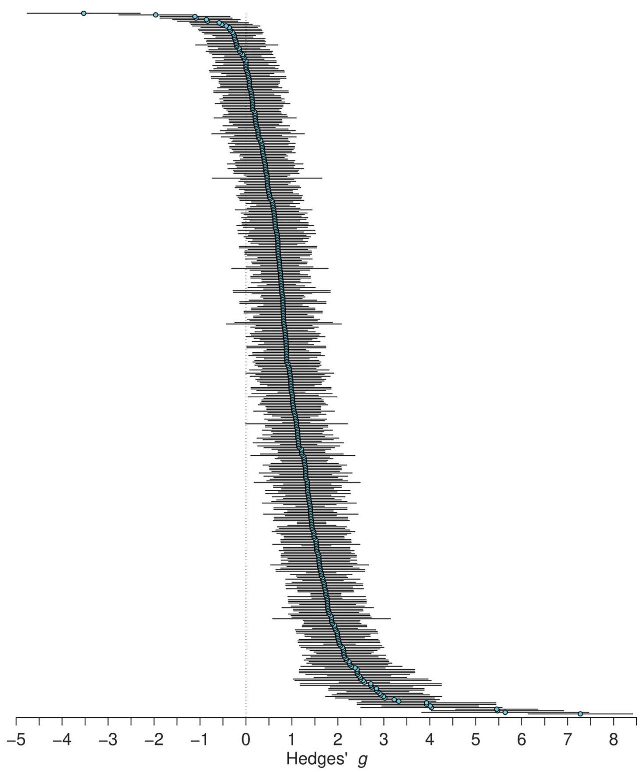
Meta-Analytic Results

Of the studies that we collected examining the enactment effect on episodic memory performance, 145 fit our inclusion criteria and contained enough information to be meta-analyzed (of these, 6 were translated from languages other than English). Comprising the set of eligible studies were data from 140 peer-reviewed research articles, three master's theses or doctoral dissertations, and two unpublished data sets. From these, we were able to enlist RVE techniques to extract 443 effect sizes while accounting for data clustering. There were on average 1.76 effect sizes per study ($SD = 1.12$, min = 1, max = 8). Studies were recorded from as far back as 1965, and from as recently as 2021, with more studies published in 2003 than in any other year ($m = 15$). As one might expect, the average sample size for the SPT condition in each entry ($M = 23.63$, $SD = 16.29$, min = 6, max = 101) was almost always identical to that of a comparison task condition ($M = 23.63$, $SD = 16.27$, min = 6, max = 101). Likewise, the average age of participant samples was similar for SPTs ($M = 26.65$, $SD = 8.69$, min = 18.52, max = 59.40) and comparison task conditions ($M = 26.66$, $SD = 8.68$, min = 18.70, max = 59.40). Finally, the proportion of male participants was equal across conditions: SPT, $M = 0.39$, $SD = 0.16$, min = 0, max = 1; comparison tasks, $M = 0.39$, $SD = 0.16$, min = 0, max = 1. Supplemental Appendix A reports these demographic characteristics broken down by moderator level. Supplemental Appendix B lists the frequencies and co-occurrences of moderator levels.

Random-effects meta-regression using RVE across all included studies (m) and effect sizes (k) found that the average pooled enactment effect size was large and robust, $g = 1.06$, $t(142) = 16.5$, $p < .001$, 95% CI [0.93, 1.18]. Filtered down to only cases where VT was the comparison task, the average "classic" enactment effect of reading versus self-generated action was also very strong and robust, $g = 1.23$, $t(120) = 17.9$, $p < .001$, 95% CI [1.09, 1.36]. See Figure 3 for an overview of all included effect sizes, ordered from smallest to largest.

Figure 3

A Caterpillar Plot of the Included Behavioral Effect Sizes



Note. CIs = confidence intervals. This caterpillar plot depicts all 443 of the included behavioral effect sizes (and their 95% CIs) in ascending order. Positive effect sizes indicate better memory performance following enactment relative to a comparison task, whereas negative effect sizes indicate the opposite. See the online article for the color version of this figure.

Publication Bias and Data Structure

To assess publication bias while maintaining robust variance estimates, we used the "Egger sandwich" analysis method (Rodgers & Pustejovsky, 2020). The result was significant, $B = 1.11$, $SE = 0.30$, $p < .001$, suggesting funnel plot asymmetry that could indicate publication bias. The asymmetry of published effect size estimates is also apparent in the upper left quadrants of the significance funnel plots in Figure 4. The unequal distribution of point estimates in Figure 4 demonstrates that there are many more affirmative effect sizes (significant and positive) than nonaffirmative ones (nonsignificant or negative) within the considered literature.

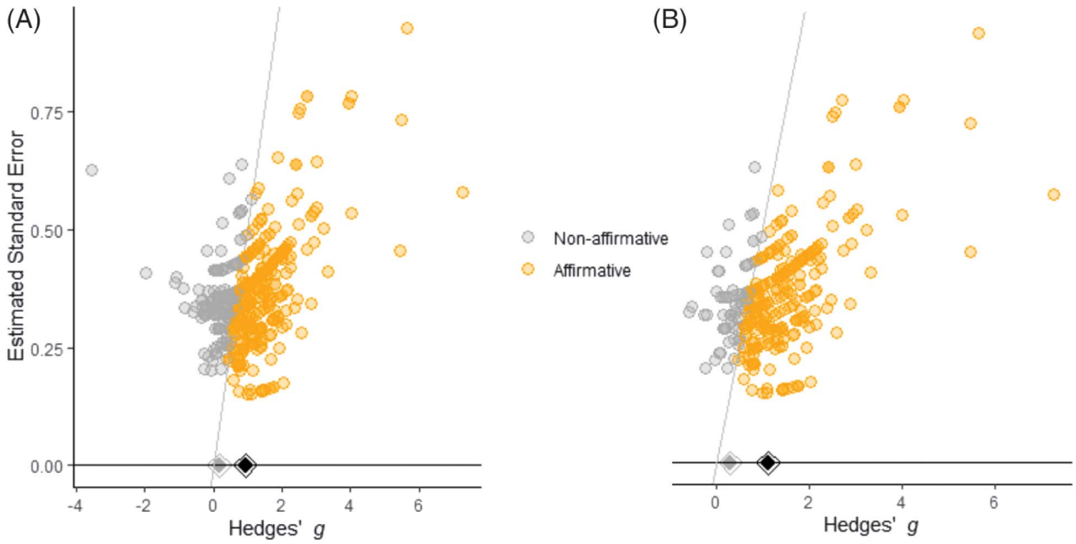
If publication bias is present, it would hardly be surprising. Mathur and VanderWeele (2020) suggested that within top psychology journals, articles that contain significant results are 4.7 (95% CI [1.94, 11.34]) times more likely to be published. With this in mind, we created a corrected meta-regression model assuming that the enactment literature suffers from an average amount of publication bias ($\eta = 4.7$). The resulting overall pooled effect size estimate was sharply attenuated, $g = 0.60$, $p < .001$, 95% CI [0.50, 0.70], as was the VT-only pooled effect size estimate, $g = 0.84$, $p < .001$, 95% CI [0.70, 0.97]. To accompany these analyses, Figure 5 presents sensitivity plots that show estimated effect sizes across varying degrees of publication bias. Even in extreme cases, where publishing a significant result is 200 times more likely than is publishing a null or undesired result, point estimates do not reach zero nor do their confidence intervals. In all cases of publication bias, then, the mean effect is expected to be robust.

Finally, to explore the structure of our data, we created Q–Q plots of the overall intercept-only model, the full model, and the final regression model. These plots, shown in Figure 6, indicate that, for the most part, the data in each model follow a normal distribution, except for "heavy tails" indicating some kurtosis in the extremes of each distribution and a right skew.

Publication bias has been a well-known problem for decades (Begg & Berlin, 1989; Dickersin et al., 1987), but some suggest that

Figure 4

Significance Funnel Plots for the Overall (A) and VT-Only (B) Intercept Models



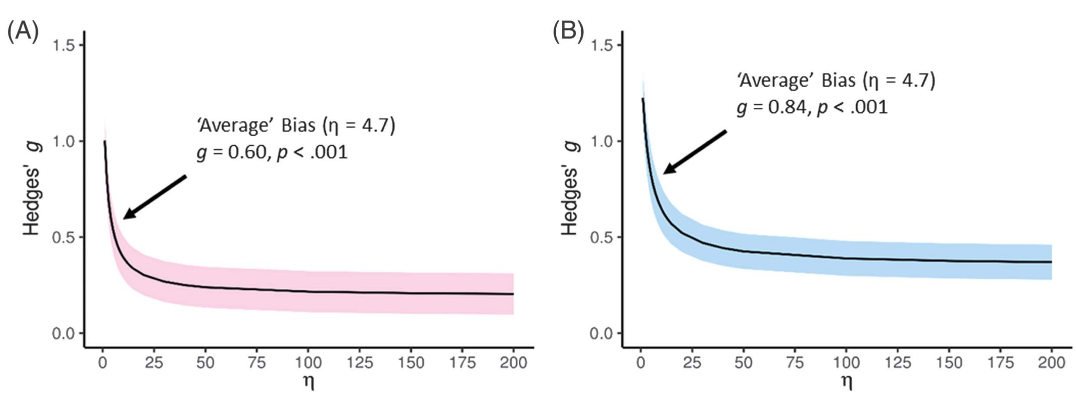
Note. VT = verbal task. Black diamonds represent the robust mean point estimates of the pooled effects across all studies. Positive effect sizes indicate better memory performance following enactment relative to a comparison task, whereas negative effect sizes indicate the opposite. Gray diamonds represent robust mean pooled estimates for only the nonaffirmative effects and therefore represent the estimate corrected for publication bias. Studies lying on the diagonal line have $p = .05$. See the online article for the color version of this figure.

it may have been more prevalent in the late 20th century (Ivanov et al., 2017; cf. Fanelli, 2012), precisely when the enactment effect literature was blooming. Nevertheless, corrected meta-analyses and sensitivity plots concur that, even with adjustment for cases of average or heavy publication bias, the enactment effect remains real.

Before discussing moderator effects, it should be noted that substantial heterogeneity is apparent in the data. While the prediction intervals presented in Table 4 should be viewed cautiously because they may not be cluster-robust (see Footnote 8), their widths temper interpretation of the meta-analytic point estimates that they are centered on. In meta-analyses, confidence intervals are typically used to quantify the accuracy of the estimated population-level effect size, whereas prediction intervals specify the range that a new observation (e.g., a primary study) would likely fall into (IntHout et al., 2016). Therefore, although confidence intervals can be used to determine statistical significance, prediction intervals normally are much wider because they encompass the range of possible effects rather than the population mean. A recent review concluded that

Figure 5

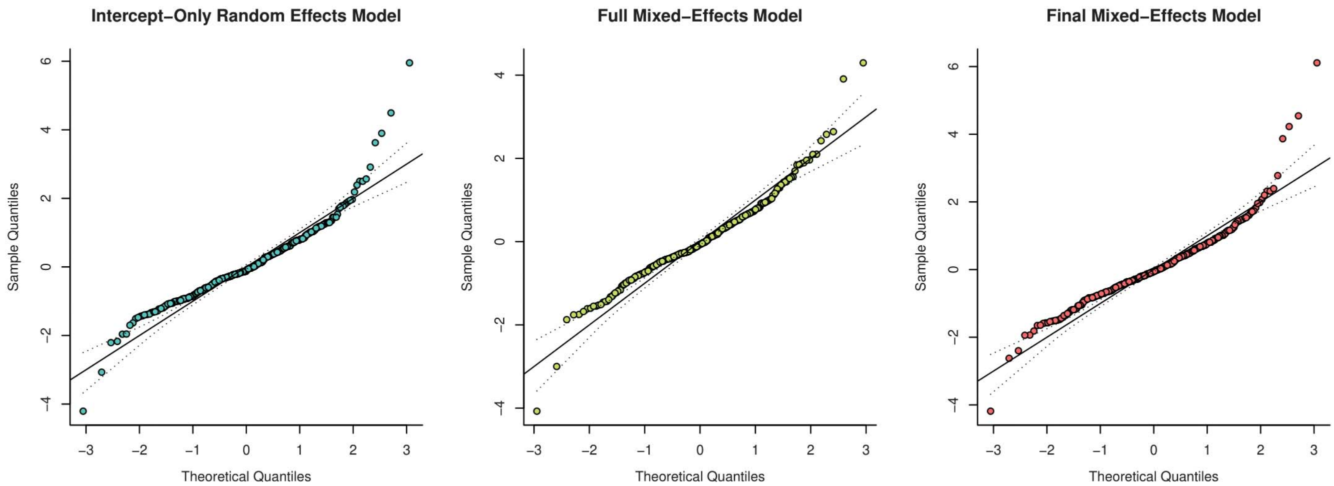
Publication Bias Sensitivity Plots for the Overall (A) and VT-Only (B) Intercept Models



Note. VT = verbal task; CIs = confidence intervals; RVE = robust variance estimation. Black lines represent mean effect size estimates; shaded areas around them represent 95% CIs. Positive effect sizes indicate better memory performance following enactment relative to a comparison task, whereas negative effect sizes indicate the opposite. Values of $\eta > 1$ represent varying degrees of positive publication bias. When $\eta = 1$, this is the "naïve" model assuming no publication bias, making it equivalent to our unadjusted RVE-based intercept estimates. See the online article for the color version of this figure.

Figure 6

Quantile–Quantile (Q–Q) Plots for the Intercept-Only, Full, and Final Regression Models



Note. See the online article for the color version of this figure.

80.2% of studies with continuous dependent measures (as is the case here) had prediction intervals that overlapped zero (IntHout et al., 2016). Consequently, meta-analyses that have prediction intervals crossing zero are not rare, but they are still important to consider, especially in the case of patient studies where the outcome of any new experiment could have ramifications for treatment outcomes (this point is discussed further in the Patient section).

Moderating Effects

In this section, we used meta-analysis to address the first six of our major questions (shown in Table 3) regarding potential moderating variables that have been manipulated across experiments: comparison task, test format, experimental design, learning instructions, use of objects, and test delay. This list of factors is, of course, not exhaustive, and some other factors have already been examined in the literature (e.g., list length in Steffens et al., 2015; age-related differences in Nyberg et al., 2002). Table 4 provides a breakdown of the influence of the six study factors as they were entered separately into random-effects meta-regression models with RVE. Here, we highlight moderators that were statistically significant at the $p < .05$ level.

Nonsignificant Moderators. As can be seen in Table 4, three of the six included moderator variables were statistically nonsignificant in single-variable regression models testing the omnibus effects: test format ($p = .810$), learning instructions ($p = .077$), and use of objects ($p = .901$). The meta-analytic results pertaining to these research questions—numbers 2, 4, and 5, respectively—will therefore only be reported in Table 4 and addressed qualitatively in the behavioral discussion. Statistically significant moderators, on the other hand, addressed by questions 1, 3, and 6, are further delineated with pairwise comparisons along with consideration of potential confounding factors.

Comparison Task. Variations in encoding tasks have direct implications for our understanding of broader multimodal encoding mechanisms. Therefore, we assessed whether effect sizes differed within the moderator "comparison task" (3 levels: VT, EPT, and IT).

Subject-Performed Task (SPT) Versus Verbal Task (VT). According to our meta-analysis (see Table 4), the omnibus F test provides evidence of joint significance across all levels of the comparison task variable, indicating that it is a significant moderator of the enactment effect. Breaking the moderator down into its constituent levels, when VT is the comparison task, the enactment effect is large and robust (i.e., the "classic" enactment effect; $g = 1.23$, $p < .001$). Pairwise contrasts showed that using VT as the comparison task leads to significantly larger enactment effects on average relative to when EPT ($p < .001$) or IT ($p = .001$) are used as comparison tasks. It remains possible, however, that the larger effect size observed when VT is the comparison task could reflect confounding from a correlated presence with other moderator variables. Study design, for example, could be contributing to this boost because VTs are more commonly used in within-subject designs that tend to elicit larger effect sizes (see Supplemental Appendix B).

Subject-Performed Task (SPT) Versus Experimenter-Performed Task (EPT). Quantitatively, our meta-analysis suggests that when EPT is the comparison task, the enactment effect is moderate and robust ($g = 0.51$, $p < .001$; see Table 4). However, we must again consider the potential for confounding between EPT and other moderator variables. In this case, the marked reduction in effect size seen when EPT is the comparison task could lead to other moderator effects being "pulled down" into nonsignificance. Supplemental Appendix B shows, however, that there are no cases in which a level of a moderator is more common alongside EPT, IT, or the combination of the two, relative to VT.

Subject-Performed Task (SPT) Versus Imagery Task (IT). Results from our meta-regression models indicate that the enactment effect persists when IT is used as the comparison task ($g = 0.54$, $p = .005$). But, as previously mentioned, this effect size is still significantly reduced relative to the classic enactment effect (i.e., using VT as the comparison task instead, $p = .001$; see Table 4).

Experimenter-Performed Task (EPT) Versus Imagery Task (IT). Comparing EPT and IT is uncommon in the literature, although this is a theoretically interesting contrast. It is possible that performing mental imagery (as in IT) is akin to EPT in that the two tasks might share comparable levels of motor visualization despite both lacking

Table 4

Intercept-Only and Moderator Models Using Robust Variance Estimation (RVE) With Moderators Entered Separately

Moderator variable	Analysis	*m*	*k*	*g*	95% CI	95% PI	*F* Omnibus	*F* Pairwise	*t*	*df*	*p*-value
	Intercept-only model	145	443	1.06	[0.93, 1.18]	[−0.35, 2.46]			16.5	142	$p < .001$
Comparison task	Omnibus *F*						17.3			2, 32.9	$p < .001$
	VT vs. EPT							25.7		1, 43.3	$p < .001$
	VT vs. IT							15.3		1, 16.3	$p = .001$
	EPT vs. IT							0.03		1, 23.8	$p = .870$
	VT	123	316	1.23	[1.09, 1.37]	[−0.07, 2.52]			17.25	112.7	$p < .001$
	EPT	33	98	0.51	[0.26, 0.76]	[−0.84, 1.86]			4.17	28.8	$p < .001$
	IT	17	29	0.54	[0.19, 0.90]	[−0.90, 1.98]			3.27	13.9	$p = .005$
Test format	Omnibus *F*						0.21			2, 61.9	$p = .810$
	Free recall vs. cued recall							0.22		1, 39.6	$p = .640$
	Free recall vs. recognition							0.18		1, 59.4	$p = .670$
	Cued recall vs. recognition							0.43		1, 54.6	$p = .515$
	Free recall	107	285	1.05	[0.92, 1.19]	[−0.37, 2.47]			15.43	97.5	$p < .001$
	Cued recall	33	69	0.98	[0.68, 1.28]	[−0.51, 2.47]			6.66	27.3	$p < .001$
	Recognition	42	89	1.11	[0.83, 1.39]	[−0.36, 2.59]			8.04	35.3	$p < .001$
Study design	Omnibus *F*						18.1			1, 137	$p < .001$
	Within-subject	89	233	1.27	[1.09, 1.45]	[−0.08, 2.63]			11.0	81.4	$p < .001$
	Between-subjects	75	210	0.79	[0.65, 0.93]	[−0.56, 2.14]			14.0	68.9	$p < .001$
Learning instructions	Omnibus *F*						3.09			2, 14.1	$p = .077$
	Intentional vs. incidental							0.03		1, 21.7	$p = .868$
	Intentional vs. implied							6.56		1, 6.71	$p = .039$[a]
	Incidental vs. implied							2.92		1, 9.99	$p = .118$
	Intentional	100	322	1.03	[0.87, 1.19]	[−0.42, 2.49]			12.71	95.83	$p < .001$
	Incidental	18	36	1.00	[0.59, 1.40]	[−0.60, 2.60]			5.19	15.84	$p < .001$
	Implied	8	20	0.56	[0.15, 0.97]	[−1.26, 2.39]			3.37	6.05	$p = .015$
Use of objects	Omnibus *F*						0.11			2, 8.65	$p = .901$
	None vs. viewed							0.18		1, 3.45	$p = .695$
	None vs. touched							0.04		1, 83.5	$p = .840$
	Viewed vs. touched							0.23		1, 3.66	$p = .658$
	None	85	224	1.02	[0.89, 1.14]	[−0.25, 2.29]			15.68	79.09	$p < .001$
	Viewed	5	10	1.18	[0.01, 2.35]	[−1.09, 3.45]			3.10	3.22[b]	$p = .049$
	Touched	47	130	0.99	[0.74, 1.24]	[−0.32, 2.29]			7.98	42.14	$p < .001$
Test delay	Omnibus *F*						4.15			1, 139	$p = .044$[c]
	Immediate	85	223	0.93	[0.80, 1.07]	[−0.49, 2.36]			13.9	77.7	$p < .001$
	Delayed	82	205	1.19	[0.97, 1.41]	[−0.25, 2.63]			10.9	73.1	$p < .001$

Note. m = number of studies included in analysis; k = number of effect sizes included in analysis; g = meta-analytic point estimate of effect size Hedges' g; 95% CI = confidence intervals; 95% PI = prediction intervals that estimate where true effects are expected to be for 95% of similar future studies (Borenstein et al., 2017); df = adjusted degrees of freedom; VT = verbal task; EPT = experimenter-performed task; IT = imagery task. Omnibus F values determine whether a variable is a significant moderator by testing whether effect sizes vary overall across its levels. Therefore, omnibus F tests for moderators with only two levels test whether the levels differ from one another. For moderators containing more than two levels, pairwise comparison F tests (denoted by "vs.") were conducted. t-statistics here assess whether each level of a moderator is significant by itself (i.e., that it differs from zero). Positive effect sizes indicate better memory performance following enactment relative to a comparison task, whereas negative effect sizes indicate the opposite.

[a] This difference was no longer statistically significant when outlier data were removed ($p = .055$). [b] Because $df < 4$, we also tested the omnibus F with this level removed, but it remained nonsignificant (additionally, due to the df, significance for this t-test should be determined at the $p < .01$ level). [c] This difference was no longer statistically significant when outlier data were removed ($p = .056$).

physical motor action by the participant. Supporting this idea, our meta-analysis revealed no significant difference in the size of the enactment effect (comparison task vs. SPT) when EPT is used relative to IT ($p = .870$; see Table 4).

Study Design. We compared effect sizes within the moderator "study design" (two levels: within-subject and between-subjects). In our meta-analysis, an omnibus F test presented in Table 4 provides clear evidence that study design is indeed a significant moderator of enactment effect size ($p < .001$). The enactment effect is reliably demonstrated in both within-subject ($g = 1.27$, $p < .001$) and between-subjects ($g = 0.79$, $p < .001$) designs but is significantly larger when a within-subject study design is used.[8] The enactment benefit is thus reliable regardless of experimental design but joins other encoding techniques (e.g., the production effect; Fawcett, 2013; MacLeod et al., 2010) in showing a smaller effect when the key manipulation takes place in a between-subjects context.

It is still possible that these effects were observed because study design has been conflated with the comparison task moderator. For instance, the VT task is more often used in within-subject designs than in between-subjects designs (179 vs. 137 instances; see Supplemental Appendix B); inversely, the EPT task (leading to smaller effect sizes in general) is more common in between-subjects designs than in within-subject designs (59 vs. 39 instances). Unmatched frequencies of co-occurrence between the comparison task and study design moderators could be leading to effect size inflation such that within-subject designs *look* like they produce bigger effect sizes, but the difference could actually be driven—at least in part—by VT leading to larger effect sizes than EPT, and VT simply co-occurring more often with within-subject designs.

Test Delay. We compared effect sizes within the moderator "test delay" (two levels: immediate and delayed). In our meta-analysis, we recorded the test delay time between encoding and retrieval in each included study. That roughly half the literature used immediate testing with no delay meant that we could not statistically compare the variable continuously. Therefore, we dichotomized our analysis by classifying studies as either "immediate" or "delayed," the latter including test delays equal to or longer than 30 s.

Meta-analysis of test delay as a binary variable revealed a significant influence on effect size ($p = .044$; see Table 4). Note, however, that this difference was no longer statistically significant when outlier data were removed ($p = .056$). The enactment effect was reliable whether tests were administered immediately following learning ($g = 0.93$, $p < .001$), or they were delayed ($g = 1.19$, $p < .001$), but the omnibus F test implies that enactment effects may be larger on average when a retention interval is present relative to when it is absent. Due to the unavoidable dichotomization of our test delay variable, and acknowledging that this effect is nearing nonsignificance, some support may exist for the view that the size of the enactment effect is largely insensitive to test delay. However, if this moderator were to be truly statistically significant, one could be reasonably confident that it is *not* because one of its levels is correlated with use of the VT comparison task in studies (which, as reported earlier, tends to lead to the largest effects): There are exactly the same number of instances of VT within each level of this moderator (see Supplemental Appendix B).

Full and Final Regression Models

In an attempt to determine the amount of variance explained by all potential moderators, we created a full model, entering all study factor variables into the model simultaneously. We then used a backward elimination strategy to trim the least significant moderator (i.e., highest p-value) until we arrived at a final model that contained only significant moderators (see Table 5).

The full model ($m = 99$, $k = 313$) indicated an R^2 of 0.29, which signifies that including all moderators at once explains a large amount of variance (Cohen, 1988). However, the model still retained substantial between-study variance that cannot be explained by sampling error, $I^2 = 77.25$ (Higgins et al., 2003). Starting from this full model, our backward elimination strategy resulted in the following nonsignificant moderators being removed in each subsequent "trimmed" model, in order: use of objects ($p = .957$), test format ($p = .824$), learning instructions ($p = .362$), and test delay ($p = .087$). The final model contained only two remaining significant moderators: comparison task and study design. Nevertheless, the final model ($m = 145$, $k = 443$) indicated an R^2 of 0.22, which demonstrates that including only significant moderators still explains the majority of variance seen in the full model (Cohen, 1988), though heterogeneity persisted in the final model, $I^2 = 78.27$.

Overall, moving from a full model to the final model resulted in $\Delta R^2 = -0.07$, suggesting that the trimmed moderators did account for some variance in memory performance outcomes. That significant between-study heterogeneity persists in both models could indicate that some unstudied experiment parameter(s) account(s) for a considerable portion of variance. Alternatively, the high between-subjects variance in the models could also simply be the symptom of a wide array of effect sizes with varying point estimates and standard errors. The latter explanation seems most plausible given the variation in effect sizes stemming from our inclusion of different comparison tasks (i.e., VT, EPT, and IT) in the data set.

Discussion of Behavioral Studies

In the meta-analytic review of behavioral studies, we sought to address the first six of our eight major research questions (see Table 3). Our random-effects meta-regression of behavioral enactment studies evaluated evidence from 145 studies resulting in 443 effect sizes. RVE was used to account for data clustering and dependency stemming from nonindependent effect sizes. Clearly, the enactment effect is large and robust. The "classic" enactment effect (motoric > verbal encoding) was unsurprisingly larger than the "overall" meta-analytic effect size estimate that included other, more potent comparison tasks (EPT and IT). Cluster-robust analyses revealed a high probability of publication bias in the enactment literature. Sensitivity analyses, however, showed that neither the size of the effect nor its confidence interval was expected to reach zero, even in extreme cases of publication bias.

Individually fit and simultaneously fit regression analyses assessing study parameters as potential moderators were aligned, clearing up some uncertainty that persisted in the literature. Although relatively stable in the face of a variety of other manipulations, the size of the enactment effect is reliably influenced by study design and comparison task. Relative to the enactment condition—that is, the SPT—the three most common comparisons tasks—EPT, IT, and VT—are inherently different and really should be treated as

[8] Because we transformed from within-subject to between-subjects effect size metrics in our statistical procedure, it is possible that the significant moderation from study design observed here is due to statistical bias in that process.

Table 5
Full and Final Regression Models Using Robust Variance Estimation (RVE) With Moderators Entered Simultaneously

Model	Regression variable	*m*	*k*	*F*	*df*	*p*-value	I^2	τ^2	R^2
Full model	Intercept	99	313				77.25	0.35	0.29
	Comparison task	118	313	10.90	2, 17.3	$p < .001$			
	Test format	124	313	0.27	2, 31.1	$p = .766$			
	Study design	113	313	1.40	1, 64.44	$p = .054$[a]			
	Learning instructions	106	313	0.95	2, 12.5	$p = .412$			
	Use of objects	113	313	0.04	2, 6.59	$p = .957$			
	Test delay	118	313	0.72	1, 59.55	$p = .601$			
Final model	Intercept	145	443				78.27	0.39	0.22
	Comparison task	145	443	19.40	2, 32.8	$p < .001$			
	Study design	145	443	2.09	1, 135.1	$p < .001$			

Note. m = number of studies included in analysis; k = number of effect sizes included in analysis; *df* = adjusted degrees of freedom. Omnibus F values determine whether a variable is a significant moderator by testing whether effect sizes vary overall across its levels. The *df* for each level of each moderator was greater than 4, except in the case of the "viewed" level of the Use of Objects variable (removing this level from the analysis made no difference; the moderator was still nonsignificant).
[a] When outlier data were removed, this variable was statistically significant ($p = .008$).

theoretically interesting comparisons instead of as different variations on a potential "baseline" control task. Next, we discuss how the results of the meta-analysis align with a qualitative review of the literature.

RQ1: Does the Form of Enactment Matter in Determining Whether a Memory Benefit Will Occur (i.e., Real vs. Imagined; Performed vs. Viewed)? How Do the Three Most Common Comparison Tasks (VT, EPT, and IT) Relate to the Classic Enactment Task (SPT)?

By investigating the effects of distinct encoding tasks, we can determine the relative contributions of different physical and mental aspects of enactment. Further, we can explore whether these aspects are additive or synergistic in their contribution to enactment.

Subject-Performed Task (SPT) Versus Verbal Task (VT). A long-standing idea is that the memory boost provided by enacting a word or phrase (an SPT) relative to reading it (a VT) stems directly from the ability of the motor component to facilitate mental imagery (Saltz & Donnenwerth-Nolan, 1981). Enacting may invite imagery, and it is this imagery that benefits memory—a kind of mediator effect (see Baron & Kenny, 1986). Considerable weight has been placed on the importance of this motor/imagery component, a type of dual-coding explanation when coupled with memory for the word itself (Cohen, 1989a; Engelkamp & Zimmer, 1985; Saltz, 1988). Nevertheless, certain experimental manipulations, such as context reinstatement (Mandler, 1980), have been shown to affect SPTs and VTs similarly (Sahakyan, 2010). The consistency in the literature of better memory following SPT than VT is hard to overstate: Of 443 effect sizes recorded in our meta-analysis, only a single experiment has reported a significant reversed enactment effect (VT > SPT; Li & Wang, 2018), and that lone finding should be viewed with caution because we had to rely on machine translating it to English before interpretation.

In assessing each different permutation of SPT and VT employed at encoding and retrieval, Kormi-Nouri et al. (1994) found that whereas a typical enactment effect did occur (motor encoding > verbal encoding, both using verbal retrieval), there was no reported enactment benefit when action was implemented only at retrieval (verbal encoding and motor retrieval). Perhaps more critically, "dual enactment" (motor encoding and motor retrieval) resulted in no greater benefit to memory than that already seen in the normal SPT condition (motor encoding and verbal retrieval), suggesting that the enactment effect is largely encoding-based.

Subject-Performed Task (SPT) Versus Experimenter-Performed Task (EPT). The motor component of the enactment effect has been touted as the critical component underlying the memory boost, yet there has been disagreement as to whether the performer of the action—participant or experimenter—is critical. Despite VT and EPT sharing the same semantic verbal basis, EPT also invokes sensory information from seeing the action performed. Cohen (1981, 1983; Cohen et al., 1987) reported that SPTs improved memory consistently relative to VTs but that EPTs often led to memory performance on par with SPTs. In sharp contrast, Engelkamp and Zimmer reported that SPTs were consistently better remembered than EPTs (e.g., Engelkamp & Zimmer, 1983, 1985; Zimmer & Engelkamp, 1996).

Common coding theory (Chandrasekharan et al., 2010; Tye-Murray et al., 2013; van der Wel et al., 2013) could help to explain why studies sometimes find that EPTs lead to effects similar to those of SPTs. This theory postulates a shared representation for perception and action, such that performing an action activates the perceptual concept tied to that action and, similarly, that perceiving an event activates action schemas related to that event (Prinz, 1984). For enactment, this implies that seeing the experimenter perform an action—as opposed to performing the action oneself—can lead to similar motor activation in the participant. This would be consistent with the suggestion by Ping et al. (2014) that one's own motor system is activated when simply viewing another person gesturing.

A distinction must be made regarding the encoding benefits that follow from seeing an experimenter perform an action, from imitating the experimenter, and from self-generation of an action to the same word/phrase. Zimmer and Engelkamp (1996) showed that whereas *watching* an experimenter perform an action led to better memory than verbal encoding, the memory benefit of watching did not differ significantly from the memory benefit gained by *imitating* the experimenter. In contrast, when a participant *self-generated* an action in response to a phrase (i.e., the typical SPT), memory was superior to watching and imitating an experimenter. Moreover, when the same participant watched an experimenter perform after their own self-generated action had taken place, there was no additional benefit to memory. Thus, it has been shown that self-generated action leads to better memory than does watching or imitating.

Quantitatively, our meta-analysis suggests that when EPT is the comparison task, the enactment effect is moderate and robust. It would be easy to attribute this SPT–EPT performance discrepancy purely to a difference in motor action. However, in their review, Steffens et al. (2015) summarized work to date that measured memory performance following SPT and EPT conditions. They argued that SPTs likely facilitate item-specific processing which can lead to enhanced performance on recognition tests, whereas EPTs boost item-relational processing, such that participants' memory performance should be comparable on tests of free and cued recall (Steffens et al., 2015). Further, they argued that in mixed lists containing EPT and SPT tasks, memory performance tends to be best for the SPT items, whereas in pure-list designs, SPT and EPT are often equivalent. Thus, when the two tasks are pitted against each other, SPT versus EPT enactment effects emerge more often in cases of recognition testing (pure and mixed lists) or in cases of recall testing with mixed lists. When studies employ pure-list designs followed by recall testing, however, SPT and EPT are often equivalent (Steffens et al., 2015). Zimmer and Engelkamp (1996) argued, in contrast, that the patterns observed for EPT and SPT may be more a function of who generates the action plan than who performs it or how it is tested.

Overall, then, the enactment effect literature has shown that self-performance of a task often leads to better memory than does watching others perform. However, the question remains open as to whether this difference is qualitative or quantitative in nature. That is, it is still unclear whether EPT leads to processing at encoding that is similar to that of a typical SPT—just to a lesser extent—or whether the underlying mechanisms are actually distinct.

Subject-Performed Task (SPT) Versus Imagery Task (IT). SPT versus IT represents a "mixed bag" of findings. Some have reported a significant enactment effect with SPT better than IT (e.g., Guttentag & Hunt, 1988; Saltz & Dixon, 1982; von Essen & Nilsson, 2003); others have reported no difference (e.g., Bäckman & Nilsson, 1985; Foley et al., 1991; Kormi-Nouri, 2000; Steffens et al., 2009). One study even showed a significant benefit of IT over SPT when an interference task co-occurred (Saltz & Donnenwerth-Nolan, 1981).

Kormi-Nouri (2000) tested sighted participants in free-viewing versus blindfolded conditions and compared their performance to that of blind participants. He found that IT led to superior memory in free-viewing participants, but not in blindfolded or blind participants. Given reports that mental imagery ability remains intact in blind individuals (e.g., Vecchi, 1998), it is unlikely that this difference between groups was due to discrepancies in mental imagery of actions. Using a divided attention paradigm, Saltz and Donnenwerth-Nolan (1981) demonstrated a double dissociation such that a secondary motor task interfered with memory for SPT items but not for IT items, whereas a secondary imagery task interfered with memory for IT items but not for SPT items, consistent with SPT and IT encoding relying on different underlying mechanisms.

Is the enactment benefit due purely to activation of a separate cognitive motor system then? Not likely: Movements that are semantically associated with a given item but are not physical emulations (e.g., sign language) have been shown to boost memory performance on par with SPTs (Zimmer & Engelkamp, 2003). Critically, however, performing entirely unrelated actions does not improve memory beyond simple verbal rehearsal (Daprati et al., 2005; Sivashankar & Fernandes, 2022; Zimmer & Engelkamp, 2003). The motoric aspect of enactment is therefore thought to differ qualitatively from a purely kinesthetic (i.e., the movement of an item in space) component of action (Zimmer & Engelkamp, 1985). Results from our meta-regression models indicate that the enactment effect persists when IT is used as the comparison task, which is inconsistent with claims that physical motor action is inconsequential to the enactment effect. Some argue, however, that there is no motoric memory component in enactment; rather, motor activation is needed to execute the actions but is not critical for memory enhancement to occur (Helstrup, 2005).

That imagery improves memory relative to a simple verbal task suggests that action planning or generation contributes substantially to the enactment-related memory boost. Related work has also suggested that the boost from imagining oneself performing an action is separable from the boost due to sensorimotor stimulation from simply reading action words (i.e., the embodiment effect; Sidhu & Pexman, 2016). Genuine motoric planning—and, perhaps, the execution of real associated actions—could be the factors accounting for why SPTs result in better memory than either ITs or entirely unrelated motor activity.

Experimenter-Performed Task (EPT) Versus Imagery Task (IT). Although our meta-analysis demonstrated that the size of the enactment effect does not differ when EPT is the comparison task relative to when IT is, articles contrasting these two tasks have reported inconsistent patterns (even within the same study; Foley et al., 1991). Contrasting encoding conditions that manipulate who the imagined "performer" is (the participant or the experimenter) has revealed inconsistencies that may stem from varying test types. Imagining oneself versus another person performing can lead to similar performance on free recall tests, but not on cued recall tests, where imagining others can actually aid memory further (Denis et al., 1991; Engelkamp et al., 1989). This finding maps well onto the item-specific versus item-relational distinction discussed earlier (Engelkamp, 1998; Hunt & Einstein, 1981). That is, it seems possible that SPT and self-imagery provide better item-specific information, whereas EPT and other-imagery provide better item-relational information which is more critical on tests of cued recall. Thus, test format is an important factor to consider when contrasting self- versus other-centric memory boosts, both in the case of real action (SPT vs. EPT) and in the case of imagined movements (self-imagery/IT vs. other-imagery).

RQ2: Does the Enactment Benefit Manifest Differently Across Free Recall, Cued Recall, and Recognition Memory Tests? How Does Enactment Unfold at the Time of Retrieval?

As alluded to previously, the type of retrieval test is of theoretical relevance in any enactment study—indeed in any memory study. Distinct types of processes (e.g., item-specific vs. item-relational) may interact with type of retrieval test. The broader memory literature suggests that recognition tests result in larger memory effects than do free recall tests (Hollingworth, 1913; Kintsch, 1968), although cases exist where this does not hold true (Mulhall, 1915; Tulving & Thomson, 1973). Our meta-analysis suggests that the enactment effect is large and robust in all of the included testing formats, but that the size of the effect remains stable across them. Of course, comparing these test types leads to a substantial "apples and oranges" problem in assuming that they are on the same scale.

For example, many studies have found what appears to be a stronger enactment effect when using recognition tests as opposed to recall tests (e.g., Engelkamp & Krumnacker, 1980; Mohr et al., 1989; Steffens et al., 2015). A comparison by Mohr et al. (1989) showed that whereas the enactment effect is present in both free recall and recognition testing, the latter results in a larger effect size primarily due to lower false alarms in the SPT condition. Because of these studies, caution is advised when drawing conclusions from our meta-analysis comparing retrieval test types, due to the likelihood of inherent processing differences between the formats. Moreover, in trying to make the test formats more comparable, we only explored effects on hit rate in our meta-analysis (*not* on false alarms, overall accuracy, or memory sensitivity). Although hit rates are numerically comparable between test formats, the introduction of false alarm rates or differences in underlying cognitive processes could very well change the overall story if accuracy or memory sensitivity is the outcome measure of interest.

Recognition testing is thought to be based primarily on item-specific processes (Hunt & Einstein, 1981), suggesting that hit rates should increase with this test format. Presumably, item-specific processing benefits both recollection and resistance to false memories (McCabe et al., 2004) such that hit rate mechanisms are similar in free recall and recognition, but item-specific processing on recognition tests has the additional benefit of reducing false alarms. Indeed, similar mnemonics such as the generation effect have previously been explained in terms of enhanced item-specific processing of generated stimuli leading to increased distinctiveness that aids their retrieval relative to read items (Gardiner & Hampton, 1985, 1988). From a broader perspective, it seems plausible that the information encoded via multimodal techniques like enactment benefits from the enhanced details of individual study items, which of course also aid in the rejection of similar-appearing lure items.

RQ3: Does the Enactment Effect Occur Regardless of Experimental Design (i.e., in Both Within-Subject and Between-Subjects Designs)? Does the Size of the Effect Differ Between Designs?

Here, study design refers to whether encoding task was manipulated between-subjects (each participant underwent only SPT *or* only one comparison task) or within-subject (each participant experienced both SPT *and* at least one comparison task). Study design is an important variable to examine when discussing methods of encoding. To illustrate, the generation and bizarreness effects easily found in within-subject designs are diminished (or often eliminated) in between-subjects designs (McDaniel & Bugg, 2008).

Whether the enactment effect occurs between subjects also has direct implications for a potential role for distinctiveness in the memory benefit. For instance, Engelkamp and Zimmer (1994) found that memory for SPTs was reduced when lure items on a recognition test were conceptually similar, but especially when lures were also motorically similar. These results suggested to them that SPTs benefit from distinctive motor information gained via action. Although many researchers have reported that enactment produces a benefit even when using a between-subjects design (e.g., Arar et al., 1993; Bäckman et al., 1986; Engelkamp & Jahn, 2003), others have found less consistent results (e.g., Bäckman & Nilsson, 1985; Engelkamp & Dehn, 2000; Steffens et al., 2009). Direct explorations of study design often show an expected reduction in enactment effect size following a switch from a within-subject to a between-subjects design (Engelkamp et al., 1993; Engelkamp & Seiler, 2003; Steffens et al., 2009). Indeed, our meta-analysis confirmed that whereas the enactment effect is reliably demonstrated in both within-subject and between-subjects designs, it is significantly larger in the former.

One potential explanation for the different results due to study design is that of a distinctiveness advantage (Hunt, 2013) for SPTs: The enactment effect is most prevalent when tasks are either intermixed at encoding or at least available for comparison such that the most interesting or distinct encoding task (often, the SPT) stands out as important to remember. McDaniel and Bugg's (2008) item-order hypothesis offers a different explanation. Their idea is that for pure lists, sequence information—a form of relational processing—is routinely encoded for the more common type of processing (e.g., reading) but not for the more novel type of processing (e.g., enactment). In mixed lists, however, that order information cannot be encoded because the conditions are randomized, so the more common type of processing suffers but the more novel type does not, increasing the memory difference between the conditions. This account explains findings that distinctiveness cannot, such as that an SPT advantage is often found for pure lists when using recognition tests but not free recall tests (Engelkamp & Dehn, 1997).

It is important to emphasize the finding that enactment does benefit memory in both designs because this is not typical for mnemonic encoding tasks. Related effects such as the generation (e.g., Hertel, 1989) and production (e.g., MacLeod et al., 2010) effects can disappear when using between-subjects designs. That the enactment benefit is routinely found in between-subjects designs implies that it likely does not occur simply due to distinctiveness. However, the significant difference in effect size magnitude between the two designs leaves open the possibility that in a within-subject context, there are benefits of both multimodal encoding and distinctiveness, whereas in a between-subjects context, only a benefit of multimodal encoding is realized. Enactment, therefore, may share additive properties of "distinctiveness" and "strength," similar to those argued to operate in the production effect (Fawcett & Ozubko, 2016; MacLeod et al., 2010; MacLeod & Bodner, 2017). The broad implication is that similar encoding tasks could benefit from the same underlying mechanisms but to varying degrees.

RQ4: Does Intentionality of Encoding Matter for the Enactment Effect (i.e., Does the Effect Occur Under Both Intentional and Incidental Learning Conditions)?

The intentionality of encoding has long been studied as a potential moderator of memory (Arciuli et al., 2014; Craik, 1977; Hyde & Jenkins, 1969, 1973; Neill et al., 1990; Saltzman, 1953), usually by contrasting intentional and incidental learning instructions (see McLaughlin, 1965, for a review). In intentional learning, participants are forewarned of the upcoming memory test before any encoding occurs; in incidental learning, they are not. Intentional encoding promotes the use of more explicit memorizing strategies

(Eagle & Leiter, 1964). Because the strategy employed when using a mnemonic technique can interact with intentionality, it is important to observe whether enactment manifests under varying levels of deliberateness to infer the amount of cognitive control required to gain a memory benefit. We also considered one more level of learning instructions in the meta-analysis: "implied." Here, despite no forewarning of a later memory test, participants experience multiple study–test cycles and so become aware after the first test that any subsequent studying would likely also be tested. Our meta-analysis revealed that the enactment effect is reliable in cases of intentional, incidental, and implied learning instructions, and that the size of the effect is relatively stable across these encoding formats.

In enactment studies, intentional learning instructions have been the primary method of choice. Qualitatively, several studies have confirmed an enactment effect regardless of whether instructions are intentional (e.g., Bäckman & Nilsson, 1991; Watanabe, 2003; Zimmer & Engelkamp, 1999) or incidental (e.g., Cohen et al., 1987; Guttentag & Hunt, 1988; Wippich & Mecklenbräuker, 1995). So far, no enactment study has pitted intentional and incidental encoding against each other, although Cohen (1981) did compare an immediate intentional test to a delayed incidental test of the same material, finding a significant enactment effect on both recall tests. He suggested that because memory does not show primacy for SPT, it could be that active encoding strategies (e.g., rehearsal) commonly used with words are not used with actions. In our meta-analysis, we considered whether the enactment advantage is reliably affected by intentionality of encoding, targeting the question of whether there are potential contributions of nonstrategic mechanisms at work in enactment. More generally, enactment may provide an example of enhanced encoding that can occur without explicit awareness or strategy, suggesting that the benefits of some multimodal techniques can arise implicitly.

RQ5: Does the Inclusion of Real Objects in SPTs Influence the Size of the Enactment Effect?

The use of a real-world object when performing an action is presumably one way to weave rich multisensory information into episodic memory. Yet debate persists on the efficacy of object use in improving memory beyond that gained by simply pantomiming an action. By comparing memory performance with and without objects, we can extrapolate whether multisensory encoding factors (e.g., tactile feedback) offer unique contributions to multimodal encoding more generally. Indeed, it has been conjectured that, relative to not having an object, the use of meaningful real-life objects offers a more realistic concrete prop when producing an action (Bäckman & Nilsson, 1991, 1985) and consequently leads to improved memory. This aligns with intuition, as the additional encoding of tactile and visual information from interacting with an object might reasonably be expected to enrich memory for the action.

In fact, though, numerous studies that have directly compared object to no-object conditions have found that inclusion of objects did not enhance the enactment benefit (Kormi-Nouri, 2000; Nyberg et al., 1991). These findings stand in opposition to Bäckman et al.'s (1986) early theory that the enactment effect results from a rich multimodal experience at encoding due to object details. Indeed, research measuring the influence of these "extra-environmental" objects has found that actions with objects do not improve memory beyond pantomimed enactment (e.g., Cohen, 1981; Cohen et al., 1987). The results of our meta-analysis align with the latter findings that objects are largely inconsequential to the enactment benefit: Use of objects at encoding was found to have no significant bearing on the size of the effect.

Presenting real objects during VT has been found to improve memory, though, even more than any small parallel boosts seen in SPTs (Engelkamp & Zimmer, 1997; Lieberman & Culpepper, 1965). However, doing so still does not boost VT performance to the level of enactment itself (at least when SPTs also use objects). Interestingly, while the study of enactment has largely moved away from using real objects, in gesturing, there is ongoing debate concerning whether external objects play a cognitively beneficial role (Ping & Goldin-Meadow, 2010).

Others have sought to determine whether different *types* of objects make a meaningful difference. Nyberg et al. (1991) classified objects and compared them: real objects that were interacted with (e.g., "bounce the ball"), body parts used for an action (e.g., "tap your finger"), objects in the scene (e.g., "point at the ceiling"), and objects from a common category (e.g., kitchen utensils—"turn the fork"). Strikingly, action sequences that did *not* involve physical interaction with external objects (i.e., "point at the ceiling," "tap your finger") were better remembered than those that did (i.e., "bounce the ball," "turn the fork"; Nyberg et al., 1991). Similar to Cohen (1981), Nyberg et al. concluded that external object manipulation does not play an important role in the enactment benefit.

How can encoding theoretically benefit from multiple modalities but not gain an additional boost through added sensory information stemming from real objects? Consider converging evidence from related literature. In the drawing effect, directing participants to add more detail to their writing relative to their drawing did not decrease the benefit of drawing, and severely limiting the time allowed for drawing (and therefore limiting the possible detail) still resulted in enhanced performance relative to writing (Wammes et al., 2016). Moreover, both the production (MacLeod et al., 2010) and enactment (Cohen, 1981; Zimmer & Engelkamp, 1999) effects gain little additional benefit from conceptual levels-of-processing orientations, especially relative to the large benefits seen in verbal conditions with the same manipulations present.

Clearly, many multimodal encoding strategies do not benefit substantially from an increase in encoded detail. We therefore speculate that the richness of multimodal encoding may outweigh any additional benefits gained from further processing derived from interaction with highly detailed stimuli. Alternatively, as Zimmer and Engelkamp (1999) have pointed out, a high level of conceptual processing is inherent in the enactment task and may simply leave little room to magnify the effect with the addition of superfluous detail. Enactment, therefore, seems to be part of a more general class showing that whereas multimodal encoding techniques can aid memory, the *detail* associated with any one component seems less consequential.

RQ6: Does Enactment Provide More Robust, Longer Lasting Memory Compared to Verbal Rehearsal?

Despite retention interval being perhaps the most fundamental variable in memory research, test delay has received relatively little attention in the enactment literature. By examining the robustness of enactment over time, we can infer relative differences in memory strength and resistance to forgetting. In one direct test of the enactment forgetting function, Nilsson et al. (1989) assessed participants' recall after 2 min, 24 hr, or 1 week. Forgetting functions over time did not differ for the SPT and VT conditions, suggesting similar underlying storage for the two tasks (Nilsson et al., 1989). This finding has been corroborated by several other articles demonstrating similar forgetting curves in SPT and VT conditions (Knopf, 1991; Kubik, Söderlund, et al., 2014), including after a 30-min test delay (Spranger et al., 2008).

At odds with the foregoing, though, Engelkamp et al. (1995) found that after a delay of 30 min, recognition test performance for VT items had dropped significantly relative to performance on an immediate test, whereas performance for SPT items remained relatively stable, suggesting different forgetting functions. Future work in this domain is especially warranted given the wide variety of test delays used in the past—up to a 2-week study–test interval (Manzi & Nigro, 2008). Indeed, elsewhere researchers have begun to address the nuances of long-term retention as of late (e.g., McDermott & Zerr, 2019). For now at least, evidence appears to weigh slightly in favor of VTs and SPTs sharing similar forgetting curves. Indeed, our meta-analysis did not reveal any convincing evidence that the size of the effect differs over time. The long-lasting effects of enactment, therefore, likely result from the superior encoding of actions rather than from their greater resistance to forgetting.

Interest in the influence of retention interval in other multimodal encoding techniques has been limited. This makes sense as long-standing models of human declarative memory often assume that forgetting rates are relatively universal (Ebbinghaus, 1880; Murre & Dros, 2015; Wixted & Ebbesen, 1991; cf. Sense et al., 2016). Possibly the main reason that enactment researchers have pursued forgetting functions is Cohen's (1981) seminal article arguing that action and verbal memory operate as entirely separate classes, with different recall curves serving as a key piece of evidence supporting that notion. Search for parallels and dissimilarities in retention curves following multimodal encoding relative to basic verbal learning is clearly an area for targeted future research in enactment and in multimodal encoding more generally.

Neuroimaging Studies of Enactment

Having meta-analyzed the majority of behavioral studies in samples of neurotypical young adults, to see the full picture, it is also important to consider the brain basis of enactment. Next, we used the same methodology for article collection as described in the behavioral section, save for the addition of more relevant search terms and the removal of a requirement for behavioral statistics reporting (see our article collection guidelines on OSF). Here, we answer our seventh major research question.

RQ7: What Is the Neural Basis of the Enactment Effect?

Whether it be motor activity, semantic representation, or imagery processes, summarizing the neuroimaging literature regarding enactment provides insight as to when and where neural activation differs between solely verbal versus multimodal encoding strategies.

Neural Localization of Enactment

In applying our study-filtering criteria to ensure comparable study designs, we found that the neural localization of enactment has been explored in two positron emission tomography (PET) and in two functional magnetic resonance imaging (fMRI) studies, and its temporal characteristics have been examined in two electroencephalography (EEG) studies and in one magnetoencephalography (MEG) study. The primary motivation of both PET studies was to investigate the claim that motor areas are activated more when retrieving enacted trials relative to verbal trials (Nilsson et al., 2000; Nyberg et al., 2001). In these studies, results indicated that activity in the right primary motor cortex was greatest for enacted trials, intermediate for imagined trials, and lowest for verbal (i.e., reading) trials. Clearly, motor reactivation can occur during a verbal memory test (e.g., free recall), dependent on the task employed at encoding (see Figure 7). Although these patterns of activation could have represented motor area reactivation at retrieval, it is possible that recalling a noun tied to a verb during cued recall could involve motor imagery processes during the retrieval test itself, in turn activating areas similar to those hypothesized to be involved in enactment at encoding (Nilsson et al., 2000). However, the significantly higher level of motor activation with SPT items relative to IT items at test can be taken to indicate that additional processing is evoked by physically performing actions during encoding relative to imagining them.

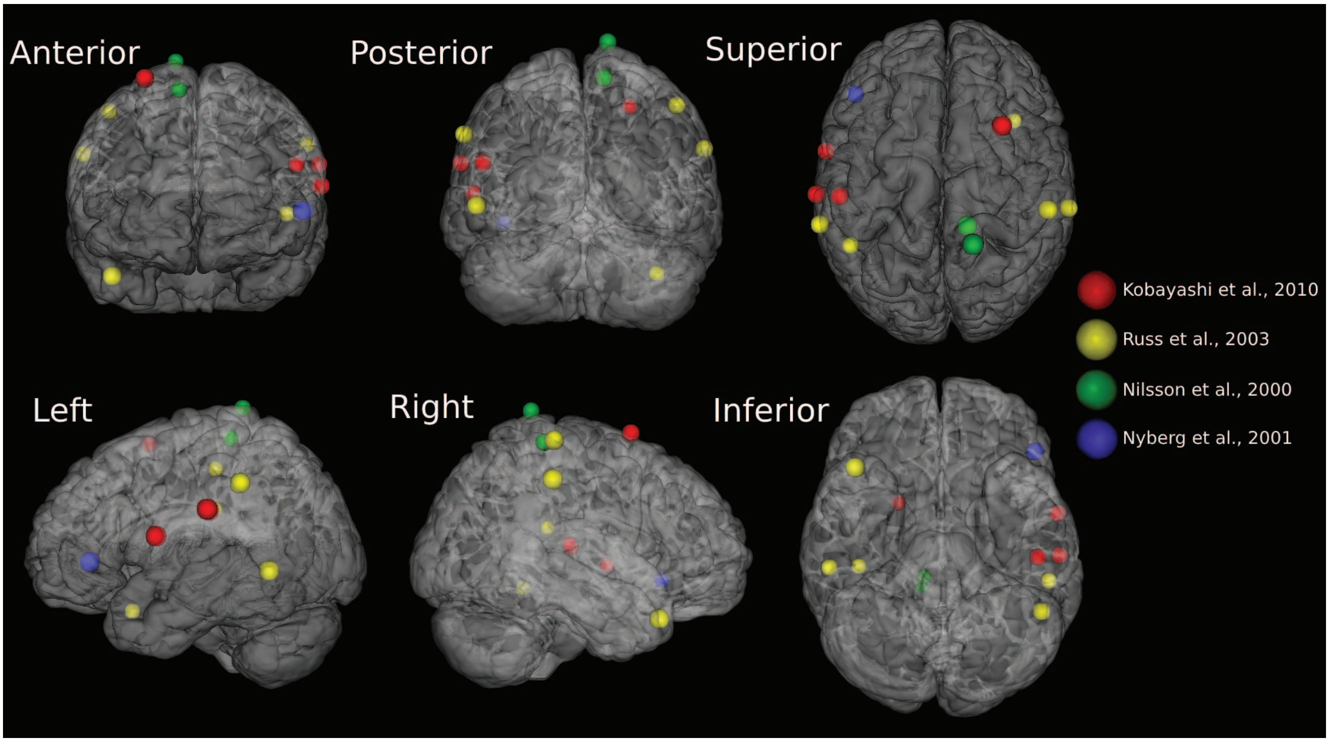
PET scanning has further suggested that, during encoding, SPT versus VT differences in activation can be seen within the premotor and primary motor cortices, areas that were reactivated at test (Nyberg et al., 2001). In addition, PET scans at retrieval have implicated the left inferior parietal lobule—especially the supramarginal gyrus (SMG; in Brodmann Area 40)—a part of the somatosensory association system thought to be involved in high-level perceptual processes (Brodmann, 1909; Nyberg et al., 2001; Reed & Caselli, 1994), mental images of movement (Buxbaum et al., 2005; Sirigu et al., 1996), and monitoring of kinesthetic actions (Sirigu et al., 1999). Relatedly, damage to nearby occipito-parietal sites can also lead to major visuomotor disconnects such as oculomotor apraxia, simultanagnosia, and optic ataxia (a triad of symptoms often referred to as Bálint's syndrome; Bálint, 1909).

Russ et al. (2003) were the first to use fMRI to investigate enactment. Their goal was to find neural evidence in favor of either a classic motor reactivation hypothesis, as Nilsson et al. (2000) and Nyberg et al. (2001) had proposed, or a higher level "action representation" hypothesis, which would involve both motor reactivation and conceptual (semantic) processing of the action. Results indicated SPT–VT activation differences in the previously reported motor and parietal areas at test (see Figure 7). The most prominent differences, however, were again found in the SMG which Russ et al. argued resulted from a complex integration of motor planning, object knowledge, and the combination of these factors into a coherent action representation. Notable activation of the primary motor cortex and SMG was further observed in an fMRI study by Kobayashi et al. (2010), including for older participants. Finally, using fMRI, both Krönke et al. (2013) and Macedonia and Mueller (2016) showed that strong activation within the SMG emerged following actions.

Localization studies of enactment have reported more activation in primary motor areas than in premotor and somatosensory–motor areas. It has long been maintained that primary motor cortex is

Figure 7

Overview of Brain Areas Where SPT Items Led to More Activation Than VT Items



Note. SPT = subject-performed task; VT = verbal task; fMRI = functional magnetic resonance imaging; PET = positron emission tomography; MNI = Montreal Neurological Institute. Superimposed coordinates originating from fMRI and PET articles included in this review, showing areas on a translucent brain where SPT-encoded items led to greater activation than VT-encoded items during retrieval. This figure was created by forming 5-mm radius spherical regions of interest (ROIs) using the Multi-Image Analysis graphical user interface (Mango) image processing system (V. 4.1; Lancaster & Martinez, 2019), centered around MNI *XYZ* coordinates (available on OSF), and overlaying them on a standardized brain (anatomical data set N27; Holmes et al., 1998) obtained from the MNI (http://www.bic.mni.mcgill.ca/).

implicated in the generation of neural impulses sent to the spinal cord for execution of movement, whereas premotor and somatosensory–motor areas are more involved in motor control, preparation, and planning (Nachev et al., 2008; Picard & Strick, 1996; Roland et al., 1980). Therefore, if action planning is critical to the enactment effect, one might expect to see greater activation in premotor and somatosensory–motor areas during brain scanning under SPT, EPT, and IT conditions. However, premotor area activation was only evident when remembering SPTs in two of the four localization studies of enactment (Kobayashi et al., 2010; Nyberg et al., 2001).

One possible reason that consistent activation of the premotor cortex has not materialized may be that most neuroimaging scanning is conducted during retrieval. Scanning at retrieval is often done for practical reasons, as body movement artifacts (such as those inherent in enactment at encoding) during neuroimaging can lead to troublesome levels of noise in the imaging data. It may be the case, then, that retrieving an enacted item activates slightly different areas than those involved in the actual encoding of the action. Therefore, whereas premotor and somatosensory–motor areas may appear relatively muted in the literature, this does not mean that they fail to come online during encoding of SPT, EPT, or IT tasks. We anticipate that future brain imaging studies will clarify this picture.

Although there seems to be a link with the inferior parietal lobule during retrieval of actions, the same area has also been implicated in word recognition (Stoeckel et al., 2009). The implication is that these areas of interest in the parietal cortex could simply be activated by the nature of word-based recognition testing, not by processes related to action representations. That said, Nyberg et al. (2001) used cued recall testing and found SMG activation, though obviously this procedure still involved visually presented words. Perhaps more convincingly, then, one must consider that all of the SMG effects shown in Table 6 represent cases of higher activation in SPT *relative to* VT. Thus, reported activation in these areas exceeds the activation seen in simple verbal encoding and retrieval, including effects of word recognition, the latter of which is equated between the two tasks. Therefore, evidence implicating the SMG in memory for actions has been accumulating, but the link between this area and memory remains uncertain. What seems clear, however, is the prominence of motor area reactivation during retrieval of enacted items.

Temporal Sequence of Enactment

Understanding enactment in terms of brain localization undoubtedly is important for understanding the neural processes involved in the memory benefit. But to understand how enactment manifests in

Table 6
Brain Regions Where Activation Was Higher During Retrieval of SPT-Encoded Relative to VT-Encoded Items

		Neural regions activated (and BA in parentheses)													
Study	Methodology	FE	PE	CE	CR	PSC/PG (3, 1, 2)	PIMC (4)	PEMC/SMA (6)	SPC (7)	MTG (21/37)	MCC (32)	STG (38)	SMG (40)	AC (41/42)	IFG (45/47)
Heil et al. (1999)	EEG	■□													
Ma et al. (2021)	EEG	■□	■□	■□											
Kobayashi et al. (2010)	fMRI							■□					■		
Russ et al. (2003)	fMRI					□				■		□	■□		
Masumoto et al. (2006)	MEG						■		□				□		
Nilsson et al. (2000)	PET						□								
Nyberg et al. (2001)	PET				□	■	■	■	■		□		■	■	■

Note. This table is organized first by neuroimaging method, then alphabetically by author. The studies included here are only those that share a very similar experiment paradigm, allowing for direct comparisons. Studies with more variable methods are described in the main text. SPT = subject-performed task; VT = verbal task; FE = frontal electrodes; PE = parietal electrodes; CE = central electrodes; CR = cerebellum; PSC = primary somatosensory cortex; PG = postcentral gyrus; PIMC = primary motor cortex; PEMC = premotor cortex; SMA = supplementary motor area; SPC = superior parietal cortex; MTG = middle temporal gyrus; MCC = midcingulate cortex; STG = superior temporal gyrus; SMG = supramarginal gyrus; AC = auditory cortex; IFG = inferior frontal gyrus; EEG = electroencephalogram; ■ = left hemisphere; □ = right hemisphere; fMRI = functional magnetic resonance imaging; MEG = magnetoencephalography; PET = positron emission tomography; BA = Brodmann's areas.

the brain, temporal sequence must also be considered, and time is not well indexed by PET or fMRI. Instead, MEG and EEG provide good temporal resolution. Using MEG, Masumoto et al. (2006) observed very early activation within the left primary motor cortex (150–250 ms) during retrieval of enacted items. Their result contrasts with EEG enactment studies, however, which have observed enactment-related fronto-parietal event-related potentials (ERPs) beginning around 600 ms and continuing into later epochs (Heil et al., 1999; Leynes et al., 2005; 2006; Leynes & Bink, 2002; Leynes & Kakadia, 2013; Leynes & McGowan, 2021; Ma et al., 2021; Senkfor, 2008; Senkfor et al., 2002, 2008; Zhao et al., 2016). This discrepancy in timing may, however, be explained by the other important result of Masumoto et al. that does indeed match the just-cited EEG literature—significantly greater right parietal cortex activity when retrieving enacted items relative to verbal task items, occurring in the 600–700 ms range after stimulus onset. So, while the use of MEG by Masumoto et al. may have allowed for early detection in motor areas, the majority of enactment sequencing studies employing EEG have indicated later encoding task differences at more posterior fronto-parietal electrode sites.

Some investigators have taken early temporal EEG evidence as support for a heuristic explanation of enactment, such that motor reactivation automatically facilitates item discrimination that precedes later decision processes (Leynes & Bink, 2002). This claim, while speculative, is consistent with an earlier "pop-out" mechanism of enactment proposed by Zimmer et al. (2000) where, relative to a verbal task, enactment facilitates faster automatic retrieval of actions such that movements help to make representations more quickly and reliably accessed without active search (see also Li & Wang, 2016; Li et al., 2019; Spranger et al., 2008).

Overall, a common pattern has emerged from the EEG studies: Motor regions, localized within fronto-central sites, were differentially reactivated at test following enactment relative to comparison tasks (word or phrase presentations for most studies; cost estimation of presented objects for Senkfor et al., 2002, 2008). Furthermore, studies have also reported significant enactment-based fronto-parietal activation during later epochs (600 ms and beyond; e.g., Ma et al., 2021; Masumoto et al., 2006; Senkfor et al., 2002, 2008; Zhao et al., 2016) that could be indicative of SMG activity similar to that previously described in localization studies (Kobayashi et al., 2010; Krönke et al., 2013; Nyberg et al., 2001; Russ et al., 2003).

Neuroimaging Studies Summarized

For well over a century (see Campbell, 1904), scientists have investigated representations of movement in the brain. The recent enactment work has helped to illuminate the subject, suggesting two core theories about the neural basis of the enactment memory benefit. As summarized nicely by Russ et al. (2003), the first holds that, following enactment-based encoding, motor information is reactivated at test, leading to improved memory along the lines of transfer appropriate processing (Morris et al., 1977; Nilsson et al., 2000; Nyberg et al., 2001). The second maintains that motor activation during enactment-based encoding leads to a more integrated action representation of the to-be-remembered item in the brain, encompassing both physical movement and an enhanced conceptual representation that comes with performing the action oneself (e.g., Helstrup, 1986, 1987, 1989a; Knopf, 1991; Russ et al., 2003). Whereas the former theory emphasizes primarily reactivation of motor areas, the latter emphasizes conceptual integration processes that may follow in parietal and/or frontal sites.

Both theories have received support; they need not be seen as contradictory and may even be complementary. Generally, neural studies of enactment have found motor regions to be reactivated during retrieval of SPTs, and temporal sequencing reveals that this activation can often spread to parietal areas during later epochs—although the associated consequences of such transfer remain to be determined. Certainly, though, future studies should pay particular attention to areas that have theoretically grounded ties to the enactment effect. One such area is the SMG—a structure highlighted in the literature for its reported role in motoric representations (Leiguarda & Marsden, 2000), planning (Rushworth et al., 1997), learning (Jenkins et al., 1994), and perception (for a meta-analysis, see Grèzes & Decety, 2001). We also caution that it is still early days with respect to neuroimaging research on enactment.

If enacting during encoding leads to later reactivation of motor regions that then spreads to parietal cortex, then motoric reactivation at test could be facilitating additional conceptual processing of the presented item. A recent fMRI study of the production effect (Bailey et al., 2021) points toward a similar pattern of activity whereby brain regions associated with movement, speech, and semantic conceptualization are all activated more by production of the item itself than by unrelated repetitive speech. Recent neuroimaging work on the drawing effect has also established the importance of similar action representation connections (Fan et al., 2020). In considering multimodal encoding more broadly, we see a consistent pattern that the multifaceted nature of these techniques is echoed in their neural substrates.

Enactment in Neurological Patients

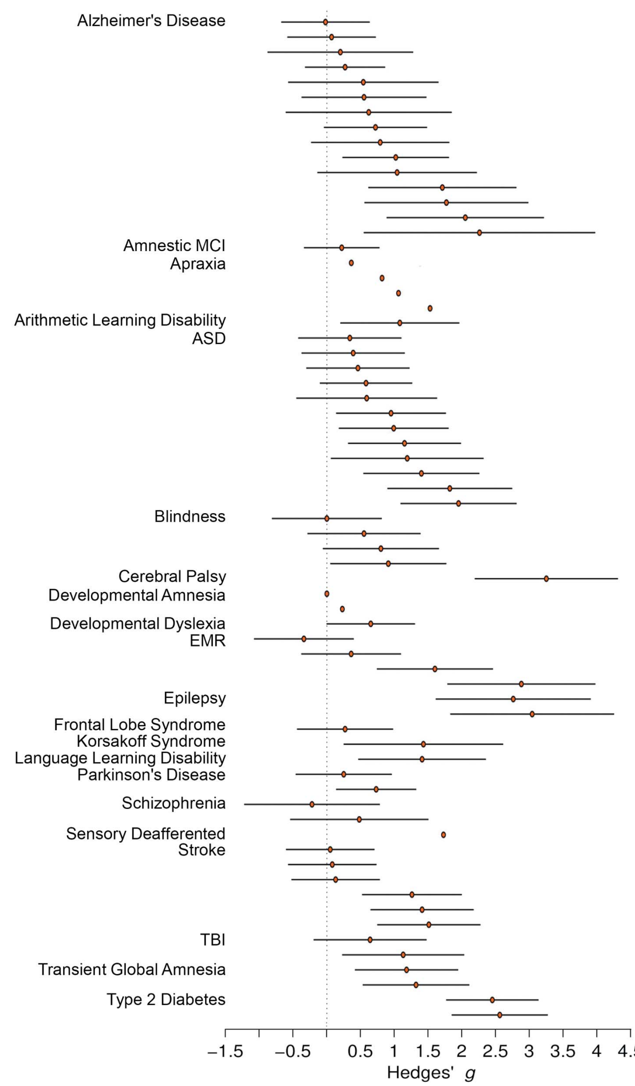
The enactment literature is rich with articles that have investigated a wide variety of patient samples. Here, we used meta-analysis where there were sufficient data available and relied on qualitative review of motor-impaired and non-motor-impaired patient groups where there were not. Due to the low number of studies, participants, and/or effect sizes in most patient groups, it was only possible to provide meta-analytic estimates for the Alzheimer's disease (AD) and autism spectrum disorder (ASD) patient groups. The meta-analytic technique employed here was the same as for the first stage of our behavioral meta-analysis (raw data files and statistical code are available on OSF). We used the same methodology for article collection as described in the two preceding sections, save for the addition of relevant search terms and the removal of participant age restrictions. Figure 8 provides a summary of neurological patient studies of enactment (more details can be found on OSF). Based on this, we answered our eighth and final major research question.

RQ8: Can Enactment Benefit the Memory Performance of Various Neurological Patient Groups? Do Motor or Memory Impairments Alter the Efficacy of Enactment?

Observing the effects of enactment within patient populations can provide converging evidence concerning both localized brain regions and broader processes involved in enactment-based memory enhancement. The study of patient groups has the further benefit of determining whether multimodal encoding techniques such as enactment can provide practical, self-administered aid to those living with neurological impairments.

Figure 8

A Caterpillar Plot of the Included Patient Effect Sizes



Note. MCI = mild cognitive impairment; ASD = autism spectrum disorder; EMR = educable mentally retarded; TBI = traumatic brain injury; CIs = confidence intervals; OSF = Open Science Framework. This caterpillar plot depicts all patient effect sizes (and their 95% CIs) in alphabetical order by patient group, then in ascending order of effect size. Positive effect sizes indicate better memory performance following enactment relative to a comparison task, whereas negative effect sizes indicate the opposite. For single-patient case studies (those without CIs), the effect size presented is Glass' Δ (details available on OSF; Busk & Serlin, 1992; Glass et al., 1981). See the online article for the color version of this figure.

Non-Motor-Impaired Patients

The most thoroughly studied patient group in the enactment literature is individuals with AD (see Figure 8). Starting in the late 1980s, studies have investigated enactment as a potential mnemonic to aid Alzheimer's patients. This is not surprising given public interest in AD research plus the fact that the hallmark symptom of the disease, particularly early on, is a decline in memory performance (Korolev, 2014). Of the seven Alzheimer's enactment studies included in our review, five found significant memory benefits in AD patients following enactment (relative to a VT comparison task; De Lucia et al., 2019; Hutton et al., 1996; Karlsson et al., 1989; Lekeu et al., 2002; Masumoto et al., 2004), whereas two did not (Dick et al., 1989; Mack et al., 2005). Meta-analysis of the enactment effect in AD patients across the latter six studies ($m = 6$, $k = 15$) revealed a moderate and statistically significant enactment effect, $g = 0.61$, $t(4.57) = 2.76$, $p = .044$, 95% CI [0.03, 1.19], 95% PI [−0.67, 1.88].[9]

With respect to the influence of impairment severity among AD groups on the enactment benefit, findings have been mixed. Karlsson et al. (1989) found a significant enactment effect (SPT > VT) for AD patients at each of three severity levels (mild, moderate, and severe), whereas Herlitz et al. (1991) found a curious pattern: The mild group did not benefit, the moderate group showed the opposite effect (VT > SPT), and only the severe group actually showed an enactment benefit. That said, the general trend is that Alzheimer's patients of each severity level have the potential to gain a memory benefit from performing actions at encoding. Hutton et al. (1996) found an enactment effect in mild-to-moderate Alzheimer's patients and found even greater memory benefits when the performed actions were part of a larger coherent goal-directed task. Lekeu et al. (2002) had "probable" AD participants (average score on the Mini-Mental State Examination [MMSE] = 21.4; classified as "mild" severity) perform free recall, semantic cued recall (object category as cues), and object cued recall (reenactment at recall using studied objects). Their results indicated a benefit of enactment beyond a verbal task across all groups, test types, and levels of action familiarity. An enactment benefit has also been reported in mild severity AD participants after a retention interval of 30 min (Masumoto et al., 2004), although it should be noted that performance was at floor in the VT control condition (no VT items were recalled while only 4% of SPT items were recalled).

Studies of other non-motor-impaired patients have included the following neurological disorders: amnestic mild cognitive impairment, "educable mentally retarded," frontal lobe syndrome, ASD, Korsakoff's syndrome, obsessive–compulsive disorder, and schizophrenia (for a full list, see Figure 8 and the associated data on OSF). Unfortunately, for most of these patient types, there has been only one study of the enactment effect, thereby limiting confidence that any given finding is reproducible in that population. Still, enactment evidently offers a very robust memory benefit despite numerous different neurological and cognitive impairments. In fact, only four of the 31 neurological patient studies reported here failed to find any significant enactment effect within patient samples—two studies of AD (Dick et al., 1989; Mack et al., 2005), one of transient global amnesia (Hainselin et al., 2014), and one of schizophrenia (Daprati et al., 2005). Due to the uniqueness of the patient groups studied to date, we will now briefly discuss several in turn.

In five of the six studies involving ASD patients, a significant enactment benefit has been demonstrated (Daprati et al., 2013; Grainger et al., 2014, 2017; Summers & Craik, 1994; Yamamoto & Masumoto, 2018); only one article (Zalla et al., 2010) has failed to find the effect using free recall testing (despite finding an effect with recognition testing). Meta-analytically speaking, the enactment effect in studies of ASD patients with sufficient data ($m = 4$, $k = 12$) is significant and large, $g = 1.08$, $t(2.94) = 3.47$, $p = .042$, 95% CI [0.08, 2.07], 95% PI [−0.94, 3.09].[10] These qualitative and quantitative results align with work demonstrating that those with ASD suffer from a diminished ability to spontaneously deploy item-relational processing, yet have spared item-specific processing (Gaigg et al., 2008). Therefore, the results of enactment research with ASD patients pose a challenge to an episodic integration view of enactment (Kormi-Nouri, 1995), insofar as subject–environment integration is necessary to drive the effect.

In patients with damage specifically to their frontal lobes, one might predict an inability to benefit from enactment. These patients are characterized by a deficit in the ability to plan a sequence of operations (Shallice & Burgess, 1991)—an element of enactment thought to be critical to the memory boost (Knopf et al., 2005). Contrary to this prediction, studies have shown that when patients with frontal lobe lesions act out an item relative to simply naming it, they gain a significant enactment benefit for serial-order memory (McAndrews & Milner, 1991). However, a later study by Knopf et al. (2005) partially contradicted these findings by reporting that, in free recall, frontal lobe syndrome patients were not able to benefit from enactment, citing a lack of ability to plan motor sequences. It may be that experimental factors such as test type interact with action planning ability in determining memory. More work with this particular patient group should help to clarify the specific contribution of action planning to the enactment effect.

In patients with schizophrenia, absence of an enactment effect has been interpreted as being due to their characteristically diminished ability to monitor voluntary actions (Daprati et al., 2005; Frith, 1987). Later work, however, reported significant enactment benefits in larger samples of patients with schizophrenia when employing reenactment at retrieval on a cued recall test (Brodeur et al., 2009). Later studies often failed, however, to find any benefit of enactment on source memory tests (Brodeur et al., 2009; Gawęda et al., 2012). Gawęda et al. (2013) later suggested that auditory hallucination subtypes may especially struggle with gaining benefits from enactment. Indeed, neurotypical behavioral work from Kaji and Naka (2006) showed that SPTs led to better internal source monitoring than ITs but, when a source decision had to be made between two external voices, SPT and IT tasks led to equivalent performance. Thus, it is perhaps the ability to discriminate internal versus external auditory experience that modulates the capacity for patients with schizophrenia to benefit from enactment.

Finally, observing the effects of enactment in patient GL offers a unique look into the contribution of sensory feedback to the memory benefit. Patient GL suffered from a single episode each of Guillain–Barré syndrome (Winer, 2001) and polyneuropathy whereby her body's immune system, following an infection, attacked her somatosensory nerve pathways, ultimately demyelinating the majority of the peripheral pathway nerve fibers. The result left her with complete loss

[9] Because this prediction interval crosses zero, it is possible that a new primary research study using enactment with AD patients could find a zero or negative enactment effect size. Therefore, caution should be used when relying on enactment in clinical settings for the purpose of improving patient outcomes. For more information, see Footnote 6.

[10] Note that because $df < 4$, these results should be interpreted with caution (Tipton, 2015); the meta-analytic point estimate in ASD patients may not be truly significant. Similar to the case of AD patients, the width of the prediction interval suggests that enactment in clinical settings with ASD patients may not enhance memory reliably in every study.

of vibration, touch, pressure, and kinesthetic movement senses below her nose (Cooke et al., 1985; Daprati et al., 2019). Critically, GL's motor abilities were entirely spared. The intriguing findings of Daprati et al. (2019) are that (1) patient GL demonstrated a significant enactment effect, (2) the magnitude of her enactment effect did not differ from neurotypical controls, and (3) GL's response times on a recognition test also matched those of controls. GL demonstrates that the enactment effect can occur without any somatic sensation below the nose, suggesting that enactment may be more reliant on motor planning and/or execution than it is on tactile feedback from objects or kinesthetic feedback from motion.

Motor-Impaired Patients

Studying neurological patients who have motor-related deficits is clearly most relevant to enactment and may help to clarify the mechanism(s) that underlie the memory benefit. Two intriguing patient groups to study are those with apraxia and those with Parkinson's disease, both conditions characterized by difficulty performing actions.

Apraxia is characterized by damage to the posterior parietal cortex, resulting in a severe inability to plan motor actions despite the instructions and task being clearly understood (for a review, see Canzano et al., 2016). Patients with apraxia therefore seem to be the obvious group for examining limitations of the enactment benefit. Unfortunately, by definition, patients with apraxia cannot physically perform actions very well, making it difficult to compare their data to neurotypical controls. Nonetheless, Masumoto et al. (2015) provided the first exploratory work on enactment with two patients who suffered from different forms of apraxia.

Patient KT had ideational and ideomotor apraxia, indicating trouble integrating functional knowledge of an action with related object knowledge. Critically, KT also suffered from diminished ability to organize or execute actions. Patient OT suffered from corticobasal syndrome (an atypical parkinsonism) that resulted in similar but milder apraxia symptoms relative to KT, while being mostly spared from ideational deficits. However, OT also exhibited limb kinetic apraxia—impairment in the ability to perform simple movements and actions. Therefore, whereas KT had trouble performing smooth actions and lacked action–conceptual integration ability, patient OT's impairment was mostly due to the former. Interestingly, Masumoto et al. (2015) observed a significant enactment effect for both patients in recall, but only for OT in recognition. For KT, there were no significant differences in memory for actions that were completed versus those which KT struggled with or outright failed to complete. The proposed explanation was that visual, tactile, and motor information is linked to a word at encoding and that, however awkward the action, the process of combining these modalities led to a benefit similar to that seen in controls. By comparing these two apraxia patients then, we can infer that internal movement representations are important for enactment when needing to discriminate between action phrases, such as on a recognition test. Indeed, according to Masumoto et al., it is the pattern of neural activity moving from motor to parietal sites during retrieval that determines whether an enactment benefit occurs, regardless of diminished motoric coordination during encoding (Masumoto et al., 2006, 2015).

Parkinson's is another neurological disease that severely affects motor control (Rice & Thompson, 2001; Smith et al., 2010) but spares knowledge of actions, making it highly relevant to enactment research. Using SPT and VT encoding trials, Knopf et al. (2005) showed that patients with Parkinson's disease were able to benefit from enactment when the retrieval task was free recall. In the same study, they also showed that patients with frontal lobe syndrome, characterized by a deficit in cognitive planning capabilities, did *not* show an enactment benefit. Both findings are consistent with Masumoto et al.'s (2015) work with apraxia patients, in that a participant's own movement is perhaps less vital in producing an enactment benefit than is successful planning of the action and any subsequent action integration.

In support of this view is work by others who tested patients with Parkinson's disease and found that these patients had more trouble than controls in performing actions during encoding, but they could at least plan their actions (unlike apraxia patient KT; Masumoto et al., 2015; Smith et al., 2010). The result of this key difference in cognitive abilities was another significant enactment effect. Taken together, these few studies of motor-impaired patients highlight the importance of action planning and semantic integration while downplaying the importance of precise action sequences at encoding.

Patient Studies Summarized

Patient studies demonstrated significant enactment effects across a wide range of neurological disorders, including those characterized by memory and motor impairments. Furthermore, these studies are indicative of a promising future for the use of enactment as an encoding strategy to aid memory in numerous patient groups, even when substantial motor or memory impairments exist. Multimodal encoding techniques more generally are becoming recognized as potent mnemonic tools for patients. For instance, the drawing effect has recently been shown to enhance memory for older adults, including those with probable dementia (Meade et al., 2020). Production also enhances memory in older adults (Lin & MacLeod, 2012) and in people with dysarthria (a disorder of speech production; Icht et al., 2019). A key feature in the everyday efficacy of a mnemonic tool is the ease with which it can be routinely deployed. Thankfully, many of these multimodal techniques are straightforward to implement in daily life, only requiring one to act, draw, or speak. Hence, further exploration of powerful and easily implemented encoding strategies is certainly justified.

General Discussion

We have explored enactment in terms of behavioral patterns, neurobiological activity, and patient manifestations. Meta-regression of behavioral studies confirmed that the enactment effect is large and robust to experimental perturbations. Study design and comparison task influenced the size of the effect, but four other experimental factors did not (test format, learning instruction type, retention interval, and presence of objects). Neuroimaging studies highlighted action-relevant activity predominantly in motor and inferior parietal areas. Patient studies underlined the effectiveness of multimodal techniques in aiding memory in those with cognitive impairments.

Each of these three major sections serves its own valuable purpose, but it would be optimal to incorporate them into a coherent view of the enactment effect as it stands today. We do so by discussing underlying mechanisms driving enactment, then by revisiting two major theories of enactment to determine how they hold up in light of our newly synthesized information. Finally, we offer suggestions for future work to address theoretical gaps or limitations that appear after all the evidence presented here has been considered.

Relative Contributions From Motoric Planning and Real Action

In thinking about enactment, the intuitive assumption is that the physical action in the task is solely responsible for the memory benefit. As our analyses and review have shown, however, the explanation is not that simple. Even without first-person motor actions by a participant (as in the SPT condition), both the EPT and IT conditions most often confer memory benefits significantly beyond those of simple verbal learning (the VT condition). In both EPT and IT, the participant ordinarily is required to plan, envision, or watch performance of an action. Clearly, these mental activities themselves benefit memory without the requirement of physical action. Based on our meta-analytic review, we see the best explanation of the memory benefit as involving two components. First, planning or watching a movement likely brings online several important facets of enactment, including action schemas and multimodal semantic integration. Then, actual execution of an action enhances memory in the SPT condition above that of the EPT and IT conditions. Physical performance of the action therefore must be adding *something* extra that provides a further boost to memory, but the nature of that contribution is unclear. To illustrate, it could be due to unconscious motor system information, to further enhancement of ongoing action planning processes, or even to binding of these two factors together. Regardless, the research suggests that separating action planning from action execution is no easy feat.

In 1996, Helstrup wrote of a "preparatory effect" on enactment that interacted with encoding and retrieval processes. While Helstrup's ideas were distinct from those argued here, the general claim that preparation stages are important for enactment holds true and has therefore been a known yet underrepresented area of enactment research. Action planning processes are likely implicated even when the task involves only mental imagery, as in the IT condition. Demonstrating this, clear motor area activation during an internal motor imagery task has been reported (Naito et al., 2002). Further, research with certain motor-impaired neurological patients shows that a coherent motor action is not critical to obtain a boost whereas the ability to plan movements may be essential (Knopf et al., 2005). In the case of EPTs, related research on the mirror neuron system suggests that watching others perform can activate motor areas similar to those engaged by SPTs (Rizzolatti & Craighero, 2004). Thus, while EPTs do not benefit from action generation or from planning, they may profit from motoric representation activation as well as from any conceptual integration that accompanies viewing the performed action.

Put simply, if the SPT condition is taken to be the only true enactment, then both the mental component and the physical component contribute to improved memory. Of course, these two components could be further subdivided—into verbal, planning, imagery, motor, and action—and the argument could be made that as more of these are involved, the size of the memory benefit increases. Yes, SPT memory is demonstrably better than VT memory. But the fact that EPT and IT often also provide a benefit relative to VT—although typically less than SPT—supports the idea that motor planning and imagery likely are also important in improving memory over simple verbal processing.

We are not arguing that motor area activation is absent in the EPT and IT conditions. Rather, we reason that integrative processes—that implicate motoric planning and imagery—activate brain areas similar to those engaged by real movements and are therefore common across SPT, EPT, and IT conditions. Our idea is similar to that proposed in Jeannerod's (2001) "simulation theory" of motor cognition, whereby covert actions (i.e., imagery, planning, watching others perform) are thought simply to be neurally simulated real actions, lacking only final execution. While Jeannerod (2001) took a brain localization approach to motor cognition in general, we add that there are likely qualitative differences in semantic integration of actions that can modulate later memory. For instance, the finding that prototypical actions do not improve memory for unrelated words, whereas performing semantically integrated nonemulative actions do (Zimmer & Engelkamp, 2003; Sivashankar & Fernandes, 2022) serves as an illustration of how action–semantic integration of *related* content may aid memory separately from any distinct benefit of emulative actions tied to a given word or phrase. Indeed, activation of the motor cortex both during encoding (Nyberg et al., 2001) and during retrieval (Nilsson et al., 2000; Nyberg et al., 2001; Russ et al., 2003) has consistently been demonstrated in brain imaging studies of enactment. Perhaps more to our point, Nilsson et al. (2000) used PET imaging to show similar motor area activation for SPT and IT, both of which differed from VT.

Neuroimaging evidence of consistent motor and parietal cortex activation during recall following these various encoding tasks could suggest, then, that mental representations of movement may be formed at encoding and subsequently activated during retrieval, regardless of whether real actions were performed at encoding (Masumoto et al., 2006; Nyberg et al., 2001; Senkfor et al., 2002, 2008). Specifically within the parietal cortex, several researchers have pointed to the SMG as an area of special interest due to its high activity when retrieving enacted items and its reported link to movement representations and high-level perceptual processes (Kobayashi et al., 2010; Krönke et al., 2013; Masumoto et al., 2006; Nyberg et al., 2001; Reed & Caselli, 1994; Russ et al., 2003).

Perhaps even more crucial to demonstrate the importance of action planning, Eschen et al. (2007) showed that planning to perform an action at a later time led to activation in the same brain regions that much of the enactment literature has implicated for retrieval of actual performed actions (i.e., premotor and inferior parietal sites, including the SMG). This pattern of neuronal activity is supported by behavioral evidence from other studies demonstrating memory benefits for items that were simply planned to be performed but never executed (Engelkamp, 1997; Koriat et al., 1990). In fact, in the only study that scanned during enacted trials at encoding, premotor area activation was found during both SPT and IT trials (Nyberg et al., 2001). Thus, while one might expect motor planning operations to be reactivated during retrieval of enacted items, motor planning at *encoding* may be what integrates a word with an action representation, whereas it is primary motor area reactivation that serves as the "key" to unlock the stored action memory at test, regardless of whether actions were performed at study.

The benefit of planning has also been shown in other mnemonic techniques as well: Planning to create a drawing confers a sizable and reliable memory benefit over writing (Wammes, Roberts et al., 2018). Indeed, the existence of a distributed network predominantly in the left hemisphere, common to both planning and execution of learned actions, has already been established in the literature (e.g., Johnson-Frey et al., 2005).

Findings from neurological patients also support the idea that both action knowledge integration and planning may play important roles in the enactment effect. Parkinson's patients (Smith et al., 2010; Knopf et al., 2005), as well as apraxia patients OT and KT (Masumoto et al., 2015), all produced coarse actions at encoding. Nonetheless, enactment effects were demonstrated in each case—except for patient KT who notably lacked the ability to organize actions effectively. Further underscoring the importance of planning, frontal lobe syndrome patients were not able to benefit from enactment (Knopf et al., 2005). Finally, that patient GL showed a significant memory advantage following SPTs relative to EPTs (Daprati et al., 2019) also suggests that there are direct benefits to memory from executing real actions, beyond the motor imagery processes that many assume to be in play during EPTs, or the tactile/kinesthetic feedback provided by movement during SPTs (which GL did not experience). These patient studies highlight the contribution of action–conceptual integration to the enactment effect even in the absence of coherent movement or sensorimotor feedback. One way to isolate motor imagery from action in the future may be to study enactment in those with aphantasia or hyperphantasia (representing the two extremes of one's voluntary ability to form mental images; Dawes et al., 2020; Galton, 1880; Milton et al., 2021).

More broadly, a related literature in social psychology surrounding goal forming also maintains that the binding of future episodic mental representation with action is key to improving later memory (Wieber et al., 2015). It has been reported that planning if-then statements for future goals—"implementation intentions" as Gollwitzer (1999) calls them—brings memory benefits to those who adopt a high commitment to the intentioned plan (for a meta-analysis, see Gollwitzer & Sheeran, 2006). Similar to theories of enactment, it has been suggested that implementation intentions act by binding representations of the goal to actions.

Overall, in integrating evidence from behavioral, neuroimaging, and patient studies, we have argued that actions themselves are sufficient to obtain a quite large enactment benefit. We have suggested that to perform an action requires planning, and that planning alone produces an enactment benefit, albeit smaller than the "full" effect that occurs when planning is followed by actual movement. Motoric generation and planning appear to serve as catalysts for action–conceptual integration to occur, which in turn leads to an overall more robust and perhaps quicker-to-access episodic memory; these catalysts are simply and conveniently brought about by real actions as well. What remains unclear, however, is whether individual facets of action memory (i.e., planning, generation, and action) are independent subprocesses or are instead units of an inseparable whole, a question that Smith (1896) considered some 125 years ago.

Revisiting Major Theories of Enactment

In light of our meta-analytic review, we now revisit Engelkamp's (1998) system-oriented approach to a multimodal processing theory, as well as Kormi-Nouri's (1995) episodic integration theory. Respectively, they represent the most prominent ideas within the motor-based versus the non-motor-based accounts of enactment. Engelkamp's is a leading theory that promotes special emphasis on multimodal encoding (including real actions), whereas Kormi-Nouri's provides a contrasting perspective, arguing for a theory of enactment that de-emphasizes the role of action in favor of more holistic memory integration.

Engelkamp's (1998) multimodal encoding theory operates similarly to contemporary notions of multisensory processing: Certain tasks routinely implicate specific modalities (e.g., touch, language, vision, motor) and, as a rule of thumb, the more modalities implicated, the better memory will be. Similar ideas have been offered to explain the memory benefits seen in drawing (Fernandes et al., 2018; Roberts & Wammes, 2021; Wammes et al., 2019; Wammes, Meade et al., 2018), in production (MacLeod et al., 2010), and in picture viewing (Paivio & Csapo, 1973), as well as in combinations of the aforementioned, such as a boosted generation effect when words are produced aloud (MacLeod et al., 2010), improved picture memory when generation is involved (Zormpa et al., 2019), and even an enhanced production effect for pictures (Fawcett et al., 2012).

Practically speaking, however, there must be a limit to the benefits of additive multimodal encoding: One cannot simply keep adding modalities and gain an infinite ability to recover memories. In the case of enactment, one such limitation has already been discovered: There is no further benefit to SPTs from deeper semantic processing (i.e., a levels-of-processing manipulation; Cohen, 1981; Craik & Lockhart, 1972; Nilsson & Craik, 1990; Zimmer et al., 2000; Zimmer & Engelkamp, 1999). At the risk of belaboring this point, multimodal encoding does not necessarily mean that more brain activation leads to better memory. A recent direct test of this idea using transcranial direct current stimulation (tDCS), a form of neuromodulation, led to no enhancement of the enactment effect (Meier & Sauter, 2018).

The findings of this meta-analytic review do not fully support Engelkamp's (1998) multimodal encoding account. Critically, physical action during encoding is sufficient but not necessary to bring about substantial benefits to memory. Motor planning may be beneficial and in turn could provide a foundation for actual motor execution to enhance that benefit. Indeed, data from patients—especially motor-impaired individuals—suggest that, at encoding, coherent actions related to the study item are not critical as long as the intention was to perform a related action. Conversely, individuals who cannot plan movements well, such as those with frontal lobe syndrome, have been unable to benefit from enactment, implicating planning as a critical first step upon which multimodal encoding can then build.

Kormi-Nouri's (1995) episodic integration view has drawbacks of its own. While certain aspects of episodic integration theory are appealing given the data—in particular, aspects of holistic integration with action schemas—the theory itself lacks a level of nuance to fully explain the enactment effect at this time. For example, the episodic integration view does not account for differences in item-specific and item-relational processing that are prevalent and that represent an important feature of the enactment literature. A further dilemma unique to Kormi-Nouri's episodic integration theory—which stresses the importance of self-integration for a memory benefit to occur—is that the neurological patient literature surrounding self-referential processing is mixed. On the one hand, findings demonstrating that patients with schizophrenia do not benefit from enactment (Daprati et al., 2005) could point toward self-referential involvement as key to the effect. Because these patients are known to suffer from poor self-awareness and attenuated source memory (e.g., Harvey, 1985), their inability to benefit from enactment could be due to the poor integration of action representations with the self (Daprati et al., 2005). On the other hand, however, that patients with ASD can benefit from enactment directly contradicts this notion because they are also thought to have reduced self-referential processing (Huang et al., 2017). Overall, then, any integration of "the self" with conceptual memory via action remains uncertain.

Although neuroimaging studies often show reactivation of motoric regions during retrieval of enacted items, it is possible that this motor information simply leads to downstream conceptual integration (such as that theorized to take place in parietal areas). If so, activity in motor regions serves as an important catalyst but is not the main basis of the enactment memory benefit (as the concept of distinct "motor memory" in some theories would imply). This "transfer" of activation from motor systems to conceptual areas within the parietal lobe seems to be theoretically possible—to varying degrees of efficacy—in motor planning, imagery, and perhaps even when watching others perform (the latter of which could be due to mirror neuron system activation; Rizzolatti & Craighero, 2004). The notion of a network that binds multimodal information with meaning is an example of what is sometimes referred to as "distributed interactive neuronal assemblies," due to their quick, automatic, and often direct ("cortico-cortical") connections that persist regardless of spatial proximity in the brain (Matsumoto et al., 2007; Pulvermüller, 2005; Rolls, 2000).

Thus, we posit that motor planning at encoding may be the main driver of action–conceptual binding, while primary motor area reactivation facilitates access to the stored memory at test, regardless of whether real actions were performed at study. Based on this notion, it stands to reason that execution of movements at encoding (such as in SPTs) could lead to enhanced motoric reactivation at test, thus allowing for more reliable access to stored memories.

That neuroimaging evidence presented in this review has often highlighted the pathway between motor areas and the parietal lobe is consistent with the idea of motoric–conceptual integration of a memory following enactment. Masumoto et al. (2006, 2015) suggest that it is the transfer of activation from motor to parietal areas that is key (regardless of how the initial motor activation is instantiated). Motor–parietal interaction does not preclude the possibility that individual differences modulate the effect, nor does it address aspects of the quality or amount of motor or conceptual activity that may differ between tasks (see Nyberg et al., 2001, for differences between SPT and IT items at retrieval; cf. Nilsson et al., 2000).

While numerous motor-based and non-motor-based accounts of enactment have contributed substantially to the literature, none seem able to fully explain the findings presented here. Rather, each must be adjusted to account for nuances presented in this meta-analytic review and elsewhere in recent literature, until a new or adapted theory is created that better fits data from behavioral, neuroimaging, *and* patient studies. Any future theory of enactment will need to be able to explain, at minimum, the following three clear outcomes of enactment research: (1) enactment encompasses multiple modalities that bring online several neural systems (whether these modalities operate independently is still an open question), (2) the enactment benefit can be—at least in part—strategic and is therefore likely not entirely reliant on unconscious motor memory, and (3) real coherent actions, while potent, are not necessary for substantial enactment-like memory benefits to occur (as in EPT and IT). Future theories should focus on explaining these aspects as parsimoniously as possible.

Implications for Multimodal Encoding and Suggestions for Future Work

Our overall objective has been to highlight the benefit of multimodal encoding techniques through an examination of the enactment effect as an example of these powerful mnemonic strategies. In so doing, we have raised questions to be addressed by future research. Is there a motor component independent of the planning component? If so, does it contribute directly to the enactment effect, or does it instead contribute to overarching action schemas and integrate with verbal memory for the to-be-remembered stimuli? One promising way to address these questions would be to try to tease apart the contributions of motoric planning and physical action by drawing parallels to other mnemonic techniques.

Emerging programs of research have demonstrated that both drawing and speaking during encoding, compared respectively to writing or reading silently, confer significant boosts to later memory (the drawing and production effects, respectively; Fernandes et al., 2018; MacLeod & Bodner, 2017). A common attribute of these two techniques, as with enactment, is that of purposeful conceptually related generation of an item during encoding. It likely is no coincidence that much of the research in these distinct areas has homed in on links between the act and conceptual knowledge as a key factor leading to improved item-level memory.

This leads us to a critical point: There are examples in production, drawing, and enactment that all demonstrate the power of multimodal encoding despite coarse output. Pointedly, each effect has been demonstrated in patient populations in which disorders preclude the ability for "proper" execution of the desired task: production in dysarthria (Icht et al., 2019), drawing in dementia (Meade et al., 2020), and enactment in apraxia (Masumoto et al., 2015). Common in all three cases is the retained ability for each patient group to generate mental plans of what they intend to do, even if their physical output is limited. While production, drawing, and enactment are relatively distinct tasks, a similar requirement for task representation binding induced by generative planning processes could be the common bedrock for each one. Therefore, although multimodal encoding techniques are no doubt powerful in boosting memory, it remains uncertain whether it is truly their "multimodal" nature per se that is driving the benefit. That all of these strategies can be freely and easily engaged by those with neurological disorders is a significant advantage, both in terms of improving patient outcomes and in applying theory to delineate underlying mechanisms. Moreover, by continuing to compare and contrast these encoding methods, we can explore how internal self-generated goals can seamlessly integrate with overt behavior, advancing our understanding of fundamental cognitive processes.

Limitations of the Current Review

Here, we briefly consider three possible limitations of our meta-analytic review method. First, we did not conduct an exhaustive "gray literature" search. We included dissertations in our search and reached out to authors for unpublished data, but there may still be a collection of unpublished or forthcoming work in registries such as PsyArXiv. Our search strategy, while limited in this respect, is unlikely to have significantly influenced the overall findings presented here because our analyses indicated that enactment is robust in the face of extreme publication bias. Second, our artificial dichotomization of the test delay variable was necessary due to the majority of studies simply not using any retention interval or not indicating whether a test delay was used. Nonetheless, this limits what we can glean from enactment in terms of its durability and forgetting function. Future studies (or analyses of our current data set that is freely available on OSF) should further delineate the forgetting function of SPTs as well as those of associated comparison tasks. Third, we note a shortage of studies in certain moderator variables (e.g., the "viewed" level in the use of objects moderator). When empirical work is lacking with respect to a given condition, we recognize the limitation placed on meta-analyses exploring the influence of that condition on the enactment effect.

Finally, as a fundamental limitation of the enactment research to date, we note the almost total absence of demographic and cultural descriptions in the enactment literature. Although most studies report the ages and sexes of their samples (see Supplemental Appendix A, for a breakdown of study demographic characteristics by moderator variable), the vast majority of the articles considered here were written in English (m = 393). We came across just 20 journal articles not written in English. Of these, we were able to translate eight. This leaves 12 unaccounted studies that could very well be influential. These counts should make it obvious that English-based—and likely therefore Western-based—research has dominated the study of enactment since its inception. This problem is not unique to enactment, of course: It likely is shared by many related research domains due to factors such as translation costs, the lack of available research funding in developing countries, and limited indexing of foreign journals by popular research databases. Further, although we have no a priori reasons to believe that culture, language, race, or sex would affect the cognitive processes implicated in enactment, the lack of international research in the literature necessarily limits the generalizability of our conclusions. We therefore urge researchers who have the opportunity to study enactment in underrepresented cultures or demographics to do so.

Conclusions

From the humble beginnings of Asher teaching participants to speak Russian in Cold War era America, to improving memory outcomes in modern-day clinical samples, the enactment effect has proven useful across a wide array of settings. Early studies in the 1980s conducted by Cohen, Engelkamp, Krumnacker, Zimmer, Saltz, Donnenwerth-Nolan, Kormi-Nouri, Nilsson, and others would go on to spark an area of research that would eventually constitute a wealth of knowledge spanning well over 200 empirical studies and several books. Their work has been instrumental in developing our understanding of action and its ties with memory, while further contributing to the maturation of broader theories of multifaceted cognition.

In this meta-analysis and review of the last 6 decades of research, we had three primary intentions: to create a detailed catalogue of enactment-related articles, to meta-analyze the behavioral literature with the aim of evaluating evidence for several theoretically significant study factors, and to integrate evidence from behavioral, neuroimaging, and patient work to deliver the most comprehensive review possible of how action relates to memory. In so doing, we answered eight key research questions pertaining to the enactment effect.

Continued research on the enactment effect and related phenomena will offer more evidence to settle ongoing debates and will also increase our understanding of how multifaceted human cognition operates at its most fundamental levels. Even outside academia, the enactment effect has real-world applications that people can employ right now. As just two illustrations, comprehension of scientific texts improves with actions (Stull et al., 2018), as does the preservation of memory for everyday tasks in AD (Rusted & Sheppard, 2002). Given the relative power and easy deployment of enactment as a mnemonic technique, its applicability to real-world settings is readily achieved. We hope that researchers will be able to use this review as a foundation for determining what empirical work needs to be done, for contextualizing new developments in multimodal encoding techniques, and for advancing theory linking action with memory.

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*Indicates studies included in the behavioral meta-analyses.
†Indicates studies included in the patient meta-analyses.

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