Enactment and Embodiment Impact the Recall of Object-Location Associations

Suesan MacRae (smacra2@uwo.ca)
Department of Psychology, Centre for Brain and Mind, University of Western Ontario, 1151 Richmond Avenue,
London ON, N6A 3K7, Canada

Ken McRae (kenm@uwo.ca)
Department of Psychology, Centre for Brain and Mind, University of Western Ontario, 1151 Richmond Avenue,
London ON, N6A 3K7, Canada

Stefan Köhler (stefank@uwo.ca)
Department of Psychology, Centre for Brain and Mind, University of Western Ontario, 1151 Richmond Avenue,
London ON, N6A 3K7, Canada

Abstract

The role of self-generated movement in memory retrieval has been demonstrated in enactment paradigms. However, in the context of object-location memory, the impact of action during learning has not yet been investigated, despite the ecological relevance of such behaviors. In the current project, we present new evidence that actively placing an object in a target location during learning leads to more precise, and faster, subsequent recall of the object-location associations than simply observing this placement. We further demonstrate differences in object-location memory depending on the category of stimuli that participants are engaging with by showing that images of objects with high manipulability are placed more precisely, more quickly, and more directly (mouse-tracking) than images of objects with low manipulability. We suggest that these latter differences are due to the motor information implicitly activated during processing of high manipulability items, and reflect the embodied nature of concepts. Although both enactment and manipulability impacted object-location recall, they did not interact. This research extends findings on enactment to associative encoding processes, and informs our understanding of the relationship between enactment and embodiment in human memory.

Keywords: Enactment; Embodiment; Episodic Memory; Object Concepts; Object-Location Memory; Associative Processing

Introduction

In daily life, we routinely find ourselves in situations in which we are searching our environment for items that we have somehow misplaced (e.g., car keys, cellphones, shopping list). Frequently, these items are in locations in which we placed them ourselves. In the current project, we investigated potential contributions of self-generated movement to the precision of recall of associations between objects and their locations. Further, we examined whether manipulability of the type of object whose location people try to recall impacts how efficient they are in recovering these associations.

Enactment and Memory

The role of self-generated movement in memory recall has been studied in enactment paradigms. In these paradigms, participants memorize content (typically words or short phrases describing actions) in multiple learning conditions. In control conditions, participants typically are asked to read the words, whereas in enactment conditions, participants perform an action for each of the words (e.g., clapping when "clap" is presented, stomping when "stomp" is presented). In one of the earliest studies, participants executed a "total physical response" as they recited words in the studied language (Asher, 1966). These responses included, for example, standing while the instructor said the Japanese word for stand (*tate*), or jumping while the instructor said jump (*tobe*). Following learning, participants were exposed to the phrases or words that they had previously learned and were scored on the accuracy with which they performed associated actions. Performance improved for groups who learned the words with the actions compared to those who passively learned words. This general pattern of results has been replicated in numerous variants of the enactment paradigm. For instance, Sivashankar et al. (2023) directed participants to either perform actions or watch videotaped actions performed by an actor. Critically, watching actions exposed participants to the same visual and auditory information during encoding; the only difference was the addition of the motor information. As long as the action was semantically congruent with the to-be-memorized word, participants recalled a significantly greater number of words when they performed the action compared to when they observed it. Overall, this work demonstrates that self-generated action makes an important contribution to memory.

To assess whether the enactment effect is robust across the literature, Roberts et al. (2022) conducted a meta-analysis on enactment effect paradigms. They calculated effect sizes separately for comparing performed versus observed actions, and performed actions versus passive reading. Both comparisons were robust and significant.

Researchers also have investigated the role of movement during retrieval, rather than introducing an enactment manipulation during learning. Johansson and Johansson (2014) manipulated the position of participants' eyes during a retrieval paradigm to either match or conflict with the eye position that occurred during learning. Manipulating eye

In D. Barner, N.R. Bramley, A. Ruggeri and C.M. Walker (Eds.), *Proceedings of the 47th Annual Conference of the Cognitive Science Society*

position changed motor activity during the recall phase because participants were not able to replicate actions they made during encoding. Participants viewed items in spatial quadrants on a computer screen. During test, they recalled items in one of four viewing conditions: fixating on a center fixation, free-viewing, fixating on the location where the tested item was encountered (congruent), or fixating on a location where the tested item was not encountered (incongruent). During free viewing participants had more spontaneously fixations to the location where the item had been presented. Furthermore, participants had more accurate and faster reaction times when they were fixating in the congruent location. This demonstrates that reactivation of motor information during retrieval improves memory. Johansson and Johansson interpreted these results as an enactment effect where similarity between action during learning and recall benefits retrieval.

Jones and Martin (2009) also used enactment during recall to improve memory. This study is interesting because it probed memory for information that participants had encoded implicitly through repeated motor experiences. Participants were presented with a 3x4 grid that mimicked the shape of a cellphone keyboard. They filled in the cells with the correct numbers or letters according to either the order in which the numbers appeared on a calculator, or the order and grouping in which letters appear on a cellphone. Prior to completing this task, participants were assigned to an enactment condition in which they tapped out a friend's phone number, an action condition in which they rhythmically tapped, or a passive condition in which they were not given specific movement instructions. Recall accuracy was higher following the enactment condition for both the letter and calculator task. This suggests that enactment during recall improves memory even for spatial information that is learned implicitly through repeated motor experiences.

A number of accounts have been suggested to explain the mechanism for the enactment benefit in memory processing. One early account was provided by Zimmer and Engelkamp (1989), who attributed the participant-performed task benefit to contributions from a motor system that was separate from the verbal memory system (proposed to support verbal memory tasks such as those in enactment paradigms). The view that a distinct motor system contributed to the enactment benefit is not unique to their account. Others including Cohen (1981) and Bäckman and Nilsson (1985) proposed that the motor system supported this memory boost. Some neuroimaging work has offered support for this hypothesis. Two fMRI studies on the enactment effect have demonstrated greater activity in motor areas during retrieval for items learned with enactment compared to items learned with verbal strategies (i.e. passively; Russ et al., 2003; Kobayashi et al., 2010). Roberts et al. (2022) provide a comprehensive review of the evolving theoretical background of the enactment literature. They conclude that modern multimodal memory theories of encoding, which suggest that specific modalities are particularly relevant for specific tasks, are the primary contemporary account for the enactment benefit. According to multimodal memory theories, incorporating information from multiple modalities increases the richness of the resulting memory representation, leading to more successful retrieval. By these theories, in enactment paradigms learning verb lists primarily relies on visual or auditory modalities, and incorporating action during encoding enriches memory by incorporating motor information.

Although it is clear that self-generated movement during enactment conditions boosts memory for concepts describing corresponding actions, it remains unknown whether enactment effects extend to associations that are tied to these actions. This is important given the broader importance that is assigned to forming associations (i.e., relational binding) in the episodic memory literature (Tulving, 2002). Memory for object location provides a powerful means to examine and understand relational binding, in particular for arbitrary associations unconstrained by semantic knowledge (Postma, Kessels, & van Asselen, 2008). At present little is known about the potential contributions of enactment to relational binding in episodic memory.

As such, an important question to answer is whether active placement of an object offers enactment benefits as compared to conditions in which no such active placement is involved. Conceptually, a critical question is whether motor representations enhance memory for associations between objects and their locations, such that they can support subsequent recall of a location when the corresponding object is provided as a cue.

Embodiment and Memory

It is well established that the importance of motor information differs across types of concepts. For example, motor information is central to people's knowledge of objects that people frequently touch, such as forks, keys, and socks. It is much less important for other concrete objects that people rarely if ever physically interact with, such as most animals (Martin, 2007). Given our interest in understanding potential benefits of motor information generated during memory encoding, the motor information constitutive of specific concepts also requires consideration.

Representational differences at the concept level may impact how well items are remembered. Embodied cognition suggests that we 'know' about concepts by reactivating the pattern of sensory and motor activity that is elicited as we experience the item in the environment (Barsalou, 2008; Casasanto, 2022). Previous research has demonstrated effector-specific re-activation during tasks that involve reading verbs, sentences, and observing action (Hauk et al., 2004; Jirak et al., 2010). Such findings demonstrate that concepts are defined by the pattern of sensory and motor information elicited as the action is performed, and thinking about action verbs (without performing the action) involves activity in similar regions. Further, this demonstrates that motor representations play a role in cognition even when a task does not require movement; part of understanding what the concept is, thinking about the concept, or recognizing the item concept reactivation of these motor components.

Further, Martin et al. (1996) demonstrated that naming pictures of animals and tools activated different cortical areas, and these differences relate to experiential regularities with the exemplars. For example, naming tools is associated with activity in the left pre-motor hand area, whereas naming animals is associated with activity in the left-medial occipital lobe as well as bilateral temporal lobe activation. These results support the conclusion that activating concepts involves the reactivation of sensory and motor experiences.

An important question to ask is whether differences in concept representations that are tied to embodiment are functionally relevant for memory processes. Madan and Singhal (2012), demonstrated that free recall was impacted by the manipulability of a word’s referent. Participants rated concept referents on multiple scales including personal experience with the referent, and manipulability. They then completed a lexical decision task that included the rated words and other words and non-words, and finally a free recall task where they attempted to recall the labels of the exemplars from the rating task. In free recall, differences arose for manipulable compared to non-manipulable stimuli, indicating that manipulability of the referent impacted memory. Interestingly, manipulability helped or hindered item memory in free recall depending on the task context in which the words were first presented. Thus, representational differences in the information that constitutes a concept impact memory, and the way in which these differences manifest depends on the task context.

The Current Study

It remains unclear whether and how manipulability, or representational differences more broadly, interact with enactment effects. We aimed to answer this question with a memory task that required encoding and subsequent recall of associations between objects and their locations. We contrasted the effect of enactment for concepts that are either high or low in manipulability, allowing us to examine whether previously learned motor information interacts with the motor information generated during encoding.

We used a paradigm developed by Tompary, Zhou, and Davachi (2020) that allows for the precise assessment of the accuracy of previously studied object-location associations. In Tompary et al.'s study phase, participants viewed pictures of objects presented in the center of a screen, and placed them at target locations using a mouse. Test items also appeared in the center of the screen, and participants were instructed to place them in the studied position. We modified this paradigm by including an additional condition during learning in which participants watched passively as the items were placed at the assigned location. Immediately after learning, participants were tested on these object-location associations.

We predicted an enactment effect such that actively placing objects at study, as compared to passively observing their placement, would lead to more precise recall of the object-location associations at test. We also predicted that the enactment benefit would interact with manipulability, with action during encoding having a greater effect on high compared to low manipulability items.

Methods

Participants

Thirty-five individuals (mean age = 20 years, range 18 to 33, SD = 4; 22 female, 12 male, 1 declined to report gender) participated in person for course credit or $15. All participants gave informed consent prior to participating. This project was approved by the Research Ethics Board at the University of Western Ontario.

Design and Procedure

We used a within participants two (learning condition: active vs. passive) by two (manipulability: high vs. low) design.

Experimental Paradigm. In the learning phase, active and passive trials were blocked, with the order of the blocks randomized for each participant. In each block participants learned object-location associations for 30 objects: 15 animals and 15 tools. Participants completed 2 initial active and 2 initial passive learning blocks in which each image was presented with a specific location. The participant repeated the learning phase three times (three runs). See Figure 1 for a detailed overview of the learning paradigm.

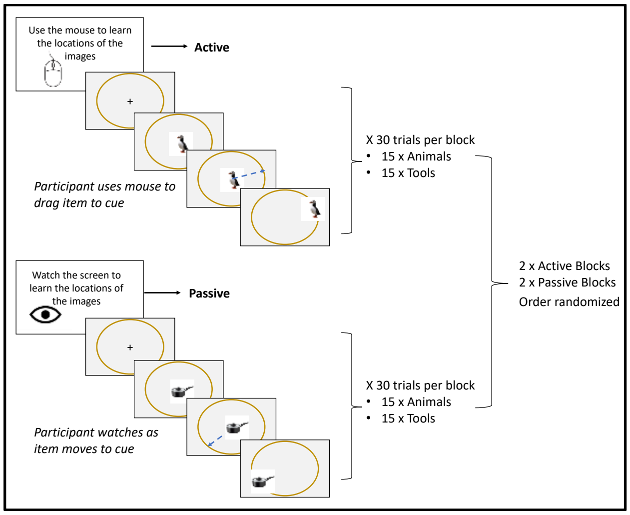

Figure 1: Overview of Experimental Paradigm. Presents trial and block structure in first (out of three) learning runs.

Stimuli. Coloured images measuring 300x300 pixels were presented on a white background. Half of the images were animals and half were tools.

Items were selected to maximally differ on Body Object Interaction (BOI) ratings (Pexman et al., 2019). BOI ratings measure the extent to which a human body interacts with an object.

The stimuli were equated on multiple lexical and visual dimensions (see Table 1). These included concreteness ratings from Brysbaert et al. (2014), and familiarity ratings from the Glasgow Norms (Scott et al., 2019), supplemented with familiarity ratings from the BOSS stimulus set (Brodeaur, 2010) for items not included in the Glasgow norms.

The normative ratings were based on words denoting the concepts, but we used pictures as stimuli. Therefore, we measured name agreement for our pictures. Ten participants viewed and labeled the images. We matched name agreement across the lists, ensuring that there were no significant differences in name agreement for animals and tools.

We also controlled for the percentage white space in the image to minimize visual dissimilarity between categories. However, we note that other potentially relevant visual features (e.g., complexity) were not measured.

Table 1: Means and paired samples *t*-tests for stimuli dimensions

	Animals	Tools	*p* value
BOI	3.92	6.12	<.0001
Name-Agreement	8.78	9.22	.109
Familiarity	4.87	5.06	.266
Percentage White Space	24.96	26.27	.156
Concreteness	4.87	4.84	.567

Recordings for Passive Condition. To create the passive learning condition, we recorded the learning sessions from five "seed participants" (whose data were not included in the analyses presented below). The seed participants were recorded as they attempted to learn the locations for images by moving images to cued locations (active learning). We used seed participants rather than programming the trajectories of the movements to ensure that the movements observed in the passive learning condition were similar to the active learning condition with respect to the shape of the movement, and the time taken to reach target location. That is, the movements viewed by participants in the passive condition were human-generated.

Item locations were randomized for each seed participant. All experimental participants who were trained using the same seed data learning identical object-location associations for both the active and passive trials. There was a distribution rule for each of the stimulus categories, wherein the centers for each category's distribution were separated by 180 degrees. Images were distributed around the center of the category so that, for each participant, tools tended to be located in one area, and animals tended to be located in another area. There was some overlap in the distributions. The location for the center of the category distribution was randomly selected for each seed participant. This ensured that, for example, tools were not always on the right of the screen.

Learning

Active Learning. Participants used the mouse to click and drag images to a specified location. All images were presented in the center of the screen surrounded by a yellow ring. The target location for each image was indicated visually, with a red line on the perimeter of the circle.

Passive Learning. Passive learning was identical to active learning except that participants watched as images travelled to specified locations, rather than moving them.

Test

The test phase occurred immediately after the learning trials. Images were presented in the center of the screen. Identical to the learning phase, the images were surrounded by a yellow ring. Unlike the learning phase, the target location was not presented with the visual cue. On each trial, participants used the mouse to click and drag the item to the learned location.

From the test data, we calculated three dependent measures. **Precision** is the angular distance between the learned location and the recalled position during the test. **Response time** is the duration between the presentation of the image and the placement of the image in the recalled location at test. **Maximum Deviation** is the largest departure from the idealized trajectory during the movement of the image from the center of the ring to the recalled location.

Results

LME Results

We used Linear Mixed Effects models with fixed effects for enactment, embodiment, the interaction between embodiment and enactment. We also included participants as a random effect. Because the stimuli were not nested within learning condition across all participants, we did not include stimulus as a random factor. We ran identical models for all three dependent variables.

Precision. Learning Condition (γ_{1000} = 7.84, p <.001) and Stimulus Type (γ_{0100} = -2.94, p<.001) were both significant predictors (Figure 2). Accounting for the contributions of the other predictors, active learning led to item placements that were 7.84 degrees more precise than those made after passive learning. Further, accounting for the contributions of the other predictors, tools were placed 2.94 degrees more precisely than animals. The interaction between learning condition and stimulus type was not significant (γ_{0010} = -0.81, p = 0.768).

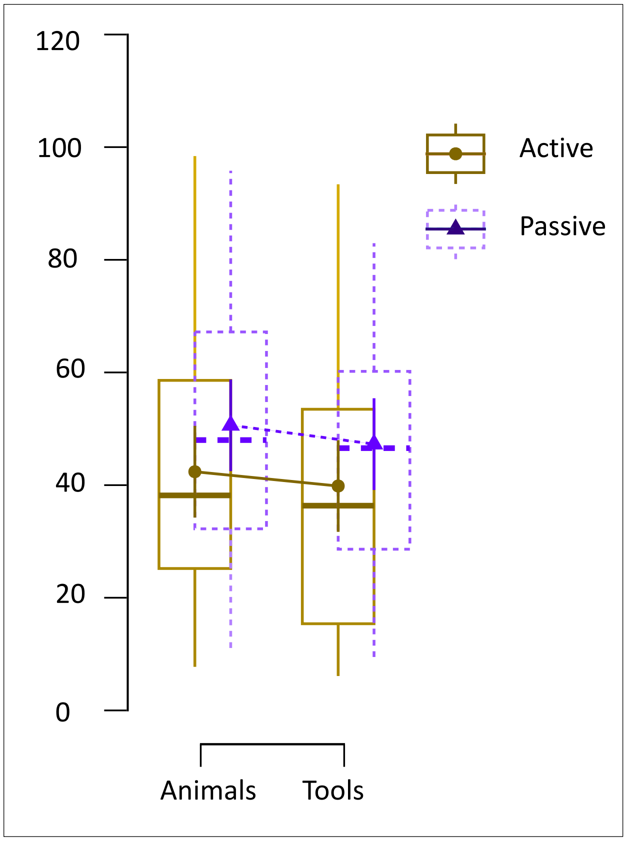

Figure 2: Precision Results

Response Time. Learning Condition ($\gamma_{1000} = 0.25$, $p < .001$) and Stimulus Type ($\gamma_{0100} = -0.19$, $p = .003$) were both significant predictors (Figure 3). Accounting for the contributions of the other predictors, active learning led to recall attempts that were 246 ms faster than those made after passive learning. Further, accounting for the contributions of the other predictors, tools were placed 191 ms faster than animals. The interaction between learning condition and stimulus type was not significant ($\gamma_{0010} = -0.03$, $p = 0.789$).

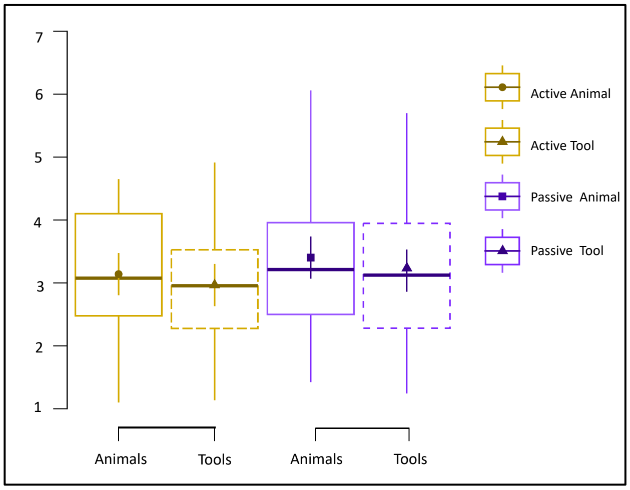

Figure 3: Response Time Results

Maximum Deviation. The largest departure from the idealized trajectory during the movement of the image was not significantly influenced by Learning Condition ($\gamma_{1000} = 2.88$, $p < .326$) (Figure 4). Stimulus Type ($\gamma_{0100} = -6.80$, $p = .021$) was a significant predictor; the height of the trajectory of the participants' movements were 6.80 pixels smaller when the item was a tool compared to when it was an animal. The interaction between learning condition and stimulus type was not significant ($\gamma_{0010} = -4.25$, $p = .459$).

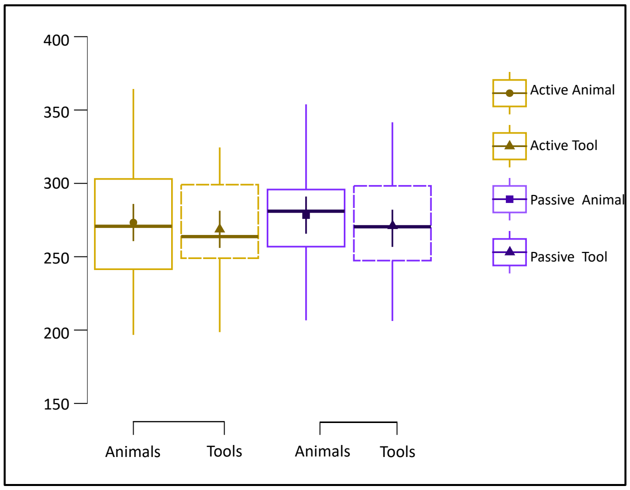

Figure 4: Maximum Deviation Results

Discussion

This is the first study to find evidence for an enactment effect in memory for object-location associations. Actively moving object images to target locations at study, rather than observing the same movements, improved the precision of subsequent recall for object locations. Furthermore, we found new evidence for an embodiment effect in that tools were placed more precisely than animals. This effect did not interact with enactment.

An enactment effect was obtained for precision and response times. Because we observed improved accuracy and shorter response times, our findings do not suggest a speed accuracy trade off.

The current findings extend the literature on enactment effects by showing that such effects also play out in the context of associative learning. Using an object-location learning paradigm allowed us to test the impact of embodiment on association learning when the association was arbitrary (i.e., when it was not semantically derived). Relational binding, perhaps especially between objects and locations (i.e., where), is an important feature of the episodic memory system (Tulving, 2002). The current study investigated enactment in this unique episodic context. We found novel evidence that enactment did benefit association learning, demonstrating that action during learning improved memory for locations when the object is used as a cue. These findings are consistent with an interpretation that motor information can support the formation of rich object-location associations and that the resulting multimodal encoding offers benefits for their subsequent recall.

Empirically, embodiment and enactment have rarely been investigated in the same paradigm in the memory literature. In one notable exception, Sidhu and Pexman (2016). compared the memorability of words that were high in embodiment (having more to do with the human body) with those that were low in embodiment. High and low embodiment words were studied by participants either in 'imagined enactment' or control conditions. High embodiment words were better remembered than low embodiment words, and enactment study conditions led to better recall of all words. Interestingly, when the enactment effect emerged, it was independent from embodiment. The authors suggested that the independence of enactment and embodiment could indicate that they act at different stages of processing, emphasizing that embodiment is an implicit automatic process whereas enactment is deliberate. The observed differences may indicate that enactment and embodiment contribute to recall at different times, making it unlikely that they would interact. The current results are open to such an interpretation as well in as much as enactment is arguably still more strongly tied to deliberate processing when forming of object-location associations is required.

One avenue for future research could be to take advantage of the temporal acuity of EEG to identify the time course of motor signals activated during enactment and during the recall of object-location associations. This would allow us to empirically evaluate whether motor representations related to enactment and embodiment influence retrieval at different stages of processing. Previous EEG work on enactment has identified an increased positive potential from 600-800ms post stimulus during retrieval of words learned with enactment (Senkfor et al., 2002; Leynes, Grey, & Crawford, 2006). In contrast, existing EEG work on manipulability has shown an earlier increased negativity for concepts high in manipulability with differences detected between 210-270ms (Proverbio, Adorni, D'Aniello, 2011; Proverbio, Del Zotto, & Zani, 2007). It is important to note, however, that the stimuli used in enactment studies often differs from those used in studies of embodiment. As such, comparing embodiment and enactment effects within the same EEG study is an important step for understanding their impact on memory.

We also found that in both active and passive learning, participants were more precise, faster, and moved more directly when placing the tools than when placing the animals in their studied locations at study. Category level differences (defined by the motor constitution of category members) have been shown to impact memory in other experimental paradigms (Madan & Singhal, 2012; Sidhu & Pexman, 2016). but to our knowledge, not in the literature on object-location memory. These effects typically are interpreted as evidence for embodiment in the representations that support memory retrieval. This type of interpretation has received the strongest support from neuroimaging studies that reveal a category specific engagement of the motor system even in tasks that do not require any online manipulation of objects (Martin, 1996; Hauk et al. 2004). Against this background, the category effect observed in the current study may reflect similar engagement of the motor system at the time of retrieval. In other words, motor information may also be driving the observed effect in memory for object-location that was observed in the current study. To the extent that the task employed at test required motor engagement (i.e. the active placement of the items in the recalled locations), motor information is clearly relevant. Indeed, the stimuli from both categories were chosen to maximize the difference in BOI scores which reflect the extent to which human bodies can interact with these object concepts. Future neuroimaging research provides an opportunity to more directly assess the engagement of motor representations when participants recall the locations of tools as compared to animals in object-location memory.

One critical consideration for future research is to determine whether the observed enactment effect in memory for object-location is present only when recall is probed through active placement at test, as was the case in the current study, or whether it may also be observed when the test does not necessitate any active movement (e.g. in a forced choice recognition memory test for object location). Theoretically, this distinction is important as it will address whether the effect reflects a beneficial alignment between encoding and retrieval processes based on motor information (i.e. the encoding specificity principle Tulving & Thompson, 1973) or whether it reflects improved encoding processes through added multimodal information that can be expressed behaviorally even when there is no engagement of the motor system at retrieval.

Overall, the current findings highlight the importance of considering the role of motor information in memory for object-locations. This research represents an important extension and integration of both the enactment and the embodiment literatures. Our findings suggest that motor information may come into play at multiple levels of processing during memory retrieval. As illustrated in the discussion, these findings invite exciting future research that will allow us to disentangle and more firmly establish the nature of the motor information that contributes to both enactment and embodiment.

References

Asher, J. J. (1966). The Learning Strategy of the Total Physical Response: A Review. The Modern Language Journal, 50(2), 79–84.

Bäckman, L. (1985). Further evidence for the lack of adult age differences on free recall of subject-performed tasks: The importance of motor action. Human Learning, 4(2), 79–87.

Barsalou, L. W. (2008). Grounded Cognition. Annual Review of Psychology, 59(1), 617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Brodeur, M. B., Dionne-Dostie, E., Montreuil, T., & Lepage, M. (2010). The Bank of Standardized Stimuli (BOSS), a New Set of 480 Normative Photos of Objects to Be Used as Visual Stimuli in Cognitive Research. PLoS ONE, 5(5), e10773. https://doi.org/10.1371/journal.pone.0010773

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. Behavior Research Methods, 46(3), 904–911. https://doi.org/10.3758/s13428-013-0403-5

Casasanto, D. (2022). Embodied Semantics. In Handbook of Cognitive Semantics. Leiden: Brill. https://www.casasanto.com/papers/Casasanto%20Embodied%C2%A0Semantics%C2%A02022.pdf

Cohen, R. L. (1981). On the generality of some memory laws. Scandinavian Journal of Psychology, 22(1), 267–281. https://doi.org/10.1111/j.1467-9450.1981.tb00402.x

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic Representation of Action Words in Human Motor and Premotor Cortex. Neuron, 41(2), 301–307. https://doi.org/10.1016/S0896-6273(03)00838-9

Jirak, D., Menz, M. M., Buccino, G., Borghi, A. M., & Binkofski, F. (2010). Grasping language – A short story on embodiment. Consciousness and Cognition, 19(3), 711–720. https://doi.org/10.1016/j.concog.2010.06.020

Johansson, R., & Johansson, M. (2014). Look Here, Eye Movements Play a Functional Role in Memory Retrieval. Psychological Science, 25(1), 236–242. https://doi.org/10.1177/0956797613498260

Jones, G. V., & Martin, M. (2009). Spatial recall improved by retrieval enactment. Psychonomic Bulletin & Review, 16(3), 524–528. https://doi.org/10.3758/PBR.16.3.524

Kobayashi, H., Seki, K., & Mimura, M. (2010). Influence of subject-performed tasks on memory in healthy individuals using fMRI study comparison of verbal tasks with subjectperformed tasks. Journal of the Showa Medical Association, 70(1), 90–96.

Leynes, P. A., Grey, J. A., & Crawford, J. T. (2006). Event-related potential (ERP) evidence for sensory-based action memories. International Journal of Psychophysiology, 62(1), 193–202. https://doi.org/10.1016/j.ijpsycho.2006.04.003

Madan, C. R., & Singhal, A. (2012). Encoding the world around us: Motor-related processing influences verbal memory. Consciousness and Cognition, 21(3), 1563–1570. https://doi.org/10.1016/j.concog.2012.07.006

Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. Nature, 379(6566), 649–652. https://doi.org/10.1038/379649a0

Pexman, P. M., Muraki, E., Sidhu, D. M., Siakaluk, P. D., & Yap, M. J. (2019). Quantifying sensorimotor experience: Body–object interaction ratings for more than 9,000 English words. Behavior Research Methods, 51(2), 453–466. https://doi.org/10.3758/s13428-018-1171-z

Postma, A., Kessels, R. P. C., & van Asselen, M. (2008). How the brain remembers and forgets where things are: The neurocognition of object–location memory. Neuroscience & Biobehavioral Reviews, 32(8), 1339–1345. https://doi.org/10.1016/j.neubiorev.2008.05.001

Proverbio, A. M., Adorni, R., & D'Aniello, G. E. (2011). 250ms to code for action affordance during observation of manipulable objects. Neuropsychologia, 49(9), 2711–2717. https://doi.org/10.1016/j.neuropsychologia.2011.05.019

Proverbio, A. M., Del Zotto, M., & Zani, A. (2007). The emergence of semantic categorization in early visual processing: ERP indices of animal vs. artifact recognition. BMC Neuroscience, 8(1), 24. https://doi.org/10.1186/1471-2202-8-24

Roberts, B. R. T., MacLeod, C. M., & Fernandes, M. A. (2022). The enactment effect: A systematic review and meta-analysis of behavioral, neuroimaging, and patient studies. Psychological Bulletin, 148(5–6), 397–434. https://doi.org/10.1037/bul0000360

Russ, M. O., Mack, W., Grama, C.-R., Lanfermann, H., & Knopf, M. (2003). Enactment effect in memory: Evidence concerning the function of the supramarginal gyrus. Experimental Brain Research, 149(4), 497–504. https://doi.org/10.1007/s00221-003-1398-4

Scott, G. G., Keitel, A., Becirspahic, M., Yao, B., & Sereno, S. C. (2019). The Glasgow Norms: Ratings of 5,500 words on nine scales. Behavior Research Methods, 51(3), 1258–1270. https://doi.org/10.3758/s13428-018-1099-3

Senkfor, A. J., Petten, C. V., & Kutas, M. (2002). Episodic Action Memory for Real Objects: An ERP Investigation With Perform, Watch, and Imagine Action Encoding Tasks Versus a Non-Action Encoding Task. Journal of Cognitive Neuroscience, 14(3), 402–419. https://doi.org/10.1162/089892902317361921

Sidhu, D. M., & Pexman, P. M. (2016). Is Moving More Memorable than Proving? Effects of Embodiment and Imagined Enactment on Verb Memory. Frontiers in Psychology, 7. https://doi.org/10.3389/fpsyg.2016.01010

Sivashankar, Y., Liu, J., & Fernandes, M. A. (2023). The importance of performing versus observing meaningful actions, on the enactment benefit to memory. Journal of Cognitive Psychology, 35(1), 47–58. https://doi.org/10.1080/20445911.2022.2102639

Tompary, A., Zhou, W., & Davachi, L. (2020). Schematic memories develop quickly, but are not expressed unless necessary. Scientific Reports, 10(1), 16968. https://doi.org/10.1038/s41598-020-73952-x

Tulving, E. (2002). Episodic Memory: From Mind to Brain. Annual Review of Psychology, 53(1), 1–25. https://doi.org/10.1146/annurev.psych.53.100901.135114

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. Psychological Review, 80(5), 352–373. https://doi.org/10.1037/h0020071

Zimmer, H. D., & Engelkamp, J. (1989). Does motor encoding enhance relational information? Psychological Research, 51(4), 158–167. https://doi.org/10.1007/BF00309143