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CHAPTER FIVE

The Role of Motor Action in Memory for Objects and Words

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Contents

Abstract

Behavioral and neuroimaging data suggest that the actions associated with objects and words are automatically activated during object and word recognition. For example, recognition of a hammer activates the grip that is used to grasp a hammer and the actions that are performed when using a hammer. The question addressed in this review is whether these motor simulations support short-term and long-term memory for objects and verbs that are associated with actions. A meta-analysis shows that there is no evidence supporting a role for motor simulations in short-term recognition and *n*-back tasks. Serial recall tasks, on the other hand, have provided evidence that motor

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simulations support short-term memory. The majority of these studies, however, used procedures that emphasized actions. These studies do therefore not provide strong evidence for the view that motor actions are automatically activated and encoded in memory. More studies are needed to establish a role for motor actions in short-term memory when actions are not primed by the context of the experiment. Only a few studies have studied the role of motor simulations in long-term memory. The available evidence suggests that motor simulations do not affect encoding in long-term memory. Overall the results cast some doubt on the idea that action has a central role in cognitive processing.

1. INTRODUCTION

When people perceive a stimulus, they activate much more information than is actually present in the stimulus itself. For example, when a printed word is presented a phonological representation is activated even when there is no intention to say the word out loud. This phonological representation is activated even when the word is presented subliminally and some have argued that the phonological representation is not a mere by-product of visual word processing, but rather plays an important role in meaning access (van Orden, 1987). Semantic priming studies suggest that the meaning of a word is also automatically activated (e.g., den Heyer, Briand, & Dannenbring, 1983; Neely, 1977; Pecher, Zeelenberg, & Raaijmakers, 2002). Some recent studies even suggest that rather specific information related to the use of objects may be automatically activated when people view (pictures of) objects or even words referring to objects (e.g., Tucker & Ellis, 1998, 2004). If object perception and word reading automatically activate associated actions, the question arises whether this information is stored in memory and supports later memory for objects and words. It seems reasonable to assume that memory would benefit from storing the actions that are associated with objects. Including actions in memory would result in a richer memory trace, increasing the number of cues that could potentially be used to retrieve items and making individual items more distinguishable from each other. Moreover, if the actions that can be performed with an object are activated automatically, they might be encoded in memory. Finally, if our cognitive system has evolved to support our interactions with the environment, one might expect that actions play an important role in memory. In recent years, this question has started to gain attention in the literature. In this chapter, we provide an early review of these studies.

1.1 Grounded Cognition and Action

Initial theories of conceptual representations treated concepts as abstract, amodal entities. More recent theoretical views propose that conceptual representations are based on perceptual and motor experiences and share processing resources with perception and action (Barsalou, 1999; Glenberg, 1997). For example, the concept *coffee* consists of the color of coffee, its smell and taste, and also the mouthfeel and temperature associated with drinking coffee. On this view, a concept such as *coffee* is represented by running a perceptual simulation that involves the same perceptual systems that are involved in actual experiences with the concept. Evidence for this view was obtained, among others, by Pecher, Zeelenberg, and Barsalou (2003). They presented concept–property pairs in a property verification task and manipulated whether the properties on successive trials were from the same modality or not. Responses to concept–property pairs (e.g., *blender-loud*) were faster if the property on the previous trial was from the same modality (e.g., *leaves-rustling*) than if the property was from a different modality (e.g., *cranberry-tart*). Pecher et al. (2003) suggested that in perceptual simulations of concepts, analogous to switching costs observed in perception (Spence, Nicholls, & Driver, 2000), switching attention from one modality to another one incurs a switching cost. Many other studies have also obtained results consistent with the idea that perceptual simulations underlie conceptual representations (e.g., Marques, 2006; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008; Zwaan, Stanfield, & Yaxley, 2002; see Pecher, 2013b for an overview).

An important aspect of the grounded cognition view is that cognition is for action (Glenberg, 1997; Glenberg, Witt, & Metcalfe, 2013). Glenberg proposed that concepts are the meshed representations of two things: the affordances that are perceived in a current situation and memories of previous actions in similar situations. The concept of a functional object such as a hammer thus is a combination of the affordances that are perceived in the current hammer (e.g., grasping the handle) and memories of previous actions that were performed with hammers. On this account, concepts support interactions with the environment by activating previous actions. This view suggests that other cognitive processes such as language understanding and memory, in the absence of the actual objects, also might rely on the activation of simulated actions.

Evidence in support of this view is that pictures of objects potentiate actions that are compatible with the objects (Tucker & Ellis, 1998, 2004).

For example, when participants have to categorize objects as natural or artifacts, responses are faster when the response grip (e.g., a pinch between thumb and index finger) matches the grip that would be used on the object (e.g., a paperclip) than when it does not match (e.g., a hammer). This effect is caused not only by the visible features of objects but also by knowledge of objects, because similar findings are obtained when the stimuli are pictures of objects or object names (Bub & Masson, 2010b; Bub, Masson, & Cree, 2008; Glover, Rosenbaum, Graham, & Dixon, 2004; Masson, Bub, & Lavelle, 2013; Masson, Bub, & Warren, 2008; Rueschemeyer, Lindemann, Rooij, van Dam, & Bekkering, 2010; Tucker & Ellis, 2004). Furthermore, Bub et al. (2008) showed that not only volumetric grasping responses were activated but also functional motor actions, and Masson, Bub, and Breuer (2011) showed that orientation congruency effects for grasping responses to object pictures depended on whether the resulting grip allowed functional use of the object. These two studies thus showed that actions that may not be directly perceived in the object are also activated, suggesting that motor actions are retrieved from memory. Neuroimaging studies have shown activation of brain areas that are associated with motor actions when participants process manipulable objects (Buccino, Sato, Cattaneo, Rodà, & Riggio, 2009; Chao & Martin, 2000; Creem-Regehr & Lee, 2005; Martin & Chao, 2001; Martin, Wiggs, Ungerleider, & Haxby, 1996; Rueschemeyer, van Rooij, Lindemann, Willems, & Bekkering, 2009). These findings support the idea that motor actions that are typically used during interactions with objects are also activated during mental representation of those objects (but see Proctor & Miles, 2014 for an alternative view), suggesting that concepts are supported by motor simulations.

During language processing, simulated motor actions seem to play a role in comprehension (Borghi & Riggio, 2009; Casteel, 2011; Myung, Blumstein, & Sedivy, 2006). For example, Klatzky, Pellegrino, McCloskey, and Doherty (1989) showed that priming a compatible hand configuration facilitated comprehension of sentences such as *squeeze a tomato*. Several other studies have shown that language comprehension activated response actions that were congruent with some aspect of the action described in the language, such as direction (Glenberg & Kaschak, 2002), rotation (Taylor, Lev-Avi, & Zwaan, 2008; Zwaan & Taylor, 2006), or the action goal (Lindemann, Stenneken, van Schie, & Bekkering, 2006). Holt and Beilock (2006) showed that sentence—picture matching was influenced by the participant's experience with the action described by the sentence, also suggesting that action simulation is based on memory for previous actions.

Activation of motor areas when participants read action verbs or sentences further suggests a role of motor knowledge for higher cognition (Hauk, Johnsrude, & Pulvermüller, 2004; Raposo, Moss, Stamatakis, & Tyler, 2009; Rueschemeyer, Brass, & Friederici, 2007; Saccuman et al. 2006; Tettamanti et al., 2005; Willems & Hagoort, 2007).

Although this evidence seems to overwhelmingly show that motor actions are fundamental for understanding concepts and language, most findings of motor activation do not necessarily reflect core features of the conceptual process itself. Rather, congruency effects might be the result of secondary activation (Bub et al., 2008; Mahon, 2015a, 2015b; Mahon & Caramazza, 2008; Masson, 2015; Page, 2006) that occurs after the concept has already been understood. In order to argue that motor actions are necessary for understanding, we need to show that when activation of motor actions is compromised, conceptual understanding suffers. In neuropsychology, however, data from patients with damage to the motor system do not always indicate major problems for conceptual processing (Mahon, 2015a). In behavioral studies, the evidence is mixed. Typically, participants are asked to perform a conceptual task on objects that are manipulable (e.g., tools) and on objects that are nonmanipulable (e.g., animals). For manipulable objects, motor actions should be important for understanding, while for nonmanipulable objects they should not. Following this logic, a concurrent motor task should interfere with the understanding of manipulable objects but not, or less, with the understanding of nonmanipulable objects. Some studies have indeed obtained evidence that motor interference is more disruptive for conceptual processing of manipulable than nonmanipulable objects. For example, when participants name or categorize object pictures, performance for manipulable objects is decreased when participants are using their grasping hand for an unrelated concurrent action, whereas performance for nonmanipulable objects does not suffer (Witt, Kemmerer, Linkenauger, & Culham, 2010; Yee, Chrysikou, Hoffman, & Thompson-Schill, 2013; see also Rueschemeyer, Lindemann, Rooij, Dam, & Bekkering, 2010). Other studies, however, have failed to find effects of motor interference on conceptual processing (Matheson, White, & McMullen, 2014a, 2014b; Postle, Ashton, McFarland, & de Zubicaray, 2013). In sum, although more research might be needed to establish to what extent motor interference disrupts conceptual processing, several studies have shown that concepts and motor actions are strongly related.

Given this importance of motor actions for concepts and language understanding, we asked what the role of motor actions would be for more explicit types of memory, such as short-term memory and long-term episodic memory. It has been long established that episodic memory is influenced by conceptual variables such as category membership. For example, the release from proactive interference effect shows that interference between items in memory depends on conceptual overlap between items (Marques, 2000; Wickens, 1970; Wickens, Dalezman, & Eggemeier, 1976; Zinober, Cermak, Cermak, & Dickerson, 1975) and memory for word lists is affected by the conceptual organization of the study list (Lewis, 1971). These, and many other findings (e.g., Barclay, Bransford, Franks, McCarrel, & Nitsch, 1974; Deese, 1959; Hemmer & Steyvers, 2009; Light & Carter-Sobell, 1970), show that people rely on conceptual information to store items in and retrieve items from memory. Assuming that motor actions form a part of conceptual knowledge, motor actions should play an important role in memory.

2. SHORT-TERM MEMORY

Below we will first describe recently published studies examining the role of motor affordances in short-term or working memory.[1] The number of published studies on this topic is still small, especially when compared to the large number of studies examining the online activation of affordances by objects and words. We take advantage of this by describing the studies in relative detail. We will then evaluate whether the results of these studies support a role for motor simulations in short-term memory for objects and words. We will also examine the factors, if any, that modulate when motor affordances do and do not play a role in maintaining representations in short-term memory.

2.1 Neuroimaging Evidence

Mecklinger, Gruenewald, Weiskopf, and Doeller (2004) investigated the role of motor affordances in visual working memory for manipulable and nonmanipulable objects in an functional magnetic resonance imaging (fMRI) study. On each trial a line drawing of an object was presented on the screen for 100 ms. After 4 s a task cue was presented, which indicated the task to be performed on the test stimulus which was presented 6 s after the task cue. The task consisted of either a memory task or a control task. In the memory task,

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[1] We use the terms short-term memory and working memory interchangeably.

participants decided if the test stimulus was identical to the studied object or whether the test stimulus was a mirror image of the studied object. In the control task, participants decided whether two digits, presented to the left and right of the test object, were identical or not. Mecklinger et al. inspected activation patterns on memory trials relative to control trials. For manipulable objects, but not for nonmanipulable objects, enhanced activation of the left ventral premotor cortex (PMC) was observed. For nonmanipulable items, enhanced activation was found in the left inferior frontal gyrus (Broca's area). These findings suggest that motor programs play a role in the maintenance of manipulable objects in working memory, whereas speech programs play a role in the maintenance of nonmanipulable objects. In a subsequent experiment, participants performed two different memory tasks (and the control task). In the movement comparison task, participants decided whether the test stimulus (e.g., *fork*) and study stimulus (e.g., *spoon*) afforded similar hand movements. In the size comparison task, participants decided whether the test stimulus (e.g., *whistle*) and study stimulus (e.g., *lipstick*) were of similar size. The primary result of this experiment was that activation of the ventral PMC was enhanced in the movement comparison task relative to the size comparison task. This result suggests that the involvement of the motor system in maintaining objects in working memory is to some degree dependent on task requirements.

A number of factors complicate interpretation of these results. First, the data analyses were performed on only a subset of the stimuli (high symmetry objects, but not low symmetry objects). Second, each object was presented only twice in the experiment. In working memory experiments, a small set of stimuli is typically presented multiple times to limit contributions from long-term memory. When stimuli are presented only once or twice in the experiment, a significant part of performance may be based on retrieval from long-term memory. Third, Mecklinger et al. (2004) also obtained activation of the left ventral PMC in a passive viewing task. The activation of the left ventral PMC can therefore not be unambiguously attributed to the maintenance of objects in working memory. Finally, drawing causal conclusions about mental processes from fMRI results is problematic (e.g., Page, 2006; Poldrack, 2008). One problem is that the observation that a specific brain region is active during the performance of a certain task does not imply that the specific region is necessary or sufficient for performing the task.

Thus, the results of Mecklinger et al. (2004) are consistent with the idea that motor simulations play a role in maintaining object representations in working memory. Alternative interpretations, however, are that the results reflect contributions from long-term or semantic memory, instead of short-term memory, or that activation of the PMC was merely epiphenomenal. In the next section we discuss behavioral studies, inspired by the findings of Mecklinger et al., that attempted to establish a causal role for motor simulations in short-term memory.

2.2 Motor-Interference Effects

The results of Mecklinger et al. (2004) showed enhanced activation of motor areas when people had to maintain manipulable objects in short-term memory. This suggests the possibility that the motor system plays a functional role in short-term memory for objects. If indeed the motor system contributes to memory for objects, interfering with the motor system should negatively affect memory performance. Witt et al. (2010) (but see Matheson, White, & McMullen, 2014b) found that a motor-interference task affected naming latencies for pictures of tools, but not for pictures of animals. They argued that the concurrent motor task interfered with the ability to form a grasping simulation and that motor simulations play a functional role in tool identification. Moreover, Smyth and Pendleton (1989) showed that working memory span for sequences of hand configurations was decreased by a concurrent task that changed the hand configuration (squeezing a tube). Likewise, if motor simulations support working memory for words and objects, concurrent motor-interference tasks are expected to affect working memory performance.

2.2.1 Effects of Interfering Actions on Short-Term Recognition Memory for Objects

Several studies have investigated whether motor-interference tasks differentially affect performance in short-term memory tasks for stimuli that differ in the way they are associated to motor actions. Pecher (2013a) studied the role of motor affordances in a short-term recognition task. On each trial, a stimulus was presented and after a 5000-ms retention interval the test stimulus was presented. Participants had to decide whether the test stimulus was identical to the studied stimulus or not. During the retention interval, participants performed a motor-interference task, a verbal-interference task, both tasks simultaneously, or no task. In the motor-interference task, participants started by making a fist with both hands. They then opened their fist by stretching their fingers one by one (simultaneously for both hands), starting with their thumbs, until their hands were completely opened.

Subsequently, participants made two fists again and opened their fingers in the same prescribed pattern, and so on. Importantly, this interfering task resulted in continuous changes in the hand configuration which were expected to interfere with activation of motor actions related to grasping and using objects. In the verbal-interference task, participants repeated four nonsense syllables (*bah-doh-ree-su*) out loud. The stimuli were pictures of manipulable (e.g., *binocular, corkscrew, calculator*) and nonmanipulable objects (e.g., *parakeet, painting, chimney*). Because manipulable objects, but not nonmanipulable objects, are associated with motor actions the prediction was that a concurrent motor-interference task would be particularly detrimental to performance for manipulable objects. However, no interaction was found between type of object and type of interference task. To be clear, performing concurrent interference tasks did negatively affect performance relative to the no-task control condition, but not differentially for manipulable and nonmanipulable objects. Across five experiments, similar results were obtained with different types of distractors ("new" nonstudied stimuli or mirror images of the presented objects), different types of stimuli (pictures of objects or words referring to objects), and different memory loads (one or four stimuli were presented during study).

In a follow-up study, Pecher et al. (2013) presented manipulable and nonmanipulable objects in an *n*-back task (rather than a short-term recognition task). The lag varied from 1 to 4 and participants performed the same concurrent interference task as in Pecher (2013a). Performing concurrent interference tasks and longer lags negatively affected memory performance, but again there was no interaction between type of stimulus and type of interference task.

Quak, Pecher, and Zeelenberg (2014) manipulated the congruency of the studied objects and the concurrent motor task. Participants continuously performed a precision grip movement (squeezing and releasing a small foam rubber cylinder between the thumb and index finger), a power grip movement (squeezing and releasing a large foam rubber cylinder with the whole hand), or no concurrent task while performing a 3-back task. The stimuli consisted of pictures of nonmanipulable objects (e.g., *chimney, bridge*), manipulable objects that required a precision grip when interacted with (e.g., *needle, paper clip*), and manipulable objects that required a power grip when interacted with (e.g., *hammer, axe*). Again, it was expected that nonmanipulable objects would suffer less from performing a concurrent motor task than manipulable objects. Moreover, if the maintenance of object representations in short-term memory is supported by motor affordances, performing an incongruent motor task (e.g., performing a power grip movement while remembering objects that are associated with a precision grip) should result in worse performance than performing a congruent concurrent motor task. However, no interaction between type of object and concurrent task was found. Again, performing a concurrent motor task relative to performing no concurrent task had a detrimental effect on performance (but equally for all conditions, as indicated by the lack of an interaction). Similar results were obtained irrespective of whether the different types of object pictures were blocked (Experiment 1) or whether the presentation of manipulable and nonmanipulable objects was mixed (Experiment 2).

2.2.2 Effect of Limb Movements on Short-Term Memory for Action Verbs

In contrast to this series of studies, Shebani and Pulvermüller (2013) obtained evidence suggesting that the motor system is involved in short-term memory for words. Shebani and Pulvermüller presented arm-related action words (*grasp, clap*) and leg-related action words (*hike, kick*) for study in a serial order recall task. On each trial, four words (either all arm-related action words or all leg-related action words) were presented one at a time for 100 ms, followed by a 400-ms inter-stimulus interval. Stimulus presentation was followed by a 6-s retention interval after which the four words had to be recalled in the order in which they had been presented. Crucially, during the retention interval, participants performed one of four interference tasks: moving with the hands, moving with the feet, articulatory suppression, or no task. Of primary interest were the hand and foot movement conditions. In these conditions, participants tapped a drumming sequence alternating between the right and left known as the single paradiddle (RLRRLRLL) with their hands or their feet. Participants made more errors in the immediate serial recall task when the type of action word was concordant with the motor-interference task performed during the retention interval than when the type of action word and motor-interference task were not concordant. Thus, tapping a paradiddle with the hands was particularly detrimental for arm-related action words, whereas tapping a paradiddle with the feet was particularly detrimental for leg-related action words. These findings are consistent with the view that tapping the paradiddle with the hands interferes with forming a motor simulation for arm-related action words that supports the maintenance of a representation of the action word in memory. Likewise, tapping the paradiddle with the feet interferes with forming a motor simulation for leg-related action words. Thus, in contrast to the studies from our lab with object pictures, the results of Shebani and Pulvermüller suggest that motor simulations play a role in working memory for action words.

Note that there are many differences between the experiment by Shebani and Pulvermüller (2013) and those of Pecher (2013a), Pecher et al. (2013) and Quak et al. (2014), in particular in the motor-interference tasks, stimuli and memory tasks being used. To uncover the critical differences responsible for these different findings, Zeelenberg and Pecher (2015b) performed two experiments. In a first experiment we examined whether the difference in results might be due to Shebani and Pulvermüller's (2013) use of the single paradiddle as a motor-interference task. The paradiddle might interfere more with the activation and storage of motor-interference in memory for several reasons. First, more so than the motor-interference tasks used by Pecher (2013a), Pecher et al. (2013), and Quak et al. (2014), the single paradiddle requires participants to closely monitor performance in the motor-interference task. Second, adequately performing the single paradiddle requires some practice to learn the correct sequence of alternating movements of the two hands or feet. Third, the speed at which participants performed the motor-interference task during the main experiment was individually adjusted depending on performance during the practice phase so that each participant did the task at the maximum speed at which they could still correctly perform the paradiddle.

In Experiment 1 of Zeelenberg and Pecher (2015b), the same materials and memory task were used as in Pecher et al. (2013), but the interference task was the single paradiddle used by Shebani and Pulvermüller (2013). Participants performed an *n*-back task for manipulable and nonmanipulable pictures of objects. Simultaneously, they performed the single paradiddle with their hands or feet. If motor simulations play a role in working memory, tapping the paradiddle with the hands as compared to tapping the paradiddle with the feet should be particularly detrimental for manipulable objects because, in contrast to nonmanipulable objects, manipulable objects are associated with motor actions (with the hands). That is, an interaction between stimulus type and type of motor-interference task should be found. No such effect was found, however, suggesting that Shebani and Pulvermüller's success in finding differential effects of motor interference on memory performance was not simply due to the single paradiddle being more interfering than the motor tasks used in other studies.

In a second experiment, we used action verbs related to the arms and legs, just as Shebani and Pulvermüller (2013). As in the first experiment, an *n*-back task was used and participants performed the single paradiddle with their hands or their feet. The interaction between stimulus type (arm-related action verbs vs leg-related action verbs) and effector (hand vs foot paradiddle) was not significant. Thus, unlike Shebani and Pulvermüller, our experiment failed to provide evidence for a role of the motor system in short-term memory for actions words.

Both experiments of Zeelenberg and Pecher (2015b) were designed to bridge the procedural gap between earlier experiments performed in our lab and the procedure used by Shebani and Pulvermüller (2013). Our results indicate that Shebani and Pulvermüller's findings were not likely caused by their use of the single paradiddle as a motor-interference task or their use of action verbs rather than pictures of objects. A more plausible aspect responsible for the different findings is therefore that different memory tasks were used in the different studies. We have used tasks such as short-term recognition and *n*-back tasks in our lab, whereas Shebani and Pulvermüller used a serial order recall task. We are currently planning an exact replication of Shebani and Pulvermüller (2013) in which we use a serial order recall task. Assuming that we replicate their findings, this would suggest that recalling items in the order in which they were presented is a critical factor is obtaining action-based memory effects. The findings that we discuss next are consistent with this idea.

2.2.3 Effects of Concurrent Motor Actions on Memory for Order

Evidence for a role of the motor system in short-term memory was also obtained by Lagacé and Guérard (2015) who studied the effect of movement congruency on performance in an order reconstruction task. On each trial, six object pictures were presented and after presentation of the list, the six objects were simultaneously presented on the screen and participants had to indicate the order in which the objects had been presented. During study, each object picture was preceded by a 300-ms video displaying one of the three possible grips: (1) a *power grip* (the object is held against the palm of the hand and the fingers close toward the palm of the hand), (2) an *index—thumb grip* (a delicate grip requiring small force where the object is held between the index finger and the thumb), and (3) a *parallel extension grip* (the object is held between the thumb and the whole surface of the fingers, which are pressed tightly against each other).[2] Participants in the grasping condition had to perform the grip displayed in

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[2] The descriptions of the grips were copied from Downing-Doucet and Guérard (2014). Note that the *index—thumb grip* is identical to what others refer to as *precision grip* (e.g., Pecher, 2013a; Tucker & Ellis, 2001).

the video during the presentation of the subsequent object picture. Thus during each trial, six videos were presented which were each followed by an object picture while the participant performed the grip presented in the video. In half of the trials the video displayed an action congruent with the object picture (e.g., a video displaying a power grip followed by a picture of a hammer). In the remaining trials the video displayed an action incongruent with the object picture (e.g., a video displaying an index—thumb grip followed by a picture of a hammer). Participants in the control condition watched the sequence of videos and object pictures, but did not perform actions during study. The results showed that, for participants performing grips during study, order memory was better for congruent trials than for incongruent trials. For participants in the control group, no congruency effect was found.

Similar findings were obtained in another experiment in which participants did not pantomime the grasping action but rather pantomimed the actions associated with the use of an object. On each trial a sequence of prime pictures (surrounded by a blue frame) and target (surrounded by a red frame) pictures was presented. In half of the trials the action associated with the prime picture was congruent with the action associated with the target picture (e.g., prime picture: *axe*, target picture: *hammer*). In the other half of the trials the action associated with the prime picture was incongruent with the action associated with the target picture (e.g., prime picture: *corkscrew*, target picture: *hammer*). Again serial order memory was better for congruent trials than for incongruent actions, but only for participants who pantomimed the actions associated with the primes, and not for participants in the control condition who simply watched the study sequence.

2.2.4 Discussion of Motor-Interference Effects

In sum, working memory studies that have used motor interference to study the role of the motor system for memory have shown mixed results. Although some studies have shown that working memory for manipulable objects or action verbs is decreased when participants perform interfering motor actions, others have not obtained any evidence for a role of the motor system. A potential explanation for this difference is that the serial recall task might be more sensitive to motor information than item recognition tasks, but at present this explanation has not been tested.

2.3 Similarity-Based Effects

The two studies that we discuss next were modeled after two well-known effects of similarity among items on short-term memory performance: the similarity effect and the isolation effect. Many studies have shown that serial order recall for lists of similar items is worse than for lists of dissimilar items. Baddeley (1966) (also see Conrad, 1964), for example, found that recall of the order in which words had been presented during study was much lower for acoustically similar words (e.g., *mad, man, mat,* …) than for acoustically dissimilar control words (e.g., *cow, day, car,* …). Likewise, Jalbert, Saint-Aubin, and Tremblay (2008) showed impaired order recall for similarly colored squares as compared to dissimilarly colored squares. The isolation effect refers to the finding that items that possess a feature or characteristic that sets it apart from other items on the list are better recalled than items that do not possess such a feature. For example, Cimbalo, Capria, Neider, and Wilkins (1977) showed that consonants that differed in size and color from other items on the study list were better remembered than nonisolated control items (i.e., items not differing in these characteristics from surrounding items). For similar findings in the recall of spatial information, see Guérard, Hughes, and Tremblay (2008).

2.3.1 Motor-Similarity Effect

Downing-Doucet and Guérard (2014) investigated the effect of motor similarity on performance in an order reconstruction task; the same memory task that was used by Lagacé and Guérard (2015). Participants studied pictures of objects that were each associated with two out of four possible actions: (1) a *power grip* (2) an *index—thumb grip*, (3) a *parallel extension grip*, and (4) a *fingers—thumb grip* (the object is in contact with most of the fingers and is held between the tip of the fingers and the thumb). For example, according to norms (Lagacé, Downing-Doucet, & Guérard, 2013) a small box is equally associated with a fingers—thumb grip and a parallel extension grip. Other objects were associated with different pairs of grips.

On each trial, Downing-Doucet and Guérard (2014) presented six different objects. Prior to each object, a 300-ms video was presented showing a hand making a grasping movement (see Lagacé & Guérard, 2015, Figure 1 for examples). On similar trials each video showed the same grasping movement; on dissimilar trials the videos showed different grasping movements.[3] An important aspect of the design was that the same objects were used in similar and dissimilar lists. What differed was the action "primed" by the video shown prior to each object picture. After

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[3] Because four different grips were used, some grips were shown more than once in a trial but all four grips were present in each trial.

presentation of the study list, the six objects were simultaneously presented on the screen and participants had to indicate the order in which the objects had been presented. Downing-Doucet and Guérard (2014) found that performance in this order reconstruction task was better for dissimilar lists than for similar lists. The advantage for dissimilar lists was absent in a follow-up experiment in which participants performed a concurrent motor-interference task (continuously opening and closing the fist in the manner used by Pecher, 2013a) during study. This finding is consistent with the idea that the concurrent motor task interfered with the formation of motor simulations for the presented objects. The results of Downing-Doucet and Guérard (2014) and the previously discussed study by Lagacé and Guérard (2015) are consistent with the notion that motor affordances play a role in short-term memory for object pictures. We note, however, that in both studies videos of hands making a grasping movement were shown prior to each object picture. This aspect of the design may have primed the use of motor affordances and be (partially) responsible for their success in obtaining evidence consistent with a role of motor affordances in short-term memory (see later for more discussion on this issue).

2.3.2 Motor-Isolation Effect

In another study, by Guérard and Lagacé (2014), motor actions were not explicitly primed. Guérard and Lagacé studied motor-isolation effects in serial recall. They reasoned that, in a way similar to the isolation effects described earlier, motor features associated with the stimuli might modulate memory performance. They presented pictures of objects that are easy to pantomime (*saw, punching bag, trampoline*) and pictures of objects that are hard to pantomime (*bust, moon, honeybee*). Although similar to the manipulable versus nonmanipulable manipulation used by Pecher (2013a), this distinction is different. For example, a *trampoline* could be considered a low manipulable object because one does not usually lift a *trampoline*, move it around, or change its orientation like one might do with a *comb* or a *fork*. Nevertheless, a *trampoline* is strongly associated with actions such as jumping and somersaulting and was thus considered a high pantomime object.

Guérard and Lagacé (2014) presented high and low pantomime objects in homogeneous or heterogeneous lists. The homogeneous lists consisted of either seven high pantomime objects or seven low pantomime objects. In heterogeneous lists the fourth object in the list differed in pantomime level from the other objects in the list (e.g., the fourth object was a high pantomime object and all other objects in the list were low pantomime objects).

If a motor-isolation effect is present, the fourth object in a heterogeneous list should be better recalled than the same object in a homogeneous list. This was indeed found by Guérard and Lagacé (2014). Moreover, their Experiment 2 showed that the motor-isolation effect was not present when participants performed a concurrent motor-interference task (continuously opening and closing the fist) throughout the experiment (i.e., during both encoding and recall). In Experiment 3, participants studied pictures of animals and pictures of man-made constructions. A (semantic or visual) isolation effect was present even though participants performed a concurrent motor-interference task (as they did in Experiment 2). This finding was taken to indicate that a motor-interference task selectively eliminates isolation effects that are based on the actions associated with objects but not those that are based on other features. In our view, this study provides one of the more convincing cases for a role of the motor system in working memory. First, unlike some of the other studies, the isolation manipulation does not explicitly draw attention to motor actions. Therefore, the effect might show that motor actions are spontaneously activated when participants memorize objects. Second, the concurrent motor task eliminated the motor-isolation effect, suggesting that the isolation effect actually depended on the motor system.

2.4 Other Studies on the Role of Motor Affordances

Apel, Cangelosi, Ellis, Goslin, and Fischer (2012) investigated the role of affordances in what they call an instruction span task. Participants watched a 3 × 3 grid on a touch screen, whose cells were numbered from 1 (upper left cell) to 9 (lower right cell), with eight cups positioned at the margins of the grid (two cups each above, below, to the left, and to the right of the grid). The cups had uniquely colored handles and participants received auditory instructions indicating which cup had to be moved to what location (e.g., “Move the orange cup to square three, then move the green cup to square nine, then move the yellow cup to square eight”). The number of instruction components per trial (i.e., cups that needed to be moved) ranged from three to six. After the instructions had been delivered, participants dragged the cups from their position around the screen to the specified cell in the grid, by touching the cups on the screen with their index finger.

Apel et al. (2012) manipulated whether participants moved the cups with their right hand or their left hand (between subjects) and whether the cup handles in a trial were all oriented to the left, all oriented to the right or randomly mixed (within-subjects). In Experiment 1, all participants were right handed. The most important result was that participants who moved the cups on the screen with their right hand executed the to-be-remembered instructions more accurately when the cup handles were all oriented to the right than when they were all oriented to the left. This spatial congruency effect was expected because cups with handles oriented to the right would activate (pre)motor neurons that control movements with the right arm and hand. Such neurons, it was reasoned, might subsequently support recall and execution of the instructions. Unexpectedly, participants who moved the cups with their left hand showed no effect of handle orientation. In Experiment 2 all participants were left handed. This experiment showed no effect at all of handle orientation used during execution of the movements. Apel et al. (2012) attributed the absence of an effect for left-handed participants to the general design of man-made objects. Objects are usually designed with right-handed people in mind. As a result, left-handed people often use their nonpreferred hand when interacting with objects and therefore may not develop strong associations between objects and action representations. Although the action-based effect was not consistently obtained across conditions, these results provide some evidence for the notion that motor simulations play a role in immediate memory.

Pezzulo, Barca, Lamberti-Bocconi, and Borghi (2010) also obtained evidence consistent with the idea that affordances support immediate memory. Participants in their study were novice climbers (less than 6 months climbing experience) and expert climbers (between 5 and 10 years climbing experience). The climbers each studied three different climbing routes: a route that was relatively easy to climb, a route that was relatively hard to climb, and a route that was impossible to climb. Participants entered the climbing arena and the trainer twice indicated the route on the climbing wall. Participants then turned around, did a brief distractor task (saying the letters A to I) and where subsequently shown a paper sheet displaying a picture of the climbing wall. Participants marked the sequence of holds composing the route just studied. In accordance with the hypothesis of Pezzulo et al. expert climbers' recall performance was better than that of novice climbers for the difficult route. For the easy route and the impossible route recall performance of the two groups did not differ. These findings were predicted because both novice and expert climbers would be able to form a motor simulation for the easy route. For the impossible route, neither group would be able to form a motor simulation. For the difficult route, however, it was reasoned that only expert climbers would be able to form a motor simulation because expert climbers, but not novices, possess the necessary skills to perform the sequence of actions needed to climb the difficult route.

2.5 Evaluating Evidence for the Role of Motor Affordances in Short-Term Memory

Comparing studies that did and did not find evidence for a role of motor affordances in short-term memory, two factors seem to affect the presence of action-based memory effects. First, the studies that found no evidence for a role of the motor system used tasks in which participants were asked to decide whether or not a test stimulus had just been presented. Pecher (2013a) presented one or more stimuli on each trial and participants had to decide whether the test stimulus was identical to the study stimulus or not (i.e., a short-term recognition task). Pecher et al. (2013), Quak et al. (2014), and Zeelenberg and Pecher (2015b) all used *n*-back tasks. These tasks are variants of recognition tasks in which targets and distractors are presented for a memory judgment. In contrast, the studies that did find action-based memory effects (Apel et al., 2012; Downing-Doucet & Guérard, 2014; Guérard & Lagacé, 2014; Lagacé & Guérard, 2015; Pezzulo et al., 2010; Shebani & Pulvermüller, 2013) all used recall or recall-like tasks in which the studied stimuli themselves or the presentation order of the stimuli had to be retrieved from memory.

Before expanding on this distinction between memory tasks, we report the results of a meta-analysis that included all 11 experiments performed by Pecher (2013a), Pecher et al. (2013), Quak et al. (2014), and Zeelenberg and Pecher (2015b). Although all 11 experiments individually showed no evidence for a role of motor affordances in short-term memory, we wanted to find out if there might be evidence for such a role when the results of all experiments were combined into a single meta-analysis. For each experiment, we expressed the critical hypothesized interaction between stimulus type and type of interference task as a difference of the differences between conditions. Note that the interaction in a 2 × 2 repeated measures ANOVA is equivalent to a paired samples *t*-test on the difference of the differences. These difference scores and 95% confidence intervals for each experiment are shown in Figure 1.[4] For example, Experiment 1 of Pecher (2013a) showed that the motor-interference effect (i.e., the difference between conditions with and without concurrent motor-interference task) amounted to

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[4] When calculating the difference scores that we entered in the meta-analysis, we collapsed over manipulations other than stimulus type and motor interference (i.e., verbal interference and lag manipulations, depending on the experiment). For the Quak et al. (2014) study the difference score was based on a comparison of the congruent and incongruent conditions only (excluding the results for nonmanipulable objects).

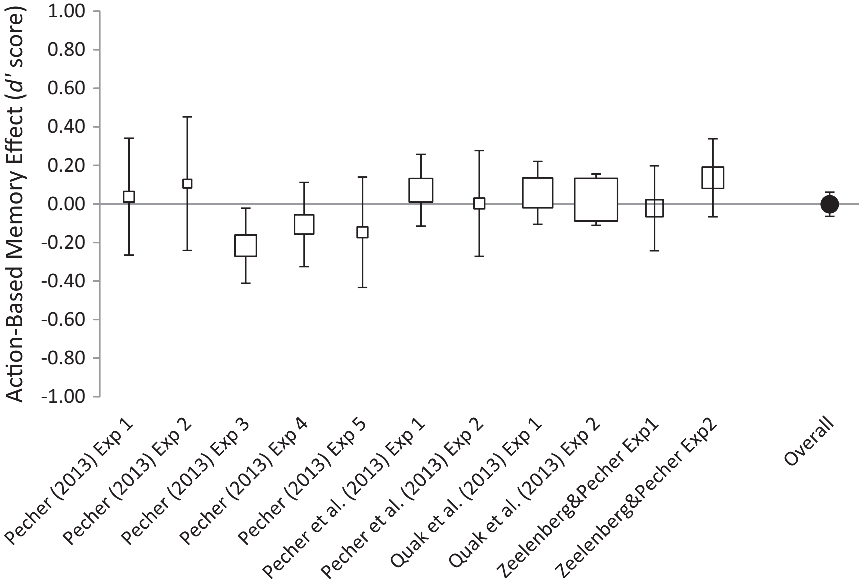

Figure 1 Results of the meta-analysis. The points show the size of the action-based memory effects for each experiment separately. The error bars show the 95% CI for each difference. The size of the markers reflects the weighing of each experiment in the meta-analysis. The overall point is the estimated effect size based on Cumming (2012).

0.394 d' points for manipulable objects and 0.356 d' points for nonmanipulable objects. Thus, the motor-inference effect was 0.037 d' points larger for manipulable objects than for nonmanipulable objects. This small and nonsignificant action-based memory effect is displayed as a positive effect in Figure 1 because it was in the direction predicted by the account that motor simulations support short-term memory for objects.

The meta-effect (indicated by the overall point) is a nonsignificant −0.002 difference in d' scores (95% confidence interval = [−0.065, 0.061]). The analysis showed no significant heterogeneity across experiments, $Q_{df=10} = 10.95$, $p = 0.361$, $I^2 = 8.69\%$. A perceptive reader may notice that Experiment 3 of the Pecher (2013a) study showed a significant effect in the direction opposite of what is predicted. Given that there was no significant heterogeneity across experiments, this most likely reflects random noise; as the number of experiments in a domain grows one is bound to occasionally find a significant effect, even when no true effect exists. Not surprisingly, an exploratory meta-analysis in which we excluded the results from Experiment 3 of the Pecher (2013a) study still showed a nonsignificant meta-effect

($M = 0.024$, 95% CI = [−0.039, 0.086]). The meta-analysis thus showed that in recognition-like short-term memory tasks, there is no evidence that motor simulations support memory performance.[5]

As we mentioned, the studies that did find action-based memory effects all used recall tasks. One question is whether it is the recall aspect itself that is responsible for the presence of an action-based memory effect or whether it is the requirement to recall order information. Note that almost all experiments required the recall of order information. Shebani and Pulvermüller (2013) and Guérard and Lagacé (2014) specifically required participants to recall the stimuli in the order in which they had been presented during study (and scored performance accordingly). Downing-Doucet and Guérard (2014) and Lagacé and Guérard (2015) presented the studied objects simultaneously on the computer screen during test and participants had to touch the objects in the order in which they had been presented during study. Pezzulo et al. (2010) required participants to recall the holds on the climbing hall in the correct sequence. Finally, Apel et al. (2012) scored the number of correctly executed action instructions regardless of the order in which they were performed. The instructions, however, implied that the actions had to be performed in a certain order (e.g., "Move the orange cup to square three, then move the green cup to square nine, then move the yellow cup to square eight"). It is conceivable that participants understood the instructions to indicate that the actions had to be executed in a particular order or at least tried to execute the actions in the order indicated by the instructions. Thus all these studies required serial order recall and most of them also required item recall during the test phase. One relevant question for future studies is therefore whether action-based memory effects in short-term memory are limited to tasks that test memory for serial order or whether such effects are also found in recall tasks in which serial order is irrelevant.

It is worth pointing out that effects of order recall and item recall can be dissociated. For example, Fallon, Groves, and Tehan (1999) found that in a serial order recall task phonological similarity negatively affected memory for the order in which the items were presented, but not memory for the items themselves. Lagacé and Guérard (2015) speculated that a serial order recall

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[5] Ten out of eleven experiments showed a significant main effect of motor interference on memory performance. Thus motor interference negatively affects short-term memory, probably due to a central attentional bottleneck, but there is no interaction between stimulus type and motor-interference task.

task recruits the motor system more than the *n*-back and short-term recognition task used by Pecher (2013a), Pecher et al. (2013) and Quak et al. (2014) and argued that this is responsible for the absence of action-based memory effects in these tasks. This speculation is in line with ideas expressed by Acheson and MacDonald (2009) who argued that because actions are inherently sequential in nature (i.e., many actions cannot be performed in parallel), the motor system may be capable of supporting the serial ordering of responses (but see Engelkamp & Dehn, 2000). If it is indeed true that the motor system plays a role in the recall of order information, and if this is responsible for the findings of action-based memory effects in short-term memory, then no such effects should be found in recall tasks where order information is irrelevant.

A second potentially important factor for the presence of an action-based memory effect is whether or not the study or test procedures emphasized actions. Actions were emphasized in Downing-Doucet and Guérard (2014) and in Lagacé and Guérard (2015) by presenting videos of hand movements during the study phase prior to each to be remembered object picture. The testing procedure used in these studies in which the participants had to touch the objects on the screen to indicate the order in which they had been presented may also have contributed to the finding of an action-based memory effect. In the Apel et al. (2012) study, the memory task consisted of moving cups to the specified locations on the grid displayed on a touch screen. Finally, Pezzulo et al. (2010) asked climbers to recall routes on a climbing wall. Although it might be argued that the climbing routes could be retained purely on the basis of visual information, climbers routinely study climbing routes by mentally simulating climbing these routes. These simulations may include specific details such as the location and orientation of holds and the movements of arms, legs, and body. Moreover, the use of motor information in recall may have helped to constrain the possible sequence of holds. The finding of action-based memory effects in these studies is interesting, but they do not, in our view, answer the question of whether affordances routinely play a role in short-term memory for object pictures and words referring to objects or actions. If affordances are activated automatically and support retention of words and objects action-based memory effects should be obtained even when actions are not emphasized by the design of the study.

The claim that motor actions are activated automatically is a very strong one and may represent only very extreme views on the role of motor actions for cognition. Many studies have provided support for the notion that the context in which stimuli are presented has a substantial influence on which conceptual features are activated and encoded in memory (e.g., Barclay et al., 1974; Barsalou, 1981, 1993; McKoon & Ratcliff, 1995; Zeelenberg, 2005; Zeelenberg, Pecher, Shiffrin, & Raaijmakers, 2003). Pecher, Zeelenberg, and Barsalou (2004) investigated whether conceptual representations were affected by recent experiences with those concepts. Each concept (e.g., *apple*) was presented twice, with different properties, in a property verification task. Pecher et al. manipulated whether the properties presented with the concept on the two occasions were from the same modality or from different modalities. On the second presentation of a concept, participants responded faster and more accurately to the concept–property pair (e.g., *apple-green*) if the concept had been previously presented with a property from the same modality (e.g., *apple-shiny*) than if it had been previously presented with a property from a different modality (e.g., *apple-tart*). This finding was obtained even though multiple unrelated concept–property pairs intervened between the first and second presentation of a concept. According to Pecher et al. (2004), the simulation on the first presentation of the concept was focused on a specific modality. For example, verifying whether the property *green* is true for the concept *apple* results in a mental simulation that focuses on the visual modality. This simulation includes the relevant visual property that needs to be verified (*green*), but also other visual properties (e.g., *shiny, round*). On later trials, these visual properties are more readily available, resulting in a benefit for verifying same modality properties relative to different modality properties. Related findings have been found by Pecher, Zanolie, and Zeelenberg (2007) (also see Pecher, van Dantzig, Zwaan, & Zeelenberg, 2009; van Dantzig, Cowell, Zeelenberg, & Pecher, 2011). In a similar vein, simulations of motor actions might be context sensitive. It is difficult to specify what kinds of contexts would lead to spontaneous activation of motor actions that are still theoretically interesting. For example, in a series of experiments, Yu, Abrams, and Zacks (2014) failed to find alignment effects for pictures of objects with handles oriented to the left or the right. A spatial alignment effect was found only when participants were instructed to imagine picking up the object while making the upright-inverted decision. Yu et al. concluded that actions may be primed only to the extent that the action-relevant aspects of an object are emphasized. In this study, context was manipulated by giving an explicit instruction, and it would be hard to argue that a motor congruency effect in this case still shows evidence of such spontaneous activation. With more subtle manipulations, for example, requiring participants to use reach and grasp actions, the evidence might be more convincing (also see Bub & Masson, 2010a).

Although several of the published studies that have found evidence for action-based memory effects in short-term memory used procedures that emphasized motor actions and interactions with the to-be-remembered stimuli, this is not true of all experiments. Two exceptions are the experiment done by Shebani and Pulvermüller (2013) and the motor-isolation effect reported by Guérard and Lagacé (2014, Experiment 1). In these studies, no movies of videos of hands making a grasping movement were shown and participants did not have to touch or move objects on the computer screen. Nevertheless the results of these studies indicated that motor affordances support short-term memory for objects pictures and action words. In our view, the results of these two studies provide the strongest evidence to date for the view that motor simulations support short-term memory. Given that the number of studies providing strong support for a role of affordances in short-term memory is still limited, future studies will have to show if these findings can be replicated and extended to other stimuli and procedures.

3. LONG-TERM MEMORY

Compared to the large number of studies investigating the online activation of affordances, only a few studies have investigated the role of affordances in short-term memory. Even fewer studies have examined the role of the motor system in long-term memory for objects and words. Short-term memory is often assumed to rely largely on phonological or visuospatial representations (Baddeley, 2003). Semantic characteristics of stimuli seem to play a relatively small role in short-term memory (Baddeley, 1966). Long-term memory, on the other hand, is known to rely heavily on semantic representations (e.g., Barclay et al., 1974; Deese, 1959; Hemmer & Steyvers, 2009; Light & Carter-Sobell, 1970). One would therefore expect that motor simulations play a prominent role in long-term memory. Just as in working memory studies, long-term memory studies have investigated how performing motor actions affects memory for objects and words. Below we will first describe two studies that investigated the effect of motor actions performed during study, addressing the role of motor simulations in initial memory encoding. Subsequently we will describe a study that investigated the effect of motor actions performed after initial encoding, addressing the role of motor simulations in memory consolidation.

3.1 The Effect of Motor Actions on Memory Encoding

In a first study (Pecher, Wolters, Stolte, & Zeelenberg, 2015), we investigated free recall for pictures of manipulable and nonmanipulable objects. If action related information is automatically activated for manipulable objects, as suggested by many studies, it is reasonable to assume that this information is encoded into episodic memory traces and supports later memory for these objects. Interfering with the activation and encoding of action-related information by means of a motor-interference task is therefore expected to harm memory for manipulable objects. Participants in our study either performed the same motor-interference task that Pecher (2013a) used (i.e., repeatedly opening the fists by stretching their fingers one by one) or no task, in separate blocks. In each block, they studied a mixed list of manipulable and nonmanipulable object pictures. After a filler task, memory was tested in a free recall task in which participants named or described the studied pictures. In separate experiments, participants performed the motor-interference tasks during study, during recall, or during both study and recall. Performing a motor-interference task, as compared to the no task control condition, was expected to be particularly detrimental for memory for manipulable objects. However, in none of the experiments was there evidence for such an interaction. Thus, no evidence was obtained that motor simulations support long-term memory for objects.

A second study (Zeelenberg & Pecher, 2015a) was modeled after the Shebani and Pulvermüller (2013) study who showed that in serial order recall performing a motor-interference task with the hands versus the feet differentially affected error rates for arm-related and leg-related action words. In our experiment, participants studied mixed lists of arm-related and leg-related action words. In one block participants performed the single paradiddle with their hands, and in another block they performed the single paradiddle with their feet (the paradiddle order was counterbalanced). After each block a free recall task was given. Assuming that the effect of Shebani and Pulvermüller (2013) extends to long-term memory we should observe an interaction between word type and type of motor-interference task; that is, free recall should be worse for the concordant condition than the nonconcordant condition. Contrary to this prediction, however, no such effect was obtained. Likewise, a second experiment did not show that free recall for manipulable objects was affected more by tapping the paradiddle with the hands (as compared to tapping the paradiddle with the feet) than free recall for nonmanipulable objects.

Thus, in a total of six experiments, we did not find any evidence that performing a concurrent manual motor task selectively affected free recall for manipulable objects or arm-related action words. These results suggest that motor actions are not spontaneously activated and encoded in memory when people study objects or words.

3.2 The Effect of Motor Actions on Memory Consolidation

In the only published study investigating action-based long-term memory effects, van Dam, Rueschemeyer, Bekkering, and Lindemann (2013) studied the effects of motor actions performed after initial learning of object names on subsequent memory performance. Participants first studied words under intentional learning instructions. The critical stimuli were words referring to objects that are associated with either a twisting action (*steering wheel, pepper mill, screw driver*) or a pressing action (*piano, remote control, doorbell*). After the study phase, participants performed a seemingly unrelated number-judgment task. Critically, during this intervening task participants responded to an irrelevant feature of stimuli that had not been presented during the study phase (i.e., whether a number of the screen was smaller or larger than 5). Responses were made either by means of a twisting action or a pressing action. The type of action performed was manipulated between subjects. Van Dam et al. reasoned that performing a motor action after initial learning would affect consolidation. More specifically, performing an action (e.g., responding by means of a twisting action) would enhance memory for congruent words (*steering wheel*) relative to incongruent words (*piano*).

Experiment 1 used a yes–no recognition task and the results showed enhanced recognition memory performance for congruent words relative to incongruent words. In Experiment 2, van Dam et al. (2013) presented words during the study phase and object pictures corresponding to the critical words during the test phase. The pictures were slowly demasked during presentation in the test phase. That is, picture presentation started with a completely black screen and 5% of the pixels became visible every 150 ms so that the picture gradually appeared out of the black mask. Participants had to indicate as quickly as possible when they identified the picture. Participants responded more accurately (but not faster) in the congruent condition than in the incongruent condition. In Experiment 3, a standard word fragment completion task was used during the test. Responses in the word fragment completion task were faster (but not more accurate) for congruent words than for incongruent words.

Although these results are interesting, the results of the implicit memory tasks are less convincing than they seem at first. For one thing, the analyses of Experiment 2 were based on performance averaged over both old (previously studied) and new (nonstudied) items. As van Dam et al. (2013) mention, one possibility is that the action performed during the intervening task biased retrieval in the subsequent picture-demasking task. Biased retrieval would operate on both studied and nonstudied items. Hence, results that include both studied and nonstudied items do not demonstrate that the motor actions performed after initial study affect consolidation processes that play a role in priming. It might just be that the retrieval for both old and new items was biased by the motor actions performed during the intervening task. To control for this possibility van Dam et al. reported an analysis that included only nonstudied items. These analyses showed no significant difference between congruent and incongruent items. This result is suggestive, but the appropriate analyses would have been to compare priming scores (i.e., the difference between the studied and nonstudied conditions) for congruent and incongruent items. Also, the word fragment completion task used in Experiment 3 is known to be susceptible to explicit retrieval processes (e.g., Reingold & Goshen-Gottstein, 1996), so it is not clear to what extend the results were based on implicit memory processes. It thus remains to be seen whether these implicit memory effects hold up under more tightly controlled conditions.

3.3 Evaluating Evidence for the Role of Motor Affordances in Long-Term Memory

The two recent studies in our lab have found no evidence for a role of the motor system in long-term memory for objects and words (Pecher et al., 2015; Zeelenberg & Pecher, 2015). Because long-term memory, more than working memory, relies on semantic information and because affordances are part of conceptual knowledge we anticipated finding evidence that motor simulations support long-term memory. Our findings contrast with those of van Dam et al. (2013) who showed that performing movements after the initial study task boosted later memory for those words that were congruent with those movements (relative to words incongruent with these movements). These different effects of motor actions on memory encoding and memory consolidation are somewhat puzzling. However, as indicated, the evidence obtained with implicit memory tasks is not very strong. Clearly, additional studies are needed to delineate the conditions in which motor actions performed after initial study affect later memory.

4. FINAL CONCLUSIONS

In this paper, we have reviewed the evidence for action-based memory effects in short-term and long-term memory tasks. A meta-analysis of 11 short-term memory experiments indicated that there is no evidence for a role of motor simulations in short-term recognition and *n*-back tasks. Serial order recall tasks have provided some evidence for action-based memory effects, but the majority of these experiments used procedures that emphasized actions. Evidence that the actions associated with words and objects are automatically activated and support short-term memory is still very limited. The few experiments that have investigated action-based memory effects in long-term memory have failed to provide evidence that motor simulations play a role in memory encoding. There is limited evidence, however, that motor simulations may play a role in consolidation.

These experimental results may limit the scope of the grounded cognition framework. Although different views exist (e.g., Wilson, 2002), most accounts give a central role to the motor system, also inspired by many neuroimaging studies that show activation of the (pre)motor cortex during conceptual processing of objects or action verbs. For example, in his highly influential paper Glenberg (1997) argues that memory is for action. On his account, concepts are integrated representations of perceived and remembered actions. This view may be correct when the person is actually performing actions, or has an action goal, but perhaps less so when visual or verbal information has to be recognized or recalled. Given the highly flexible nature of our cognitive system, it may be reasonable to assume that involvement of the motor system is task dependent and as such has no central role in cognitive processing.

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