Testing Embodiment: No Necessary Role Of Motor System In Motor Working Memory

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Abstract

Rooted in the embodied cognition viewpoint, Barsalou's (1999) Perceptual Symbols Systems theory holds that the main components of cognition are simulations run by activating primary sensorimotor brain areas. As such, it predicts the involvement of the motor system in higher order abilities like the comprehension of action sentences and the judgment of object manipulability. However, recent evidence shows that the motor system might be activated in secondary processes and not directly in support of these tasks. There are few studies that look at the involvement of the motor system in motor working memory itself. To test this, we presented arm and hand poses to participants, while they performed an interference tasks performed with either their hands or arms. Perceptual Symbols Systems (1999) predicts that the hand interference task will particularly disrupt the motor simulations and recall performance of the hand poses, less so of the arm poses, and vice versa for the arm interference task. This specific interference effect was not observed. This suggests that the motor system is not involved in motor working memory, or that other memory systems can support motor memory when the motor system is saturated.

Introduction

Does the primary motor cortex support motor working memory? The conceptualization hypothesis of embodied cognition maintains that the properties of one's body and its interaction with the environment are at the basis of all cognition (Shapiro, 2011). According to this view, primitive sensorial and motoric information is not rendered abstract in higher cognitive processes to create meaning and knowledge about the world. Instead, it describes sensorimotor information as inherently meaningful. Higher cognitive processes work by reconstructing, transforming and meshing together parts of this information, conserving their original perceptual nature. Note that in this paper the term perceptual is used to refer to information represented in the brain in sensorial, like visual and auditory information, but also proprioceptive and motoric modalities. For example, Lakoff (1987) and Glenberg (1997) maintain that abstract thinking is largely metaphorical thinking that builds upon perceptual experiences, as in sayings like "relationships are like a journey" or "you are trapped in your marriage". This might mean that primary brain areas in which sensorimotor information is represented are themselves involved in higher order cognitive processes.

Barsalou (1999) tried to show how all or most of cognition could be derived by perceptual elements, in a manner consistent with current knowledge on neurophysiology. According to his Perceptual Symbols Systems theory, the perceptual information which is at the basis of all cognition is none other than patterns of neural activation coming from primary sensorimotor brain areas. Parts of these patterns of activation can be selected for elaboration and storage by mechanisms such as attention, and are sent to secondary integrative association areas that collect information from different sensorimotor modalities. These integrative areas store and can reactivate those patterns in the different primary areas from which they originated. Through this back and forth between primary and secondary brain areas, and the separation and recombination of the original perceptual neural activation, simulators are formed, which can be used in many cognitive tasks, from reconstructing memory, to visuo-spatial reasoning and language. While simulators represent long-term memory, an actively running simulation is at the basis of working memory. Simulators integrate information about a concept from different perceptual modalities. As such hearing the cry of an animal can activate its visual representation, or seeing a movement can activate a motoric pattern.

An interesting aspect of this view is that primary brain areas are so to speak promoted from servers of information to secondary associative areas where higher cognition happens, to directly participating in processes like working memory. There is some evidence to support this view. Pertinent motor information seems to be activated during processing of language. Glenberg and Kaschak (2002) had participants judge the feasibility of action sentences. They could respond with either pushing a lever away from the body or pulling it towards it. They found that reaction times were faster when participants' responses were congruent with the content of the sentence, such as pulling the lever when reading "Ramona gives you an apple, and slower for incongruent responses, such as as pulling the lever when reading the sentence "You give Ramona an apple". This effect is called the Action-Compatibility effect (ACE) and it holds for sentences describing both concrete actions ("You give Ramona an apple"/"Ramona gives you an apple") and actions characterized by more abstract directionality ("You phone Ramona"/"Ramona phones you"). If we interpret this according to the Perceptual Symbols Systems model, we can imagine that after hearing the sentence "You give Ramona an apple", a simulation is run of the act of extending the arm outwards. The motor cortex is activated whether the act is only imagined or being prepared for actual performance. This would explain a facilitation mechanism for responses congruent with the acts described in the sentence. Similar effects were also found during visual stimulation. Tucker and Ellis (2001) had participants judge whether an object was natural or artificial by grasping or pinching a switch. Responses were faster when compatible with the task-irrelevant size of the object, such as when participants had to respond with a grasp to a grapefruit and a pinch to a pen. This also can be taken as evidence of visual representations being linked to co-occurring motoric representations.

This interaction between language, vision and motricity is perhaps not surprising. The visual and motor systems are highly interconnected (Rizzolatti et al., 1998). Hari et al. (1998) stimulated motoric activity via transcranial magnetic stimulation. Manipulating an object powerfully suppressed this involuntary activity. Interestingly, some suppression was also observed when participants were observing someone else performing the same object manipulation. Stefan et al. (2005) showed that participants observing someone practicing a task and participants practicing the task yourself had similar activations in the primary motor cortex, and that this newly formed motor memory interfered in the same way in an opposite motor task they performed later. Language related to actions and manipulable items also seems to activate motor areas. Martin et al., (1996) found through Positron Emission Tomography that the act of naming animals was correlated with activation of visual processing areas and the act of naming tools activated pre-motor areas. Kana et al. (2012) found that during comprehension of action sentences higher activation was found in the primary motor cortex than during comprehension of sentences indicating a mental state.

However, these studies are strictly speaking evidence for motor responses being primed by a variety of stimuli, not evidence for a role of motor memory in supporting higher cognitive processes. Let's consider, for instance, the Action Compatibility effect from Glenberg and Kaschak (2002). Responses congruent with the task-irrelevant dimension of the directionality in the presented sentences, such as pulling a lever when presented with the sentence "Ramona gives you candy", were faster than incongruent responses such as pushing a lever when presented with the same sentence. This shows that a relevant motor program is activated and prepared when the sentence is presented. But when and why does this activation happen? One possibility is that, as predicted by Barsalou's Perceptual Symbols Systems, the motor system gets activated before and in support of comprehension of the presented sentence. After the comprehension of the sentence is achieved, and the response is selected, the running simulation then interferes or facilitates the proper response.

But it could be equally likely that the activation of the motor system is not related to sentence comprehension and that it happens after sentence comprehension is achieved. This motor activation could still facilitate or interfere with the selected response. Bub and Masson (2010) presented sentences about object interactions. Each sentence described either a volumetric or functional interaction with one of four objects, for a total of eight actions, each corresponding uniquely to one of the response grips afforded by a specially made response apparatus. The volumetric response was the action required to simply pick up the object, while the functional response was the action required to use the object. For example, a calculator afforded a power grip for grasping and the use of pointed fingers to be used. The response to be given after each sentence presentation was given visually after a varied delay. If the delay was long enough, response times were faster if the presented cue was the functional response the described object afforded, even if the sentence described a volumetric interaction. This study indicates that the motor activation observed in studies like Glenberg and Kaschak (2002) might not be related to the meaning or comprehension of the sentence, but to other processes, and that it happens well after the comprehension of the sentence is achieved.

Interference studies can be used to explore the role of motor memory on cognitive processing. If motor memory directly supports cognitive processing, then having participants performing concurrent motor tasks should disrupt performance. Some studies have found evidence for this. Witt et al. (2010) asked participants to name pictures of graspable tools and animals, while squeezing a ball in one hand. Tool naming was easier if the handle of the pictures tools was facing the free hand rather than the squeezing hand, while naming of animals was unaffected. Shebani and Pulvermüller (2013) presented participants with sequences of either arm or leg-related verbs to memorize. During the short memorization period they had to repeat a syllable continuously, perform a tapping sequence with their hands or their feet, or do nothing. The hand interference task especially affected the memorization of hand-related verbs compared to leg-related verbs, and vice versa for the feet interference task.

However, evidence seems to be mixed as similar interference studies did not find a role for the motor system's support of cognition. Pecher (2013) presented participants with two different tasks. One involved judging pictures of manipulable objects as graspable with a power grip or a precision pinch. The other was an animacy task showing either objects with low manipulability or animals. The tasks were accompanied by either a verbal, motor or no interference task. The embodied view predicted an higher effect of the motor interference task on the graspability task, and an higher effect of the verbal interference task on the animacy task. Instead, the interference tasks didn't differently impact reaction times for the graspability or the animacy task, suggesting the motor system is not required to judge the manipulability of objects. Montero-Melis et al., (2022), in collaboration with Shebani and Pulvermüller (2013), attempted to replicate their original study. Using a Bayesian model for their analysis, they found evidence in support of the hypothesis of no motor system involvement in the memorization of action-related verbs. Both these results are not compatible with the embodied cognition view. In their review, Matheson et al. (2015) reviewed the literature on sensorimotor systems' involvement in object representation. They argued that the literature is better accounted for by relationships between vision, action and attentional processes rather than a strong form of embodied cognition like the Perceptual Symbols Systems theory.

It is possible that those specific interference effects are masked by processes operating on other elements of the pictures presented on the studies above. It might be wiser to investigate the role of simulations on tasks more closely involving the same modality. For example, to see whether motor interference disrupts motor working memory directly. According to Perceptual Symbols Systems, motor working memory should be constituted by activated motor simulations taking place in the motor cortex, in preparation of a movement to be performed or after observing a movement that needs to be learned. Since the motor cortex is divided according to somatic representations, when learning movements, a motor interference task performed with the hands should disrupt the learning of hand movements specifically, and not of other body parts.

An unpublished study from Pecher and Zeelenberg from the Erasmus University Behavioral Laboratory showed participants hand and arm poses to memorize. During each experiment block, participants were shown only hand or arm poses. During each trial they were shown two poses, then after a brief pause, they had to reenact the poses. During the presentation participants had to perform either no interference task, an interference task performed with their hands, or an interference task performed with their arms. If the primary motor cortex has a role in supporting motor memory, the interference tasks should have a specific effect on the recall of the related poses. That is, the hand interference task should make recalling hand poses harder, but have a lesser effect on recalling arm poses. And we should expect the same specific effect on the arm interference task on recalling arm poses. This interaction was not found.

In the above study however, participants often reported naming the poses to help themselves memorize the poses in a follow-up questionnaire. Once memorized the poses and assigned verbal labels, the participant could rehearse the names covertly. This mnemonic aid could have masked the specific effects of the interference poses. The following experiment will be an exact replication of this unpublished study, with an added verbal interference to try to control for the use of verbal labels. As in the previous study, a questionnaire will be presented to the participants to investigate whether they named the poses or used other strategies. If the conceptualization hypothesis is correct, we expect to find that each interference task will have a specific negative impact on the recall of the poses of the same body part. In addition, we expect less participants to report using verbal labels to remember the poses.

Method

Participants

Sixty-one Psychology students at Erasmus University participated for course credit.

Stimuli and Materials

Testing took place in one of the testing rooms of the Erasmus Behavioral Lab of EUR. The testing room was furnished with a computer on which the experiment program was run, a second computer for recording and monitoring purposes, a camera, a metronome and a foot pedal. The stimuli were 12 pictures depicting hand poses and 12 depicting arm poses, selected to be minimally overlapping in appearance. The pictures were photographs of a young male modeling the poses. In all poses the model sported a neutral expression. In both arm and hand poses, with few exceptions, the upper arms rested naturally alongside the chest. In the arm poses, the arms were in different positions (see Figure 1 for an example), while the hands were always in the same configuration, open with all fingers stretched out. In the hand poses, the upper arms rested naturally alongside the chest, hands were in different configurations (see Figure 2 for an example) and the forearms more or less extended, as necessary to allow the hands to be in the desired position.

Figure 1. Example of an arm pose.

Figure 2. The Example of a hand pose.

Procedure

The experiment began by welcoming the participants and explaining the experiment at large. The participants were then trained in how to perform the interference tasks. They were shown the interference tasks by the experimenter and they were asked to rehearse them. Both the verbal and motor interference tasks were performed at the rhythm of the metronome, set at 92 bpm. The verbal interference task consists in repeating the syllables BA DO RE SU. The hand motor interference task consisted in making a fist, stretching out each finger from thumb to pinky, then making a fist and begin again. The arm motor interference consisted in touching one own shoulders with both hands, then the head, the shoulders again and then the hips, going back and forth from the hips to the head. The verbal and motor interference tasks were conducted at the same time. In the blocks without a motor interference task, only the verbal interference task were performed by the participants. The participants saw a demonstration of a trial by the experimenter, and were welcomed to ask questions regarding the tasks or the trials before beginning with the experiment proper.

After the training the experimenter started the video recording. Participants then began the practice block, which consisted of 24 trials. Each trial began with an ISI of 1000ms, then one of the 24 poses pictures was shown for 1000ms, then a 3000ms retention interval began, followed by a beep. Then the recall phase started, during which the participants had to reenact the pose they had seen the best they could. When they had done so, they had to press the foot pedal to begin the next trial. If the poses were reenacted before the beep signaling the end of the retention interval, the trial would be considered invalid. The 24 trials showed all the 24 pictures in random order without replacement.

The participants then began the experimental blocks. Before beginning, they were warned that they would be shown two poses per trial, so the difficulty was increased. During each block, only hand or arm poses were shown, and only the hand, arm or no motor interference task were performed. There were six blocks, one for each combination of pose type and interference task. The order of these blocks was counterbalanced between participants. Each block had 24 trials. Each trial began with an ISI of 1000ms, followed by a picture shown for 500ms, a retention interval of 3000ms, then another picture for 500ms, another retention interval of 3000ms, followed by a beep. Then the recall phase started, during which the participants had to reenact, in order of presentation, the poses they had seen the best they could. When they had done so, they had to press the foot pedal to begin the next trial. At the end of each block, the participant could take a self-paced break, then press the pedal to start the following block.

At the end of the experiment, participants filled a small questionnaire. Participants were asked how they tried to remember the poses and whether they visualized themselves performing the poses or they named them. They were also asked if they had experienced having to remember sequences of poses before, for example by practicing disciplines such as dancing or martial arts. Finally they were asked what they thought the experiment was about.

Data Analyses

The recordings were scored under two aspects: trial validity and pose number. A trial was scored as invalid if the participant did not perform the interference task properly or if he enacted the poses before the recall phase started. Invalid trials were removed from the analysis. For any valid pose enactment, the scorer noted which pose in the stimuli set the enactment resembled, and if the resemblance was exact or just close enough. Pose enactments which didn’t resemble any pose in the stimuli set were marked as incorrect trials. Scorers were blind as to the correctness of the poses.

These lists of enacted poses were checked against the list of stimuli presented to the participant to judge correctness. Invalid trials did not contribute to the scores. Two scores were produced for each trial, a strict score and a lenient score. A trial was accepted as correct in the strict score if both enacted poses were those shown, in order, during the presentation phase, and both enactments strictly resembled the presented poses. A trial was accepted as correct in the lenient score if both enacted poses were those shown, in order, during the presentation phase, and both enactments at least closely resembled the presented poses.

Results

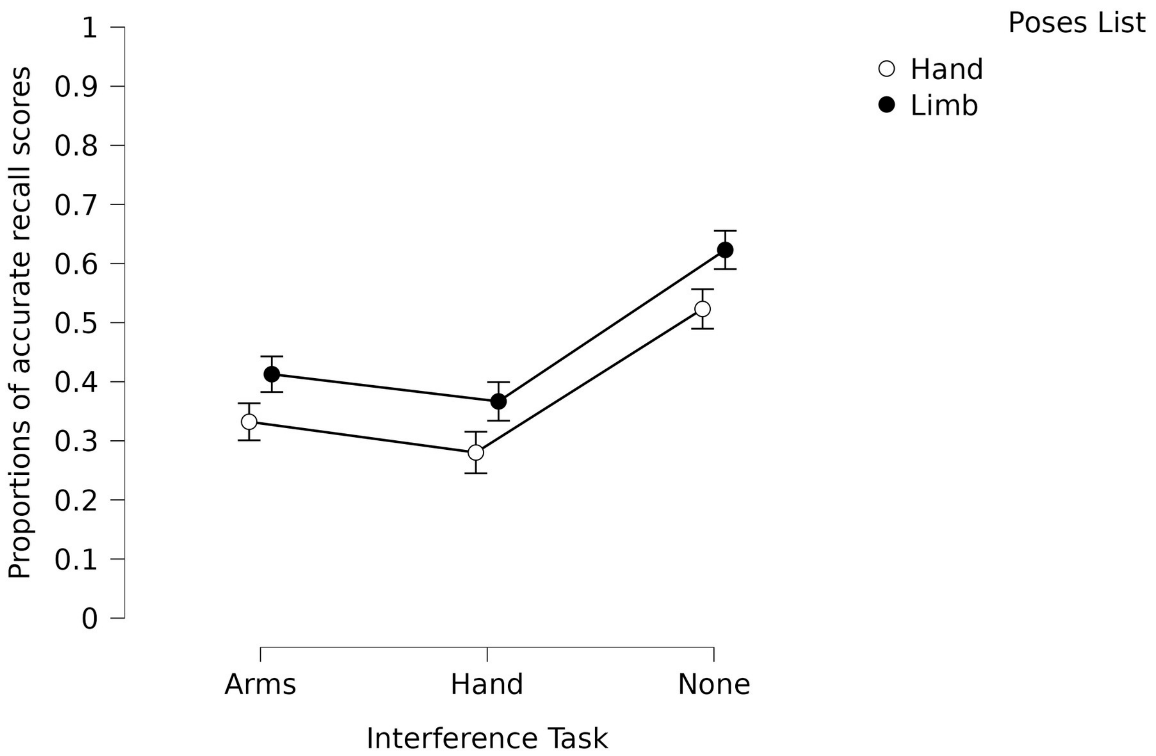
The percentage of invalid trials was 2.55%.

A repeated measures ANOVA was performed to analyze the effect of the interference tasks on recalling the hand or arm poses, on the proportion of correct recall scores, for both lenient and strict scoring.

When adopting the strict method of scoring, a main effect for Interference task type was found $F(2,118) = 107.30$, $p < 0.001$, $\eta^2 = .44$. Post-hoc tests showed that scores in the no interference condition were higher than the scores in the arm interference condition, $t = 11.11$, $p < .001$, scores in the no interference condition were higher than the scores in the hand Interference condition, $t = 13.83$, $p < .001$ and that scores in the arms interference condition were higher than the scores in the hand interference condition, $t = 2.72$ $p = 0.008$. A main effect for Poses List was found, $F(1, 59) = 32.75$, $p < .001$, $\eta^2 = .07$. Recall scores were higher for items in the limb list than for items in the hand list. No interaction between List and Interference condition on recall scores was found $F(2, 118) = .32$, $p = .728$, $\eta^2 < .01$ (Figure 1).

Figure 1

Mean proportions of accuracy of pose recall under the strict scoring system



Note. Error bars represent 95% Confidence Interval.

To see whether a more lenient method of scoring introduced any difference in results, another round of analyses was conducted. As with the stricter method of scoring, a main effect for Interference task type was found $F(2,118) = 115.07$, $p < 0.001$, $\eta^2 = .51$. Post-hoc tests showed that scores in the no interference condition were higher than the scores in the arm interference condition, $t = 11.59$, p < .001, scores in the no interference condition were higher than the scores in the hand Interference condition $t = 14.27$, $p < .001$, and that scores in the arms interference condition were higher than the scores in the hand interference condition $t = 2.69$, $p = 0.008$. No main effect for Poses List was found, $F(1, 59) = .95$, $p < .333$, $\eta^2 < .01$. This was the only difference that the two scoring methods produced. While scores were lower for hand poses under the strict scoring method, no significant difference in scoring was observed between arm and hand poses under the lenient scoring method. Similarly to the strict scores, no interaction between Poses List and Interference condition on recall scores was found $F(2, 118) = .07$, $p = .931$, $\eta^2 < .01$.

To summarize, for both strict and lenient scoring methods, interference tasks did not affect recall scores of the stimulus lists differently.

The questionnaire answers showed that the verbal interference task did not have the intended effect, as 75% of the participants reported giving names to poses during the experiment. Fifty-two percent of the participants also reported trying to visualize themselves doing the poses, with a minority of 6.7% specifying that they had to abandon the strategy because it interfered with their performance. Forty-eight percent of the participants reported having some experience in a discipline that required remembering poses, like dancing or martial arts. No participant fully understood the purpose of the experiment.

Discussion

In this experiment we investigated whether the motor system supports memory for body poses. According to Barsalou's Perceptual Symbols' model (1999), the memory of the poses should have been sustained in working memory through the simulation of the motor pattern originally activated by visual stimulation. Through our design, this mechanism should have become apparent through an interference effect. The interference task performed with the hands should have disrupted recall of hand poses more than the interference task performed with the arms, and the interference task performed with the arms should have had a larger impact on the recall scores for arm poses. This effect was not observed, which indicates that the motor system is not necessary for the functioning of motor working memory. Moreover, through the same mechanism, the verbal interference task should have blocked the production of verbal labels to assist in remembering the poses, which was also not observed.

The study used a double scoring system, strict and lenient, which respectively considered a trial correct only if both poses were reenacted exactly or close enough to be identified uniquely as the presented poses. The expected result was not observed in either set of scores. The only difference in the results between the two sets of scores regarded the main effect for poses list. When scoring strictly, participants' recall of hand poses was worse than the recall of arm poses. This was not observed when scoring the poses leniently. This might be a consequence of the stimuli sets of the experiment. Hands afford more complex poses than just arms do. Perhaps memorizing the poses in the hand stimulus sets required participants to remember, on average, more positional elements than the limb poses. Thus they would prioritize, in the limited time available during the presentation phase, on remembering the positional elements that somehow caught their attention more than others. Those salient elements would probably be novel elements not found in previously observed poses (Downar et al., 2002). Since the poses were designed to not have many overlapping elements, those novel elements would probably be unique to the observed poses. Reenacting only these novel components would award participants higher scores in the lenient system scoring condition, but not in the strict scoring system.

Another finding is that in both scoring systems the hand interference task had an overall larger impact than the arm interference task on the recall scores. It could be that the hand interference task was harder. Perhaps the issue is the rhythmic incongruency with the verbal interference task. The verbal and arm interference task both had four beats, so they would always be performed in sync (hands to hips/BA, hands to shoulders DO, to head RE, hands back to shoulders SU, hands to hips BA, and so on). The hand task had six beats, starting from a closed fist on the first beat plus the extension of each five fingers on the following five beats, so it would be out of sync with the verbal interference task from the fifth beat onward. We could not find any study in the literature that explored this topic, but it might be wise to incorporate an hand interference task with four beats on the next iteration of this experiment.

A concern more relevant to the topic at hand is that, rather than not having the same difficulty, these tasks might impact working memory differently. Motor working memory for visually targeted positional movements and body-related patterned movements is dissociated (Smyth & Pendleton, 1988). Enacting poses without a reference to an external position will probably make use of the patterned component of motor working memory. So will closing a fist or extending fingers, as in the hand interference task. However the arm interference task might have interfered with the positional component of motor working memory, as it involved and was described to participants as moving them towards targets ("touch the head, then the shoulders…"). If that was the case however, we would still have expected a differential effect of the hand interference task on recall scores for arm and hand poses. This was not observed. Perhaps it is safe to consider the arm interference task as patterned, as the targets of the arm movements are body-related and not external.

So how can these results be interpreted? The memory task was hard even in the absence of motor interference tasks. In the blocks where participants only performed the verbal interference task, they averaged less than 60% correct scores on the strict scoring system, and less than 70% correct scores on the lenient scoring system. Naturally this serves the experiment's purpose as easy tasks lend themselves to ceiling effects. Since poses were presented visually and we didn't introduce any visual interference technique, participants probably relied on visual memory to remember the poses. As shown by the responses on the final questionnaire, roughly half of the participants reported trying to visualize themselves enacting the poses at least at some point during the experiment. Interestingly, a few participants felt this strategy was interfering with their performance, and they abandoned it. One of the participants reported that if he tried to visualize himself repeating one pose, he would miss what the other pose was. Some participant reported using both strategies, but their answers did not show whether they tried to use both strategies concurrently, at different points during the study, or perhaps for different poses.

The difficulty of the task might be attributed in part to a proactive interference effect of earlier trials on visual memory (Hartshorne, 2008), meaning that poses learned in earlier trials entered long-term memory and made remembering new poses more difficult. The fact that some poses might have entered long-term memory is not unlikely, especially during the simpler practice trials. The experimenter noticed that many participants often repeated the same pose in place of other poses that couldn't be remembered. The limits of the number of features that visual working memory can hold might perhaps also explain the difference in recall scores of the more complex hand poses versus the simpler arm poses (Luck & Vogel, 1997). The complexity of poses might also explain why it was hard for participants to remember two poses at a time (Alvarez & Canavagh, 2004). Looking at the scores and as reported by the participants, the interference tasks also made the task much more difficult. As the use of either arms or hands in motor interference tasks did not have a specific effect on the memory for poses of the same body part, we can assume that motor memory is not dissociated along the confines of the internally represented body map (Rizzolatti et al, 1998).

We presented an useful design to explore the boundaries of motor working memory and found no evidence for a necessary role of the motor system in supporting it. It might be that an optional role of the motor system in supporting motor memory exists. But the performance of the participants and their self-reports suggests that it would only one be of several resources, like visual and verbal working memory, that can be accessed when another is saturated.

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