Michael D. Robinson
Laura E. Thomas *Editors*

Handbook of Embodied Psychology

Thinking, Feeling, and Acting

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Chapter 13
The Role of Motor Action in Long-Term Memory for Objects

Diane Pecher, Fabian Wolters, and René Zeelenberg

Abstract Motor actions associated with grasping or using objects are part of object knowledge and may be automatically activated during object perception. Such findings suggest that the motor system has a supporting role in object representations. We investigated the role of motor actions in long-term memory for objects. Results from the few available studies suggest that attention to motor actions is necessary in order to find support for the role of motor actions. We performed an experiment using a neutral study instruction in which participants studied manipulable and nonmanipulable objects followed by free recall. The results showed no evidence that memory for manipulable objects was affected more by motor interference than memory for nonmanipulable objects. Thus, our results do not support the view that the motor system plays an important role in object memory. Rather, these results fit with the view that object representations are flexible and contain motor features only when they are relevant. We conclude that the motor system is not necessary to represent objects and question whether it is relevant at all for abstract concepts.

Keywords Long-term memory · Motor action · Motor interference · Affordances · Grounded cognition

One of the central ideas in the grounded cognition framework is that of sensory-motor simulation (Barsalou, 1999, 2008). According to this view, in order to meaningfully represent a concept, we run a mental simulation of the perceptions, actions, and interoceptions that would also be activated in an actual experience with the concept. Thus, representing the concept *banana* could consist of a mental simulation of seeing, grasping, peeling, biting, smelling, and tasting a banana. These simulations give concepts meaning and support actions (Glenberg, 1997; Meyer & Damasio, 2009).

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The Role of the Motor System for Concepts

In this view, a special role has been proposed for the motor system in memory for objects (see Iani, 2019, for a recent discussion). Downing-Doucet and Guérard (2014) argued that object retention processes recruit the motor system and suggested that object memory might be a "by-product" of the interactions between perception and action. Glenberg (1997) has argued that the main function of memory is to support actions and that concepts are the "meshed" affordances of current and past experiences. In other words, perception of an object leads to the conceptualization of a mixture of current affordances and actions performed in the past. On this account, the motor system is necessary for concepts. Lagacé and Guérard (2015) further argued that the affordances that are activated either by a visually presented object or by object knowledge are recruited to retain objects in memory. In support of this idea, studies have shown that motor actions are activated by pictures or names of manipulable objects (Chua et al., 2018; Rueschemeyer et al., 2010; Till et al., 2014). Yet, not all findings seem to support this idea that sensory-motor simulations are central to concepts (e.g., Papesh, 2015; Petrova et al., 2018). In this chapter, we will investigate the role of motor simulations in object memory, in particular whether motor simulations support object memory.

Memory for actual actions is affected by concurrent motor actions, suggesting that action representations in memory and real performed actions at least partly rely on the same mechanisms (but see Helstrup, 2001). For example, Smyth and Pendleton (1989) found that recall of a series of movements was reduced when participants performed a configured movement task (squeezing a foam tube) compared to a spatial task (tapping a pattern with a hand) even if the interference hand and the hand used during recall were different. An opposite pattern of interference was obtained in the Corsi blocks spatial span task, indicating that the configured movement task was not overall more interfering than the spatial task. The effect of interference on memory for motor actions thus depends on the nature of the interfering task. For example, *spatial* aspects of rowing were disrupted more by a spatial short-term memory load than by a body configuration memory load, while the *configuration* aspects of rowing showed the opposite pattern (Woodin & Heil, 1996), and short-term memory for ballet moves was decreased by a concurrent arm movement task but not by visual interference (Rossi-Arnaud et al., 2004).

If motor simulations are an important part of an object's representation, as has been argued by proponents of grounded cognition, it follows that memory for objects should show similarities to memory for actions. Thus, we reasoned that object memory should also be reduced by a concurrent motor task. However, studies investigating memory for object pictures or object names do not consistently find a role of motor actions (Pecher, 2018; Pecher & Zeelenberg, 2018; Zeelenberg & Pecher, 2016). These mixed findings suggest that motor actions may not be necessary for object representation (Fischer & Zwaan, 2008), but rather result from spreading activation after the core meaning of the concept has been accessed (Mahon & Caramazza, 2008). Indeed, such criticism seems warranted by the sometimes rather vague description of how sensory-motor processing and concepts are "interconnected," "associated," or engage in "cross-talk." Some results that are taken to indicate a supporting role of motor actions might indeed also be explained by spreading activation as a result of representing an object rather than supporting it. For example, Glenberg and Kashak (2002) observed that after reading a sentence such as *close the drawer,* participants are faster to respond with a movement that is congruent with the direction implied by the sentence (e.g., away from the body) than a movement that is incongruent. Scorolli and Borghi (2007) found that action sentences facilitated response actions made by the same effector (mouth, foot) as the one implied by the action verb in the sentence. Although this finding could be interpreted as showing that the action was activated as part of understanding the sentence and thus could be necessary for representing its meaning, the alternative explanation is that the action was activated only after the sentence was completely understood and therefore not essential in the language comprehension process.

Neuro-imaging studies show that motor areas are activated by manipulable objects (Chao & Martin, 2000; Grezes & Decety, 2002) even when affordances are task irrelevant (Proverbio et al., 2011) and when stimuli are words (Rueschemeyer et al., 2009). These results could also be the result of spreading activation. Handy et al. (2006) found that activity in motor areas was obtained mostly when participants viewed objects (rock climbing holds) that they did not have experience with, so this puts into question whether activity in motor areas even indicates motor knowledge. Moreover, in a meta-analysis of imaging studies, Watson et al. (2013) found that action pictures or words did not show consistent activation in motor areas, which further calls into question the idea that motor knowledge is central to concepts (see also Postle et al., 2008).

Is Motor Knowledge Necessary for Concepts?

We argue that the idea of sensory-motor simulations requires a more stringent test where it is shown that concepts suffer when sensory-motor processing is compromised (Mahon, 2015), for example, because participants are performing a secondary interfering task that engages the same processes (Pecher, 2013; see also Helstrup, 2001). Although some studies have shown interference (Witt et al., 2010; Yee et al., 2013), these results might be due to spatial attention rather than interference of the motor system (Matheson et al., 2014). Strozyk et al., (2019, also see Miller et al., 2018) found that lexical decisions to hand- and foot-related words were faster if the response had to be made with the relevant effector (hand or foot), but that hand or foot interference did not have different effects on responding to hand- or foot-related words. They concluded that participants reactivated experiential traces linked to specific effectors, but that this reactivation was not functional to lexical processing.

The role of motor actions in short-term memory for objects has also been investigated with motor interference paradigms. A few experiments have shown memory effects of similarity in how objects are interacted with and have also shown that these effects disappear with motor interference (Downing-Doucet & Guérard, 2014; Guérard & Lagacé, 2014). In contrast, we have repeatedly failed to find selective interference effects in short-term memory. Pecher (2013) studied short-term memory for manipulable and nonmanipulable objects. If motor information is activated and contributes to memory performance, interfering with such activation should be more detrimental for objects that are often manipulated (e.g., *hammer*) than for objects that are not (e.g., *chimney*). Contrary to this prediction, however, no such evidence was found (Pecher, 2013; Pecher et al., 2013; Quak et al., 2014).

Concepts Are Flexible

Another reason that results are mixed might be that sensory-motor simulations are flexible, and their nature depends on the task and other contextual factors (Barsalou, 2016; Lebois et al., 2015). Concept features vary in accessibility (Barsalou, 1993) such that the inclusion of a particular feature in a concept representation depends on the current task context (Barsalou, 1982; Conrad, 1978; Meteyard et al., 2012; Tabossi, 1988) and by other recent contexts (e.g., Pecher et al., 1998). For example, in Pecher et al. (2007), participants verified a visual property (*chocolate is brown*) or a non-visual property (*chocolate is sweet*) for a concept. Later, they were shown grey-scale pictures of concepts in a recognition memory task. Memory performance was better for concepts that had been presented with a visual property than for concepts that had been presented with a non-visual property, even though the property was not shown in the picture. The explanation for this difference is that on the first presentation, participants were more likely to run a visual simulation of the concept if the property was visual than if it was non-visual, and that the picture in the recognition test was a better match for the previous visual simulation than the non-visual simulation.

Lebois et al. (2015) even argue that concepts have no core meanings that are activated whenever the concept is processed. Instead, they propose that all features of a concept are context-dependent and their accessibility varies dynamically according to context. That effects that would be predicted by grounded cognition theories do not always occur does not necessarily mean that the concept is amodal. It just means that only features that are relevant in the task context are active. It would probably prove hard to derive strong predictions that distinguish between this account and a spreading activation type account (Mahon & Caramazza, 2008). According to the spreading activation account, sensory-motor information may be activated when a stimulus is presented but it is not an essential part of conceptual processing. On the context-dependent activation account of Lebois et al., sensory-motor information is an essential part of conceptual processing but the features that are needed to constitute a concept will vary according to task demands. It seems that both accounts are flexible enough to explain a wide variety of results.

Manipulable objects may activate different kinds of information. Objects may activate volumetric information (how they can be grasped) if they are presented as pictures, because the shape information is directly available in the visual input, whereas this may be less so for object names. Actions activated by object names might be more related to their function than their shape (Matheson et al., 2018). The degree to which object-related actions are activated may also depend on the actions needed to perform the task (Bub & Masson, 2010; Bub et al., 2008), and different types of actions might be activated at different points in the time course of processing the object (Bub et al., 2018). Task instructions play an important role (Thomas et al., 2019; Yu et al., 2014). Sentence context influences the availability of motor actions (Borghi & Riggio, 2009; see also Dutriaux et al., 2019; Taylor et al., 2008), although Borghi and Riggio (2009) found that motor actions were available even when they were irrelevant in the sentence context, but when the sentence context made actions relevant they were more clearly defined. Osiurak and Badets (2016) argue against automatic activation of motor actions for objects, but instead argue that motor actions can be activated as a result of a reasoning process. Papeo et al. (Papeo et al., 2009) similarly concluded from a TMS (Transcranial Magnetic Stimulation) study that any activity observed in the motor cortex for action-related words is due to strategic rather than automatic processing. They observed effects only late in processing of a word, and only when the task required participants to make semantic judgments related to action.

The Role of Motor Knowledge in Short-Term Memory

This flexibility in activation of motor features might explain why some studies have found that motor features have an effect in short-term memory (Zeelenberg & Pecher, 2016). Downing-Doucet and Guérard (2014) studied the effect of motor similarity on short-term memory for object pictures. Participants studied six objects in which each were associated with two grips. Before each object, a short video was shown of a hand performing one of the two grips. In the similar condition, the same grip was shown before each object on the list, whereas in the dissimilar condition, different grips were shown. Downing-Doucet and Guérard (2014) found that short-term memory for the order of the objects was better for the dissimilar condition than for the similar condition. Thus, memory performance for the same set of six objects was influenced by the variability of the videos shown before each object. In our view, the most likely explanation for this finding is that the videos were used as cues during memory retrieval, and caused more interference in the similar than in the dissimilar condition. If, however, the effect was due to similarity in the object representations themselves, it seems unlikely that these effects show that actions are a necessary part of the object representations, because which action was represented depended on the context.

In a similar short-term memory task, Lagacé and Guérard (2015) manipulated the congruency of actions with to-be-remembered objects. Participants observed an action video that was congruent or incongruent with the object picture that followed. They were instructed to copy the grasp and memorize the order in which objects were shown. Memory was better in the congruent trials than in the incongruent trials. Lagacé and Guérard (2015) argue that the transitions between motor actions support order information. It is surprising, however, that object-action congruency would support memory for order but not for the objects themselves (Quak et al., 2014).

Helstrup (2001, see also Iani, 2019; Lagacé & Guérard, 2015; Zeelenberg & Pecher, 2016) proposed that different strategies can be used to memorize action information, depending on the availability of information. Actions may be encoded as motor programs, as visual patterns, or as verbal codes. If interference during encoding is motoric, participants may encode movements visually or verbally. Moreover, Helstrup (2001) observed larger effects of verbal and visual interference than of motor interference, suggesting that participants are even more likely to encode actions verbally or visually than motorically.

In sum, studies on short-term memory for objects and words have occasionally provided evidence consistent with the view that motor actions contribute to memory performance, but the evidence supporting this view has been far from consistent. Moreover, in studies that provided evidence for motor involvement, the method seemed to emphasize motor actions. A possible explanation for the minimal role of the motor system is that short-term memory depends to a large extent on surface characteristics of the stimuli (e.g., Baddeley, 1986, 2003; Mazuryk & Lockhart, 1974; Rose et al., 2010), which are, in the case of object pictures, mostly visual. In contrast to short-term memory, long-term memory clearly relies largely on conceptual knowledge (e.g., Barclay et al., 1974; Craik & Lockhart, 1972; Deese, 1959; Shiffrin et al., 1995; Zeelenberg et al., 2003). Under the assumption that motor knowledge is an important part of concepts, long-term memory might therefore show a more robust contribution of motor actions to memory performance.

The Role of Motor Knowledge in Long-Term Memory

Only a few studies have examined the role of motor actions in long-term memory for object pictures and names. Ross et al. (2007) tested participants in a category learning task, in which they performed arbitrary response actions to categorize novel geometrical objects. Subsequent old/new recognition performance was affected by the overlap in response actions; responses were faster and more accurate for objects that required the same motor action during study and test than for those that required different motor actions. These results suggest that actions encoded during study might work as a contextual cue during retrieval (see also Dijkstra et al., 2007), similar to other types of context reinstatement (e.g., Light & Carter-Sobell, 1970; Tulving & Thomson, 1973). In that case, the motor action may not be central to the concept but rather to the specific study episode.

Results from other studies suggest that motor actions actually contribute to memory for objects. Verbally learning the function of new objects was hindered by a concurrent manual-interference task (Paulus et al., 2009). Unfortunately, Paulus et al. (2009) did not present a control condition in which they tested the effect of motor interference on learning of nonmotor features of new objects, so it is unclear whether the interference task harmed the function information specifically or was interfering with attention in general. Rather than interference, Matheson et al. (2019) found facilitation due to a concurrent motor task. Participants learned names and functions of novel tools. During a final recognition (studied vs nonstudied), test participants performed a secondary unrelated motor task during half of the recognition blocks. The difference between RTs for studied and nonstudied object names was larger during interference blocks for participants who had learned the function of objects by manipulating the objects themselves, but was larger during no-interference blocks for participants who learned the function by observing the experimenter's action and verbally describing the function. Thus, Matheson et al. (2019) found state-dependent learning. The effect of interference was facilitatory, which contrasts with other findings.

Representations of novel objects strongly depend on the particular study episode, which might focus explicitly on motor actions, and thus result in representations in which motor actions are relatively more important. A stronger test of the role of motor actions in object representations might be long-term memory for familiar rather than novel objects. Here also the few results are mixed. Memory for pictures of manipulable objects was worse when participants adopt a posture that prevents hand actions (Dutriaux & Gyselinck, 2016), suggesting, according to the authors, that motor simulations contributed to object memory. In contrast, Canits et al. (2018) found no effect on long-term memory for objects when the study task involved compatible or incompatible grasping responses, even though grasp compatibility did affect response times during study. Moreover, (Guérard et al., 2015) found that motor interference did not systematically affect long-term memory performance for objects even though it did affect short-term memory performance. This is puzzling, because long-term memory is generally thought to rely more on conceptual processing than short-term memory.

These studies with familiar objects all manipulated motor actions during encoding, which may have motivated participants to focus especially on motor features or away from them, depending on whether the motor actions were congruent or interfering. To our knowledge, only one long-term memory study manipulated actions after initial learning (i.e., during the retention interval). Van Dam et al. (2013) studied memory for lists of object names that would require a pressing (e.g., *piano, doorbell*) or twisting (e.g., *screw driver, pepper mill*) action when interacted with. During the retention interval, participants performed an ostensibly unrelated number decision task in which they had to respond by either pressing or twisting a response button. In the final recognition task, memory for object names that were congruent with the action performed in the intervening unrelated task was better than memory for object names incongruent with the actions performed during the intervening task.

In the present study, we investigated the role of motor actions in long-term memory for objects. Specifically, we investigated whether motor actions are encoded in object memories under conditions that do not explicitly focus on motor actions. Given the important role of action in the grounded cognition framework, we expected that something as fundamental to cognition as long-term memory should be supported by the motor system. As described, only a few previous studies have addressed this topic, and only the study by Van Dam et al. (2013) could be considered evidence for the spontaneous encoding of motor features.

Neuro-imaging studies have shown larger responses of motor-related brain areas to manipulable than to nonmanipulable objects (Chao & Martin, 2000; Chao et al., 1999; Martin, 2007; Rueschemeyer et al., 2009). These observations suggest that the motor system may be involved in the representation of manipulable objects, more so than in the representation of nonmanipulable objects. In the experiment reported here, we compared the effect of motor interference during recall on memory for manipulable and nonmanipulable objects. Using this comparison, we can distinguish between a specific effect of interfering with the motor system and a more general attentional effect of performing a concurrent task, similar to our previous short-term memory studies (Pecher, 2013; Pecher et al., 2013; Quak et al., 2014).

The motor system might be involved during memory encoding or memory retrieval or, most likely, both. During encoding, motor information that is activated as part of the object identification process will be encoded in the memory trace for the object. Given the flexibility of representations, however, motor interference would prevent the encoding of motor information, resulting in representations that rely more on other, probably visual, features. During retrieval, motor interference will prevent the use of actions as cues, and it will prevent activation of the motor information that was stored during encoding, resulting in poorer recall for objects that have associated motor actions (see Iani, 2019, for a similar argument). Therefore, we used motor interference only during memory retrieval, so that there would be optimal opportunity to activate motor information during study. If motor information is an important part of the representation of a manipulable object, a neutral instruction to study the objects for a later memory test should result in the spontaneous activation of motor features for manipulable but not for nonmanipulable objects. Motor interference during retrieval should then have a larger detrimental effect on memory for manipulable than nonmanipulable objects.

Experiment

Participants

Forty-eight students at the Erasmus University Rotterdam participated for course credit. The mean age was 20.8 years (range 17–55), and 45 were female. We sampled participants sequentially using a stopping rule based on the outcome of a Bayesian test (Schönbrodt et al., 2017). Therefore, we calculated the JZS Bayes Factor (*BF*) for the interaction. The Bayes Factor is the ratio of $p(\mathrm{D|H_0})$, the probability of observing the data under the null hypothesis, and $p(\mathrm{D|H_1})$, the probability of observing the data under the alternative hypothesis (Rouder et al., 2009). Using the JASP software (JASP Team, 2017), we performed a one-sided *t*-test with a scale parameter of $r =$

1 (Schönbrodt et al., 2017). The one-sided Bayesian *t*-test tests whether the effect of motor interference on recall (i.e., the difference in recall between the motor-interference condition and the control condition) is larger for manipulable objects than for nonmanipulable objects. Our threshold for stopping was a Bayes Factor of 10 in favor of the null hypothesis or a Bayes Factor of 10 in favor of the alternative hypothesis. As planned, an initial sample of 40 participants were tested and the Bayes Factor for the data of these 40 participants was computed. The resulting Bayes Factor was below 10. As per our preregistration, we increased the sample size in steps of eight participants (because the experiment had eight counterbalanced versions). After one step increase (i.e., when we tested the data for 48 participants), the threshold was reached. Our sampling plan was preregistered at https://osf.io/e3q4t/registrations.

Materials

The study items consisted of a set of 128 color photographs of common objects (e.g., tools, animals, buildings, signs) against a white background (available from https://osf.io/2hkb7/files). These stimuli were taken from a larger set of pictures for which we collected manipulability and frequency ratings on a seven-point scale (32–35 ratings per picture) in a previous pilot study (also used in Pecher, 2013; Pecher et al., 2013; and Quak et al., 2014). In the resulting set, 64 pictures were rated as high manipulable ($M = 5.34$, range = 5.00–6.59) and 64 as low manipulable ($M = 2.02$, range = 1.21–3.06). The items were matched on rated subjective frequency ($M = 3.89$, range = 1.33–6.91, and $M = 3.50$, range = 1.56–6.54, for manipulable and nonmanipulable items, respectively). The pictures were divided into four sets of 32 pictures, each containing 16 manipulable and 16 nonmanipulable items. For the filler task, 200 multiplication problems were created. A metronome was used to play the beats that indicated the speed of finger movements. A video camera was used to record whether the participant followed the interference task instructions correctly. Participants who did not follow instructions were replaced.

Procedure

The experiment consisted of four study-test blocks. Each block consisted of a study phase, a 2-min filler task, and a test phase. In two of the four blocks, participants performed a motor-interference task during the recall phase. In the two other blocks (i.e., the control condition), participants performed no secondary task during recall. The motor-interference task consisted of sequentially touching the thumb to the index finger, pinky finger, middle finger, and ring finger of the same hand, performed with both hands. This sequence was repeated throughout the recall phase to the beat of the metronome set at 92 beats per minute. Before the start of the first block, the experimenter explained the motor-interference task and demonstrated the hand movement. The participant performed the task until the experimenter was satisfied that the participant had understood it. For counterbalancing purposes, the motor-interference task was performed during the recall phases of blocks 1 and 4 for half of the participants and blocks 2 and 3 for the other half.

During each study phase, 16 manipulable and 16 nonmanipulable objects were presented in random order. New random orders were generated for each participant. Each picture was presented for 2000 ms, followed by a 500 ms blank screen. Participants were instructed to study the pictures for a later memory test. In the 2-min filler intervals between the study and test phases, participants solved multiplication problems. At the start of the test phase, participants were asked to recall as many of the objects as possible from the preceding study phase during a 2-min retrieval period by naming or describing the objects out loud in any order.

The entire experiment took around 30 min. Participants were tested individually, with an experimenter present during the entire experiment. The experimenter monitored if participants were following instructions correctly during the recall task. In addition, participants were videotaped to check their compliance with instructions. The four picture sets and order of interference and control blocks were counterbalanced in eight versions such that, across participants, each set of pictures occurred equally often in every block, with and without a concurrent motor-interference task (Zeelenberg & Pecher, 2015). After completion of the experiment, participants were asked to provide their gender and age information. After participants' compliance with instructions was verified, their videos were deleted.

Results

The proportion of correctly recalled objects for each condition was computed and is shown in Fig. 13.1. The effect of motor interference did not differ between manipulable and nonmanipulable objects. For the Bayesian analysis, the difference between recall with and without motor interference was computed for the manipulable and nonmanipulable objects separately. A one-sided Bayesian *t*-test comparing these differences between manipulable and nonmanipulable objects showed a $BF_{01} = 10.60$. Thus, the data provide strong evidence for the absence of an interaction. This result shows that the effect of motor interference did not differ between manipulable and nonmanipulable objects. Another one-sided Bayesian *t*-test showed that motor interference did reduce recall performance, $BF_{10} = 154.86$. This main effect of interference likely shows that the interference task required attention, and therefore distracted participants from the recall task. Because the main effect of manipulability was not relevant to our question, we did not analyze it. It appears that there is an advantage for nonmanipulable objects, consistent with previous studies (Guérard & Lagacé, 2014; Pecher, 2013). The manipulable and nonmanipulable objects were matched on familiarity, but there may have been other aspects on which they differed, such as relatedness or similarity between items. The data are available at https://osf.io/2hkb7/files.

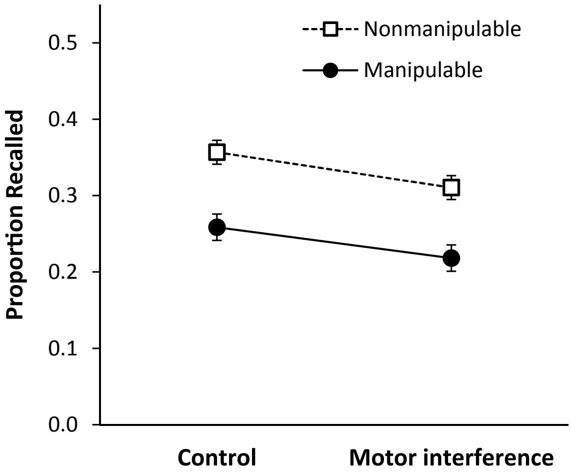

Fig. 13.1 Mean proportion correctly recalled pictures. The error bars indicate standard error of the mean interference effect for each type of object separately

Discussion

We investigated the effect of motor interference on memory for object pictures. We did not obtain evidence that motor interference had a larger effect on memory for manipulable than nonmanipulable objects. Thus, our results do not support the idea that motor actions play a necessary role in long-term memory for objects.

One objection to this conclusion might be that the motor-interference task might not have interfered with the activation of motor actions associated with the objects presented for study. Previous studies have shown, however, that similar motor-interference tasks interfere with episodic memory for actual actions (e.g., Woodin & Heil, 1996), with judgments about how objects are usually grasped (Pecher, 2013), and with short-term memory for action words (Shebani & Pulvermuller, 2013). The selective nature of motor-interference effects in these experiments, such as the limb-specific interference obtained by Shebani and Pulvermuller (2013), indicates that these effects were not due to a general decrease in processing resources. The results of many studies have been taken to imply that the actions associated with manipulable objects are automatically activated when people perceive a picture of an object or object name (Bub et al., 2008; Glover et al., 2004; Tucker & Ellis, 2004). If these afforded actions are automatically activated and encoded in memory, one would expect these to support later memory for objects. Thus, we expected that the motor-interference tasks would have a detrimental effect on memory for manipulable objects.

Flexible Use of Motor Knowledge

Our results suggest that motor actions do not support memory for objects when access to motor knowledge is not required by the memory task. Although requiring participants to use motor-related information during encoding might induce an effect of motor interference, and may explain some of the results in short-term memory studies, our results indicate that the motor system is not spontaneously recruited during encoding. Note that, in principle, recall of pictures could be based entirely on visual representations, yet hundreds of memory studies have shown that participants use semantic knowledge when recalling or recognizing previously presented stimuli (e.g., Barclay et al., 1974; Craik & Lockhart, 1972; Deese, 1959; Light & Carter-Sobell, 1970; Roediger & McDermott, 1995; Shiffrin, et al., 1995; Zeelenberg et al., 2003). If people use information associated with but not present in the stimuli themselves, such as phonological or semantic information, then this raises the question of whether this is also true for other kinds of information, such as the actions associated with stimuli.

Because in the grounded cognition view, action-related information is assumed to be activated automatically and to form a crucial part of conceptual knowledge, we reasoned that motor information would play a role in memory for objects. Precisely, this reasoning was used by researchers who did obtain evidence for the idea that motor actions support memory for objects and action-related words in recall and recognition tasks that like ours did not require access to motor knowledge (, Shebani & Pulvermüller, 2013; van Dam et al., 2013). As we discussed in the Introduction, however, most of the studies that did obtain results of motor actions on long-term memory used tasks that required or promoted attention to motor actions. When participants learned about novel tools, action information was explicitly presented during study and action manipulations during memory retrieval had some effect (Matheson et al., 2019; Paulus et al., 2009). Using familiar objects, Dutriaux and Gyselinck (2016) showed that memory for object pictures was affected by whether the participant's posture during the study phase allowed actions with the objects or not. The instruction to adopt a specific pose (i.e., to hold one's hands behind the back) may have been unusual enough to attract attention to hand actions. Canits et al. (2018), however, found no effect of grasp congruency during study, but in that study, the grasping action was integrated in a categorization task, and therefore may have been less obvious to participants. Overall, this handful of studies suggests that effects of motor actions on memory for objects depend on explicit attention to motor actions when memory representations are created. Recent accounts of grounded cognition have included flexible representations that are grounded in sensory-motor processes but do not have a conceptual core (Barsalou, 2016; Lebois et al., 2015; see also Meteyard et al., 2012). Rather, representations only consist of features that are needed in the current context. In this view, it makes sense that object representations only included motor knowledge if such knowledge was in the focus of attention during the study phase. In our present experiment, there was no focus on actions during the study phase, and we obtained no evidence that motor knowledge was part of the memory representations.

Alternative Explanations

Regarding the mixed results in short-term memory, two alternative explanations have been provided for the difference in results across short-term memory studies. First, Downing-Doucet and Guérard (2014) proposed that the motor system might play an important role in keeping order information, which would explain why manipulations of motor action are obtained in studies in which the memory task was serial recall rather than free recall or item recognition. If the motor system is used mainly to retain the order of items, its role might be very limited in long-term memory. Second, Guérard and Lagacé (2014) have suggested that motor information is only beneficial when it can be used to distinguish items from each other. According to them, the lack of effect in some of the short-term memory studies is due to the similarity in actions that would be performed to grasp the studied objects. In our current experiments, however, the lists were composed of a mixture of manipulable and nonmanipulable objects, and the manipulable objects differed from each other in the actions that they afforded. Moreover, whereas similarity can hurt short-term memory performance, in long-term memory, similarity might actually result in a benefit due to organizing processes that may operate on unorganized lists, as has been found for categorical similarity (Lewis, 1971). Thus, neither explanation seems to fully account for the mixed results. We propose that, as in long-term memory studies, the differences between results in short-term memory studies is also most likely due to the differences in how much attention to motor actions the studies induced, where studies that focused on motor actions were more likely to find positive evidence for a contribution of the motor system than studies that did not focus on motor actions.

Conceptual Knowledge

In general, conceptual knowledge plays a larger role in long-term than in short-term memory. Therefore, we expected that motor information would be more important in long-term memory (Zeelenberg & Pecher, 2016). In contrast, however, the current study did not provide evidence for this mechanism. The interference task occupied the motor system, which should have harmed recall if such spontaneously activated motor information had been encoded in the memory trace. That we did not find the expected interaction between motor interference and object manipulability suggests that motor information is not spontaneously activated during study and does not support memory for objects.

Interference manipulations, such as the ones used here, may be better suited to study the role of the motor system for cognitive processing than congruency manipulations. Studies that find relations between conceptual processing and motor actions often consist of a type of priming which does not necessarily show that motor actions are a fundamental part of the concept (Mahon, 2015; Masson, 2015). An important source of evidence for the automatic activation of motor actions is spatial alignment studies in which objects are shown with a graspable part (e.g., the handle of a frying pan) on the left or right. Participants respond faster if the graspable part is on the same side as the response hand than on the opposite side (Tucker & Ellis, 1998). This finding was interpreted as showing facilitation of a manual action as a result of automatically activated grasping actions, consistent with the idea that motor actions are fundamental parts of concepts. Other results, however, have indicated that the spatial alignment effect is more likely due to spatial correspondence between stimulus and response. For example, spatial alignment effects are also found when participants respond with their feet (Phillips & Ward, 2002), which cannot be explained by automatic activation of actions, and alignment effects disappear when there is no spatial response competition (Roest et al., 2016), suggesting there was no automatic activation of actions (see Proctor & Miles, 2014, for a review of spatial alignment effects).

Even if some evidence might point at activation of motor actions, it is questionable whether these are fundamental to the concept. Papeo et al. (2009) found only late effects of action words in the motor cortex and concluded that motor activity may result from understanding action words, but does not contribute to understanding. Moreover, Handy et al. (2006) found that motor activity is larger for unfamiliar than familiar objects, which suggests that motor activity is the result of effortful processing rather than automatic activation as part of a concept. Bub and Masson (2010) have argued that motor congruency effects depend on action intentions. Studies that have used interference to study the role of motor actions for object identification have produced mixed results (Matheson et al., 2014; Pelgrims et al., 2011; Witt et al., 2010), also suggesting that motor actions are not necessary for concepts and may even be used only strategically (Osiurak & Badets, 2016).

This conclusion, that motor actions are not automatically activated as part of concepts, appears to be at odds also with some accounts of grounding abstract concepts (Pecher, 2018; Pecher & Zeelenberg, 2018). For example, cognitive metaphor theory (Gibbs, 1994, 2005; Lakoff & Johnson, 1980, 1999) has often been proposed as a solution to the grounding problem for abstract concepts. The idea is that abstract concepts, for example *power*, are metaphorically linked to a concrete concept, for example *vertical position*, and thus are grounded in sensory-motor features of the concrete concept (Meier & Robinson, 2004; Zanolie et al., 2012). If the sensory-motor nature of concepts is flexible and context-dependent even for concrete objects, however, it seems unlikely that sensory-motor features are necessary for abstract concepts. Conventional metaphors may not even activate the concrete concept anymore (Bowdle & Gentner, 2005; see also Dove, 2016). Unless a novel metaphor is used to explicitly draw attention to sensory-motor features, there is no need to activate sensory-motor features to understand abstract concepts.

Conclusion

The idea that specific motor processes are necessary or fundamental to mental representations may be unsustainable. Rather, the cognitive system seems to flexibly use the motor system together with other representational mechanisms, such as systems for perception, emotion, introspection, and abstraction (Barsalou, 2008, 2016; Lebois et al., 2015; Mendelson Wilson-Mendenhall et al., 2011). Studies on long-term memory for objects, including the present experiment, show that memory representations do not necessarily include motor actions. Instead, memory representations may depend on features from other modalities, such as vision, abstracted semantic knowledge, such as categorical knowledge, and linguistic or other amodal symbols (Dove, 2009; Zwaan, 2014). The idea that memory is for action might hold only in situations in which there is indeed an intention to act.

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