Atten Percept Psychophys (2014) 76:2063–2070
DOI 10.3758/s13414-014-0654-y

Effects of motor congruence on visual working memory

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Published online: 7 March 2014

Abstract Grounded-cognition theories suggest that memory shares processing resources with perception and action. The motor system could be used to help memorize visual objects. In two experiments, we tested the hypothesis that people use motor affordances to maintain object representations in working memory. Participants performed a working memory task on photographs of manipulable and nonmanipulable objects. The manipulable objects were objects that required either a precision grip (i.e., small items) or a power grip (i.e., large items) to use. A concurrent motor task that could be congruent or incongruent with the manipulable objects caused no difference in working memory performance relative to nonmanipulable objects. Moreover, the precision- or power-grip motor task did not affect memory performance on small and large items differently. These findings suggest that the motor system plays no part in visual working memory.

Keywords Visual working memory · Motor system · Motor affordance

Object affordances play a role in cognitive processes such as conceptual memory and language comprehension. For example, when people categorize pictures of objects as natural or manmade, they respond more quickly if the response requires the same hand shape that would be used to grasp the object than if the response requires a different hand shape (Tucker & Ellis, 2004). These and other similar findings (Bub & Masson, 2010; Bub, Masson, & Cree, 2008; Masson, Bub, & Breuer, 2011; Olivier & Velay, 2009; Taylor & Zwaan, 2010) indicate that the motor action that is associated with the object is activated even if it is task-irrelevant, although some studies have suggested that task requirements also play a role (Bub, Masson, & Bukach, 2003; Girardi, Lindemann, & Bekkering, 2010). In the present article, we investigated whether object affordances play a role in visual working memory for objects.

According to the grounded-cognition framework (Barsalou, 1999; Glenberg, 1997), cognition shares processing resources with perception and action. Glenberg argued that the main function of memory is to support actions. The potential actions that a person can perform on an object are referred to as *affordances*, which can be activated in at least two ways. First, affordances can be activated by perception: When a person perceives the physical characteristics of an object, such as its shape and size, the object's affordances are automatically activated. Second, affordances can be activated from memory: Interactions with objects are stored in memory, and these may be retrieved on a later occasion and may affect behavior. Masson et al. (2011) showed that both visible affordances (the object's orientation) and affordances from memory (the orientation that would be needed to use the object in its conventional way) affected a primed grasp response. These results suggest that affordances are activated by both perceptual information and knowledge of the object's function (Lindemann, Stenneken, van Schie, & Bekkering, 2006). Moreover, similar effects have been found for words and sentences referring to manipulable objects or actions (Aravena et al., 2010; Borghi & Riggio, 2009; Bub et al., 2008; Glover, Rosenbaum, Graham, & Dixon, 2004; Klatzky, Pellegrino, McCloskey, & Doherty, 1989; Rueschemeyer, van Rooij, Lindemann, Willems, & Bekkering, 2009; Taylor & Zwaan, 2008; Zwaan & Taylor, 2006), indicating that direct visual information is not even necessary to activate affordances.

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If object affordances are activated automatically, the motor system might also be recruited to maintain objects in working memory. Barsalou (1999) proposed that mental representations are simulations of perception and action. An object could possibly be kept in working memory by mentally simulating performing an action with that object. Several studies have shown that working memory for actions is influenced by concurrent motor actions (Apel, Cangelosi, Ellis, Goslin, & Fischer, 2012; Rossi-Arnaud, Cortese, & Cestari, 2004; Smyth & Pendleton, 1989; Woodin & Heil, 1996) or by expertise with the actions (Pezzulo, Barca, Lamberti-Bocconi, & Borghi, 2010). For example, Pezzulo et al. found that expert rock climbers were able to recall a more difficult path on a climbing wall, presumably because their superior motor repertoire allowed for better motor simulations. These studies suggest that the motor system can be involved in working memory tasks.

In most of the studies that have shown a role of the motor system, participants were asked to remember actual actions or objects and situations that were clearly linked to actual actions by task demands. Thus, these are cases in which mentally simulating the actions seems a logical rehearsal strategy. A stronger claim would be that motor simulations also support working memory for visually presented objects or words. This was suggested by the results of a functional magnetic resonance imaging (fMRI) study by Mecklinger, Gruenewald, Weiskopf, and Doeller (2004). In their study, participants purportedly performed a working memory task on photographs of objects. Mecklinger et al. found increased BOLD responses in brain regions that are associated with motor actions of the hand (the ventral premotor cortex and the anterior intraparietal sulcus) when participants were holding pictures of manipulable objects in working memory. No such increase was found when participants were holding nonmanipulable objects in working memory. Because these brain areas are assumed to be involved with motor movement and translating movement-relevant object properties into hand actions, Mecklinger et al. concluded that the motor system supports working memory by simulating actions if the objects in memory are manipulable. In contrast, Pecher (2013; see also Pecher et al., 2013) found no interaction between motor interference and object manipulability on working memory performance. In several experiments participants kept manipulable and nonmanipulable objects in working memory and performed several concurrent tasks. The results showed no evidence for the role of object affordances in working memory.

Thus, studies on the role of the motor system in working memory have reported seemingly contradicting results. Mecklinger et al.'s (2004) fMRI results might be explained by considering the potential contribution of long-term memory to performance in these studies. They used a "working memory" task in which items were presented only once or twice during the entire experiment. Because of this, task performance might have been a mixture of both working memory and long-term memory contributions (Shiffrin, 1993). Moreover, Mecklinger et al. measured BOLD responses but not actual memory performance. Thus, their findings may reflect some by-product of seeing manipulable objects rather than a core process of working memory (see Postle, Ashton, McFarland, & Zubicaray, 2013). Many studies have obtained evidence that the motor system contributes to conceptual memory (Busiello, Costantini, Galati, & Committeri, 2011; Casteel, 2011; McCloskey, Klatzky, & Pellegrino, 1992; Paulus, Lindemann, & Bekkering, 2009; Witt, Kemmerer, Linkenauger, & Culham, 2010), and this may explain the results when the working memory task is not designed to minimize potential contributions from long-term memory. Pecher (2013) and Pecher et al. (2013) used a working memory task in which items were repeated several times in the experiment to minimize the contributions of long-term memory to performance in their working memory task. These studies showed no evidence for a role of the motor system.

One caveat of the studies that found no evidence for motor simulations (Pecher, 2013; Pecher et al., 2013) is that the motor-interference task was always incongruent with the actions that could be performed on the objects. Possibly, participants adjusted their memory strategy by shifting their attention away from the motor system. In doing so, they would not only have reduced the interfering effect of the concurrent motor task but also blocked the use of motor simulations for the memory task. If, however, the concurrent task were congruent with actions that could be performed on the objects, the motor system might play a larger role.

In the present study, we manipulated the congruency of motor tasks to further investigate the role of the motor system in visual working memory. Motor affordances for graspable, manipulable tools seem to be quite specific; there is a clear distinction between tools that require a precision grip and tools that require a power grip (Grèzes, Tucker, Armony, Ellis, & Passingham, 2003; Tucker & Ellis, 2001, 2004). Also, it is important to note that a congruent grasp type, as compared to a no-task condition, could possibly facilitate working memory performance, or at least protect from interference effects (Grèzes et al., 2003). We used the difference in grips to manipulate congruency. Participants performed a visual 3-back working memory task on pictures of objects that required a precision grip (e.g., *needle*, *paperclip*), required a power grip (e.g., *hammer*, *axe*), or were nonmanipulable (e.g., *chimney*, *bridge*). During some blocks of the experiment, participants performed a concurrent motor task. In these tasks, they either had to squeeze relatively large foam tubes in both hands with a power grip or squeeze small foam tubes in both hands with a precision grip. If motor simulations support working memory, the concurrent motor tasks should have a larger effect on performance for manipulable objects than nonmanipulable objects. The motor tasks are expected to interfere with the process of motor simulation, which we expect will impair the ability to maintain manipulable objects in working memory. However, when the motor task is congruent with the motor affordances of the presented stimuli (e.g., precision stimuli during a precision task), facilitation should emerge relative to the incongruent task and stimuli conditions (e.g., precision stimuli during a power-grip task). A congruent motor task will facilitate the use of motor affordances to keep manipulable objects in working memory, whereas an incongruent task will disrupt this process. These congruency effects were compared to the effects for nonmanipulable stimuli (Exp. 1) and to a control condition without motor interference (Exps. 1 and 2).

Experiment 1

Method

Participants A group of 26 undergraduate students (mean age 19 years) participated in exchange for course credit.

Materials A set of 54 color photographs of objects on a white background was used for the working memory task. A complete list is provided in the Appendix. Of these 54 photographs, 18 showed an object compatible with a precision grip (*needle*, *paperclip*), 18 showed an object compatible with a power grip, (*hammer*, *axe*), and 18 showed a nonmanipulable object (*chimney*, *bridge*). The pictures had been rated on object frequency and object manipulability by two separate groups of participants ($N = 65$ and $N = 69$, respectively). The average manipulability and frequency scores are shown in Table 1. Because participants performed the concurrent task with both hands, the orientation of the objects and object handles was irrelevant and therefore was not systematically controlled.

Two sets of objects were used for the motor-interference task. One set consisted of two small foam rubber cylinders (19 mm long with a diameter of 13 mm). The other set consisted of two large foam rubber cuboids (55 × 55 × 110 mm). The objects were positioned on the table in front of the participants. A personal computer and monitor were used for stimulus presentation. A foot switch was connected to an E-Prime response box for response collection. An online metronome ran at a fixed frequency of 60 beats per minute from a second computer and was played through headphones. Metronome beats and stimulus presentation times were not synchronized.

Table 1 Average ratings of the photographs used in Experiments 1 and 2

	Manipulability		Frequency	
	M	*SD*	*M*	*SD*
Precision-grip objects	4.9	0.6	4.2	1.4
Power-grip objects	5.0	0.4	4.1	1.5
Neutral objects in Experiment 1	1.6	0.3	4.1	1.6
Neutral objects in Experiment 2	2.3	0.6	3.8	1.6

Photographs were rated on a scale from 1 to 7

Procedure Participants were tested individually in a quiet room with the experimenter present. Participants were seated behind a PC with one foot on the foot switch. The experimenter explained the two motor-interference tasks. In the precision-grip interference task, participants had to pick up the small foam rubber objects and hold one in each hand between thumb and index finger. In the power-grip interference task, participants had to pick up the larger foam rubber objects and hold them in a whole hand grip, one in each hand. In both motor-interference tasks, participants had to squeeze the objects with the specified grip on the beat of the metronome. No instructions were given about their orientation of the rubber objects. After the motor-interference tasks were explained, instructions for the 3-back working memory task were given. During the memory task, participants were shown a sequence of pictures. Each picture was shown for 500 ms, followed by a blank screen for 2,500 ms. Participants were instructed to press the foot pedal whenever a picture was repeated at a lag of 3. The pictures were presented in blocks of 54 trials, of which 18 were targets. That is, of the 36 different pictures presented in a block, 18 pictures were presented once, and 18 pictures were presented twice (repeated after a lag of 3). The order of the pictures and the assignment of pictures to the target or the foil condition was randomly determined for each participant. During each block, one category of picture (precision grip, power grip, or nonmanipulable) and one type of interference (precision grip, power grip, or none) was presented. In total, nine blocks were presented, so that all combinations were used, and these were grouped by motor-interference task. The orders of motor-interference tasks and picture categories were counterbalanced across participants. After each block, there was a self-paced break in which participants were told their percentage of correct responses. If participants had less than 85 % correct responses, they were prompted to try harder.

The experimental blocks were preceded by a single block of practice trials. The practice block consisted of all 54 pictures taken from all three categories, of which nine were repeated at lag 3. No motor-interference task was performed during the practice trials. After each picture, feedback was presented for 500 ms: *GOED* ("correct") for a correct response, *FOUT* ("incorrect") for an incorrect response, and *TE LAAT* ("too late") for responses slower than 4,000 ms.

(No feedback was provided during the experimental block.) After an interstimulus interval of 750 ms, the next trial started.

Results

The proportions of *same* responses to the stimuli in the three-back task were calculated for each participant and condition. Hit and false alarm scores were used to calculate d' values [scores of 0 were replaced by 0.5/total, and scores of 1 were replaced by (total – 0.5)/total, where "total" is the total number of items in that condition]. The average d' values for all conditions are shown in Fig. 1. Differences in the d' values were analyzed in a 3 × 3 repeated measures analysis of variance (ANOVA). Overall, we found no significant interaction between the type of motor-interference task and the type of object, $F(4, 100) < 1$, $p = .689$, $\eta_p^2 = .02$. An additional analysis, which included only the manipulable objects and the two motor-interference task conditions, also showed no interaction effect, $F(1, 25) < 1$, $p = .476$, $\eta_p^2 = .02$. We next calculated the Bayesian information criterion (BIC) for these interactions, to estimate the likelihood of the null hypothesis (Masson, 2011; Wagenmakers, 2007). The p_{BIC} is the ratio of the probabilities for different models given the data, which provides the relative strength of evidence in favor of H_0 as compared to H_1. For example, if $p_{BIC}(H_0 \mid D) = .75$, the data provide three times (.75/.25) more evidence for H_0 than for H_1. The posterior probabilities favoring the null hypothesis were $p_{BIC}(H_0 \mid D) > .99$ and $p_{BIC}(H_0 \mid D) = .80$, respectively, for the full and restricted analyses above. Thus, we have positive to very strong evidence that motor task and object affordances did not interact. The main effect of motor task (precision grip, power grip, no task) was significant, $F(2, 50) = 8.29$, $p = .001$, $\eta_p^2 = .25$, $p_{BIC}(H_0 \mid D) = .03$. Post-hoc analyses using Bonferroni correction showed that performance in the precision-grip motor task was lower than in the no-interference task, $p = .001$, and in the power-grip motor task, $p = .031$, but performance in the power-grip motor task and the no-interference condition did not differ significantly, $p = .76$. The type of object did not affect performance, $F(2, 50) = 1.13$, $p = .330$, $\eta_p^2 = .04$, $p_{BIC}(H_0 \mid D) = .94$.

To summarize, we obtained no evidence that motor interference had a larger effect on manipulable objects than nonmanipulable objects. The precision motor task led to worse performance overall, which might have been due to a difference in difficulty between the two motor tasks. The rubber cylinder in the precision task was small, and keeping it positioned between the thumb and index finger may have required more attention than did keeping the larger rubber object in a power grip. In addition, the lack of an interaction between the two manipulable object types and the two motor-interference conditions indicated no benefit of performing a congruent grip.

One possible explanation for the lack of an interaction is that the setup of Experiment 1 did not invite participants to use motor affordances to maintain objects in memory. Within a block, all objects required a similar grip or no grip. Thus, grip was not particularly diagnostic for distinguishing targets and foils. To rule out this explanation, in Experiment 2 we randomly mixed manipulable and nonmanipulable objects in a block by including photographs of nonmanipulable objects as fillers. We did not mix precision and power grip objects in one block, in order to prevent carryover effects. For example, the precision motor task might increase performance for precision objects and harm performance for power objects. However, the easier congruent trials might free up resources for the harder incongruent trials, thereby eliminating the effect of congruency. Thus, we mixed nonmanipulable objects with only one type of manipulable objects within a block. We expected that participants would be more likely to use motor affordances to differentiate between foils and targets, causing motor interference to have a bigger effect.

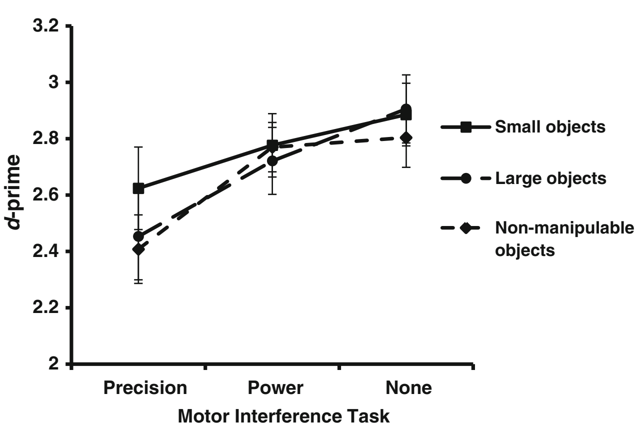

Fig. 1 Average d' values for all conditions in Experiment 1. Participants did a 3-back recognition task on color pictures of objects while doing a concurrent motor-interference task. Error bars represent standard errors of the means

Experiment 2

Method

Participants A group of 30 undergraduate students (mean age 19 years) participated in exchange for course credit. None had participated in Experiment 1.

Materials The stimuli and materials used in Experiment 2 were identical to those in Experiment 1, except for the addition of 54 new nonmanipulable object photographs, creating a total of 72 nonmanipulable stimuli. The new stimuli were taken from the same pool as in Experiment 1, and are listed in the Appendix. The average manipulability and frequency scores are shown in Table 1.

Procedure Experiment 2 was identical to Experiment 1, except that manipulable and nonmanipulable objects were randomly intermixed in each block. There were six blocks [2 stimulus categories (power-grip vs. precision-grip objects) × 3 motor-interference tasks]. In each block, photographs of nine manipulable objects and nine nonmanipulable objects were used as stimuli, resulting in a total of 54 trials, of which 18 trials were targets (repetition at lag 3).

Results

As in Experiment 1, the proportions of *same* responses to the stimuli were calculated for each participant and condition, and hit and false alarm scores were used to calculate d' values. Average d' values for all conditions are shown in Fig. 2. A 3 × 2 repeated measures ANOVA showed no interaction between the type of motor task and the type of object, $F(2, 58) < 1$, $p = .82$, $\eta_p^2 = .007$, $p_{BIC}(H_0 \mid D) = .99$. The motor-interference tasks affected performance, $F(2, 58) = 8.71$, $p = .001$, $\eta_p^2 = .23$, $p_{BIC}(H_0 \mid D) = .02$. Post-hoc analyses using Bonferroni correction showed that performance was lower in the precision-grip motor task condition than in the no-interference condition, $p = .001$. The other differences were not significant. In Experiment 1, we also found that the precision-grip motor task had the strongest effect on performance. This might have been due to the fact that it was harder to keep the small foam object in the correct position between thumb and index finger than to keep the larger foam object in a whole-hand grip. The type of object did not affect performance, $F(1, 29) < 1$, $p = .491$, $\eta_p^2 = .016$, $p_{BIC}(H_0 \mid D) = .81$.

Discussion

In two experiments, we tested the hypothesis that motor affordances are used for maintaining object representations in visual working memory. Although overall performance decreased when participants performed concurrent motor tasks, motor interference did not have a larger effect on memory for manipulable objects than memory for nonmanipulable objects. If participants had used motor affordances to maintain object representations in working memory, they would have done so to a much larger degree for manipulable objects than for non-manipulable objects. In that case, motor interference should have had a larger effect on memory performance for manipulable objects, but this was not observed. Instead, motor interference had a general effect, which suggests a central attentional bottleneck (e.g., Pashler & Johnston, 1998) as the locus of interference. Moreover, we found no effect of congruency between the grip used for the interfering task and the grip that was afforded by the object. In Experiment 2 motor affordances were more diagnostic than in Experiment 1, because manipulable and nonmanipulable objects were mixed. However, the results of the two experiments were very similar. Thus, we found no evidence that motor affordances play a role in visual working memory for objects.

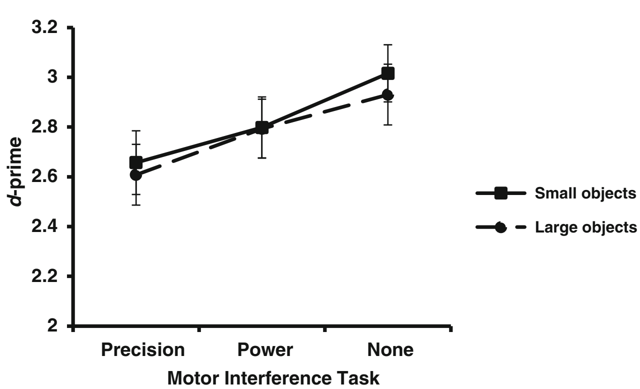

Fig. 2 Average d' values for all conditions in Experiment 2. Participants did a 3-back recognition task on color pictures of objects while doing a concurrent motor-interference task. Error bars represent standard errors of the means

We should add that our finding of a null effect (i.e., no interaction between stimulus type and motor-interference task) was not due to a lack of power. In both of our experiments, Bayesian analyses provided support for the null hypothesis. In a Bayesian analysis, an experiment with low statistical power would not result in evidence for the null hypothesis, but rather would result in no evidence for either the null or the alternative hypothesis [i.e., $p_{BIC}(H_0 \mid D) \approx .50$]. The p_{BIC} values we obtained, however, indicate positive to very strong evidence for the null hypothesis. Additionally, research has shown that motor-interference tasks similar to the one we used in the present study do show differential interference effects in other tasks. For example, Pecher (2013) showed that motor interference impaired the speed with which participants made grip decisions (participants decided if an object was usually grasped between thumb and index finger or with the full hand). Likewise, Smyth and Pendleton (1989) showed that repeatedly squeezing a rubber object interfered with memory for movement patterns. Thus, motor interference affects performance in tasks that require access to motor information. Together, these findings support our conclusion that motor affordances are not used to keep object representations in visual working memory.

Our results converge with earlier findings that motor interference did not interact with object manipulability (Pecher, 2013; Pecher et al., 2013). In those studies, the concurrent motor task involved continuous movement of the hand and fingers so that it interfered with any type of grasp. In that case, participants might have tried to reduce interference by allocating little or no attention to motor information. In the present study, however, the grasp of the concurrent task was congruent with the object on a subset of trials. We expected that a congruent motor task would lead to better memory than an incongruent motor task, because the congruent task would be compatible with activation of the object's affordance whereas an incongruent task would be incompatible with the object's affordance. Other types of studies that manipulated congruency between object affordances and actual hand configuration have often shown that performance is better in congruent than incongruent conditions. Several studies have shown that affordances are activated by object pictures, sometimes even when the picture is task-irrelevant (Bub & Masson, 2010; Bub et al., 2008; Masson et al., 2011; Olivier & Velay, 2009; Taylor & Zwaan, 2010; Tucker & Ellis, 2004; Witt et al., 2010). In addition, interactions between motor actions and object affordances have been obtained even for linguistic stimuli (Aravena et al., 2010; Borghi & Riggio, 2009; Bub et al., 2008; Glover et al., 2004; Klatzky et al., 1989; Rueschemeyer et al., 2009; Taylor & Zwaan, 2008; Zwaan & Taylor, 2006). These findings suggest that affordances play an important role in object representations. Affordances might not be activated automatically by objects, however. For example, Ellis, Tucker, Symes, and Vainio (2007; see also Makris, Hadar, & Yarrow, 2013; Murphy, van Velzen, & de Fockert, 2012; Vainio, Ellis, & Tucker, 2007) showed that the activation of affordances depended on whether participants paid attention to the object. In our experiments, however, participants needed to pay attention to the objects on all trials, and therefore it is highly likely that affordances were activated.

Overall, however, our findings do not support the view that the motor system is used to keep representations of manipulable objects in visual working memory with the help of motor affordances. These findings conflict with findings that have shown increased premotor cortex activation during a visual working memory task for manipulable objects (Mecklinger et al., 2004), which suggests a role of affordances. Pecher (2013) argued that, due to the correlational nature of fMRI studies and the problem with reverse inferencing (Aue, Lavelle, & Cacioppo, 2009; Page, 2006; Poldrack, 2008; Van Horn & Poldrack, 2009), activation of a premotor area cannot show that the motor system is causally involved in the task. In addition, the activation found by Mecklinger et al. (2004) might have reflected other processes than working memory. As we discussed above, perceptual or conceptual representations of objects seem to activate affordances fairly automatically. Mecklinger et al. also reported activation of areas in the premotor cortex in conditions under which participants passively observed manipulable objects. It is therefore possible that the motor activation found by Mecklinger et al. was related to semantic processes instead of visual working memory.

Our findings also are in contrast to those observed by Shebani and Pulvermüller (2013). They obtained effector-specific interference effects in a working memory task for action words, suggesting that in their experiment participants did use the motor system to maintain action words in working memory. Several differences between their and our experiments could be responsible for the differences in results. First, they used a more complex interference task, which required participants to tap a rhythm with their hands or feet. However, Pecher (2013; Pecher et al., 2013) also used a complex task that required the repeated execution of six different movements of the hand, and they obtained no effect of motor interference on working memory performance. Second, Shebani and Pulvermüller used a free-recall task to measure memory performance. Free recall might be more sensitive to retrieval cues than is recognition, and if participants used the motor task as a retrieval cue, this might have helped retrieve action words for the relevant effector. Third, Shebani and Pulvermüller used action words as their stimuli. Action words are directly related to motor actions, whereas objects are indirectly related to actions. For this reason, memory for action words might be supported by the motor system, but memory for object pictures might not be. Note, however, that Postle, Ashton, McFarland, and de Zubicaray (2013) did not find evidence that the motor system was involved in reading or remembering action words. Most important, however, is that Shebani and Pulvermüller did not use visual objects as stimuli, and thus their study does not bear directly on the role of motor affordances for visual working memory.

Whereas long-term or semantic memory for objects might be supported by the motor system, the results of the present study suggest that working memory depends mostly on the modality in which stimuli are presented. This is consistent with many studies showing that interference effects in working memory depend on similarity in terms of surface features rather than meaning (Baddeley, 2003; Cowan, 1999; Wood, 2007). In the present study, the stimuli were presented visually, which may have resulted in memory representations that were mostly visual. We do not claim that the motor system does not play a role in working memory in general. Several studies have shown that motor affordances are used in working memory for actions (Apel et al., 2012; Cortese & Rossi-Arnaud, 2010; Pezzulo et al., 2010; Rossi-Arnaud et al., 2004; Smyth & Pendleton, 1989; Woodin & Heil, 1996). The interference effects in working memory found in these previous studies seemed to depend on the task relevance of the actual motor properties of the stimuli that needed to be remembered. When memorizing actions, participants use motor properties to directly maintain actions in working memory. However, in a visual working memory task, object features such as shape and color seem sufficient to memorize visual objects, regardless of whether they are manipulable or nonmanipulable. The involvement of the motor system and motor affordances in working memory seems to depend mostly on whether a person needs to remember actions or not.

In conclusion, in the present study we did not find any effects of precision- and power-grip motor tasks on working memory for objects. These findings do not support the view that motor affordances are used to keep object representations in visual working memory.

Author note M.Q. is now at Ghent University, Belgium. This research was supported by a VIDI Grant from the Netherlands Organization for Scientific Research (NWO) to D.P. We thank Christiaan Tieman and Ineke Quak-Koestering for help with the experimental setup, Sandra Lenstra for assistance with data collection, and Durk Talsma for providing useful comments.

Appendix

Objects used in the small (manipulable) category in Experiments 1 and 2 (in parentheses is the grip that is consistent with the orientation shown on the picture: Right-handed, Left-handed, or Both):

allen key (R), band aid (B), battery (B), chess piece (B), chocolate (B), cigar (B), clothes peg (B), coffee filter (B), dart (L), dice (B), key chain (B), paperclip (B), pen (R), pencil (L), pin (R), teabag (B), tweezer (L), nut (for bolt) (B)

Objects used in the large (manipulable) category in Experiments 1 and 2:

Apple (B), axe (R), badminton racket (L), blow-dryer (R), carpet-beater (R), corkscrew (L), door handle (L), dumbbells (B), frying pan (L), hair trimmer (R), hairbrush (R), hammer (B), handheld blender (R), pair of pliers (B), screwdriver (R), soda can (B), toilet brush (L), watering can (R)

Objects used in the neutral (nonmanipulable) category in Experiment 1:

Air vent, arc monument, chimney, extraction pipe, high voltage sign, lighthouse, memorial stone, monument, office building, roof tiles, statue, traffic beacon, traffic lights, traffic sign, traffic sign (2), traffic sign (3), wall, windmill

Objects used in the neutral (nonmanipulable) category in Experiment 2:

air balloon, air vent, antenna, antenna, arc, ashtray, autumn Leaf, barrel, bird house, bridge, bridge (2), bridge (3), building, bust, cactus, cat cage, chimney, climbing frame, clock, clock (2), clock (3), column, commemorative stone, concrete block, crib, exhaust pipe, factory, flat, garbage can, garden shed, glass roof, gutter, high voltage sign, lamppost, large vase, lattice, letterbox, lighthouse, living room table, monument, monument (2), mountain, plant, pole, power plant, pyramid, seashell, sign (emergency exit), signpost, smoke detector, speaker, statue, statue (2), stone table, stone, stone (2), surveillance camera, tile floor, tiles, tombstone, tower, tower (2), traffic light, traffic sign, traffic sign (2), traffic sign (3), traffic sign (4), traffic sign (5), traffic sign (6), wall, water hydrant, wind mill

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