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Relevance of the listener's motor system in recalling phrases enacted by the speaker

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Abstract

Memory for series of action phrases improves in listeners when speakers accompany each phrase with congruent gestures compared to when speakers stay still. Studies reveal that the listeners' motor system, *at encoding*, plays a crucial role in this enactment effect. We present two experiments on gesture observation, which explored the role of the listeners' motor system *at recall*. The participants listened to the phrases uttered by a speaker in two conditions in each experiment. In the gesture condition, the speaker uttered the phrases with accompanying congruent gestures, and in the no-gesture condition the speaker stayed still while uttering the phrases. The participants were then invited, in both conditions of the experiments, to perform a motor task while recalling the phrases proffered by the speaker. The results revealed that the advantage of observing gestures on memory disappears if the listeners move at recall arms and hands (same motor effectors moved by the speaker, Experiment 1a), but not when the listeners move legs and feet (different motor effectors from those moved by the speaker, Experiment 1b). The results suggest that the listeners' motor system is involved not only during the encoding of action phrases uttered by a speaker, but also when recalling these phrases during retrieval.

Key words: enactment; motor system; gesture observation; memory for actions

A growing literature on learning and memory suggests that body movements are able to shape our mind (e.g., Cook & Goldin-Meadow, 2006). This also applies to gestures, motor actions of the hands and the arms, which accompany speech and are not functional acts in the real world (Cartmill, Demir & Goldin-Meadow, 2012). Many studies have demonstrated how these gestures can improve our comprehension and learning of a given material (see e.g., Cutica & Bucciarelli, 2013; Cutica, Ianì & Bucciarelli, 2014; Novack & Goldin-Meadow, 2015). From 1980s, several studies have investigated the so-called "enactment effect" (e.g., Cohen, 1981) in which memory for action phrases like "Rowing a boat" is improved if learners accompany them with congruent gestures (hereafter, SPTs - subject performed tasks), compared to a condition in which learners keep their hands still (hereafter, VTs – verbal tasks; see, e.g., Feyereisen, 2006). Recent findings have revealed that even older adults, known to present a deficit in episodic memory, benefit from SPTs (Silva, Pinho, Souchay & Moulin, 2015). Prospective memory, which involves remembering intended actions in the future, also benefits from enactment in both healthy individuals (Pereira, Ellis & Freeman, 2012; Schult & Steffens, 2017) and individuals with mild cognitive impairment (Pereira, de Mendonça, Silva, Guerreiro, Freeman & Ellis, 2015).

Over the years, several accounts have proposed the learner's motor system has a special role in SPTs enactment effects. For example, Engelkamp and Zimmer (1985) argued that performing an action requires planning and movement control, processes that provide a motor representation able to positively affect semantic memory. In line with this motor account, theorists have suggested that the superiority of memory for enacted phrases relies on procedural learning, whereas memory for pure verbal material relies more on declarative learning (for an analysis of this theoretical point see, e.g., Daprati, Nico, Saimpont, Franck & Sirigu, 2005). There are two main types of evidence consistent with these assumptions. First, items encoded at learning in SPTs automatically "pop" into a person's mind at recall without an active effort (Zimmer, Helstrup & Engelkamp, 2000), and they are used more frequently in subsequent tasks (Macedonia & Knosche, 2011). Second, Alzheimer patients, whose declarative learning is impaired, still benefit from enactment (Karlsson, Bäckman, Herlitz, Nilsson, Winbland & Osterlind, 1989).

A main role for the motor system has been also assumed by the *multimodality hypothesis*, according to which memory is enriched by sensory and motor information provided by action (see, e.g., Engelkamp, 2001). This hypothesis implies that the classic effect observed in SPTs arises from activation and subsequent reactivation of information stored in the motor system. These processes would enable a greater elaboration of the action concept in memory (see also Engelkamp & Jahn, 2003; Zimmer, 2001). The assumption that stored information is enriched by sensory and motor information at encoding and retrieval has then led to the *reactivation hypothesis*: the motor processes which take place at encoding should be reactivated at retrieval (see, e.g., Nyberg et al., 2001). In wider terms, motor information stored in the motor system may have become part of the memory trace. In accordance with this assumption, the activation of the motor areas has been shown to be greater during the recall of phrases learnt in SPTs conditions compared to the recall of phrases learnt in VTs conditions (Nilsson et al., 2000). Nyberg and colleagues (2001) measured and compared the brain activities during both learning and recall of phrases: they observed a great overlap in brain regions activated in both phases, specifically in the left ventral motor cortex. Masumoto and colleagues (2006), using the magnetoencephalography (MEG) at recognition, observed the activation of the left primary motor cortex in all the participants in the SPTs condition, while the same activation appeared in only one of the participants in the VTs condition. All these authors have concluded that retrieval after enactment (in SPTs) can depend on motor information stored in the motor cortex. Consistently, Zimmer and Engelkamp (1985) have found that the recall of action phrases is impaired by a secondary motor task (e.g., a body related action as scratching oneself) more when they are enacted at encoding compared to when they are not.

These findings and theoretical accounts concern SPTs and its effects. Nevertheless, further findings in the literature have revealed an enactment effect also in experimenter-performed tasks (EPTs), namely when the participants just observe a speaker’s gestures (Feyereisen, 2006). Since some studies have reported that recall after SPTs is usually slightly better than after EPTs (see, e.g., Hornstein & Mulligan, 2004), some scholars have argued that motor processes have a pivotal role only in SPTs (see, e.g., Engelkamp & Jahn, 2003). The implicit assumption was that mere gesture observation should not activate motor information in the listener.

In contrast to this assumption, an extensive body of literature suggests that action observation can give rise to a covert motor representation in the observer (see, e.g., Rizzolatti, Fogassi & Gallese, 2001), also in the absence of any task demands. What's crucial to the present investigation is that a motor memory trace could be created not only through the physical experience of performing an action, but also through its simple observation. In particular, studies in the literature have revealed that both in non-human primates (Gallese, Fadiga, Fogassi & Rizzolatti, 1996) and human primates (see, e.g., Rizzolatti, 2005) action observation activates the same areas as action production. More specifically, Buccino et al. (2001) have compared activation deriving from observation of different actions involving different effectors (i.e., mouth, hand and foot). Their results have revealed a *somatotopic organization* of the premotor cortex: foot movements are located at more dorsal areas, mouth movements at more ventral areas and other body parts in between (see also Wheaton, Thompson, Syngeniotis, Abbott & Puce, 2004; Sakreida, Schubotz, Wolfensteller & von Cramon, 2005). Exploiting this cortical somatotopic organization deriving from action observation, Ping, Goldin-Meadow and Beilock (2014) have found that the listener's motor system is also involved in gesture understanding.

This evidence motivated Ianì and Bucciarelli (2017) to investigate the role of the motor system in the EPTs' enactment effect, assuming that it relies on the beneficial role gestures have in the construction of a mental model of learned material through the exploitation of the motor system. In their Experiment 1, participants were asked to observe a series of videos in which an actress was uttering a series of action phrases in the experimenter performed tasks condition (EPTs) or in the verbal tasks condition (VTs). The results replicated the usual enactment effect: participants' correct recollections were greater in EPTs condition than in VTs condition. In Experiments 2 and 3, while watching the videos in the two conditions, besides the memory task, the participants were asked to plan and execute continuous and alternate movements with their arms and hands, the same effectors used by the speaker in the EPTs condition. If the enactment effect involves motor activation in the listener, then loading up participants' motor system by asking them to continuously move their arms and hands should have canceled the beneficial effect of observing gestures on memory (i.e., the advantage of EPTs on VTs). In Experiment 4, while watching the videos in the two conditions, besides the memory task, the participants were asked to plan and execute movements with their legs and feet, different effectors from those used by the speaker in the EPTs condition. Planning and executing leg movements should have not interfered with the enactment effect simply because, consistently with the somatotopic organization of the premotor activation during action observation (e.g., Buccino et al., 2001), the interference should be specific to motor resources controlling the effectors used in producing gesture - in this case, arms and hands (for a similar procedure, see Ping et al., 2014). In line whit these assumptions, the enactment effect disappered in Experiments 2 and 3, whereas it persisted in Experiment 4.

Overall, the results of Ianì and Bucciarelli (2017) have supported the assumption that the listener's motor system plays a pivotal role in the EPTs enactment effect, specifically in the *formation* of memory traces at encoding. A still unexplored question is whether the motor system does play a similar role in the recall of memory traces at *retrieval* as well.

The literature on the enactment effect reveals that the question has been already addressed only for SPTs. According to the reactivation hypothesis (see, e.g., Nyberg et al., 2001), motor processes taking place at encoding should be reactivated at retrieval. Following the findings of Ianì and Bucciarelli (2017), the present study aims to test the same prediction for EPTs: at retrieval, the same motor areas activated in the listener by the gestures of the speaker at encoding, should be re-activated. If the motor system of the listener plays a crucial role also in the retrieval of memory traces then, when the listener performs at retrieval a motor task involving the same effectors involved in the gestures by the speaker, the enactment effect should disappear.

Two experiments were conducted to test this prediction. Participants had to pay attention to videos in which an actress uttered a list of phrases and accompanied each phrase with a pantomime (gesture condition) or uttered the list of phrases while staying still (no-gesture condition). Participants' task was to recall the phrases while performing a secondary motor task. If the motor system plays a pivotal role in the retrieval of memory traces, the speaker's enactment of phrases should:

- improve memory in the listeners who keep their hands and arms still during recall;
- not improve memory in the listeners who, during the recall, move their hands and arms, i.e. the same motor effectors moved by the speaker (Experiment 1a);
- improve memory in the listeners who move, during the recall, their legs and feet, i.e., different motor effectors from those moved by the speaker (Experiment 1b).

Participants were presented with the same experimental material as in Ianì and Bucciarelli (2017), who already demonstrated that the speaker's enactment of phrases improved memory in listeners keeping their hands and arms still during recall but not in those who moved their arms and hands during recall. We refer to our studies as Experiments 1a and 1b to stress that although they were conducted to test our hypotheses, they were not run simultaneously. The investigation was approved by the Ethical Committee of the University of Turin.

Experiments 1a and 1b: Eliciting Arms' Movements during Recall, but not Eliciting Legs' Movements, cancels the Enactment Effect

The participants in the experiments, as the participants in Experiment 1 by Ianì and Bucciarelli (2017), watched and listened to a series of videos in two conditions: in the gesture condition the actress accompanied the phrase with a pantomime and in the no-gesture condition the actress kept her hands and arms still. After having watched each series of videos, the participants were invited to recall the phrases. The only difference was that, in the recall phase, the participants were invited to move their arms and hands in Experiment 1a, and their legs and feet in Experiment 1b. In particular, the participants in each experiment were invited to accomplish the secondary motor task continuously. This instruction was meant to avoid participants stop to move their effectors throughout the task. Also, they were invited to perform alternate and non-repetitive movements; the rationale was to engage them in a continuous planning, thereby recruiting the premotor resources.

Method

Participants. The participants in the experiments were 64 adults, all Caucasians, students of a course of Psychology at the University of Turin (17 males and 47 females: mean age = 23.58 years, SD = 1.87; mean years of schooling = 15.33, SD = 1.32). All had normal, or corrected to normal, vision. They took part in the experiment voluntarily in exchange for course credits. All the participants had given their written consent prior to their participation in the study. There were 32 participants in Experiment 1a and 32 participants in Experiment 1b.

Material and Procedure. The experimental material was identical to that of Ianì and Bucciarelli (2017). They devised the experimental material through a normative study, whose aim was to identify a series of phrases eliciting a great motor activity in the listener. As an example, consider the phrases *rowing a galley-ship* and *looking at the wristwatch* from their pilot study; the former elicits in the listener more motor activity than the latter. The participants in the normative study, university students, read 60 phrases representing actions and they rated each phrase according to how strongly each one elicited movement on a 7-point Likert scale. Forty-eight of the phrases were extracted from the normative study by Molander and Arar (1998), in which the participants rated 439 actions on a 7-points scale according to the motor activity dimension. Specifically, Ianì and Bucciarelli (2017) selected, for their normative study, those phrases that received a mean rating above 3 on the motor activity dimension, and involving objects (e.g., *drinking a glass of water*): the rationale was that this kind of phrases elicit movement more than phrases not involving objects (e.g., *blowing in the air*). At the same time, they selected only the phrases that can be easily represented by arms' and hands' movements (for instance they did not select phrases involving the entire body like *standing up and sitting down*, or phrases that cannot be easily represented by a pantomime like *flying a kite*). In order to devise a set of 60 phrases they added 12 phrases, still referring to an action, on an object, that can be easily represented with a pantomime of hands and arms. The participants in the normative study were invited to carefully read each phrase one at time and rate, using a scale ranging from 1 to 7, how strongly the written action elicits movement. Ianì and Bucciarelli (2017) selected among all the phrases 24 that most elicited movement (see the Appendix). The rationale for choosing 24 phrases was that the beneficial effect of EPTs on memory is optimal when the lists of phrases are short (12-18 items, see Feyereisen, 2006). For each of the 24 phrases they created a couple of videos: in one video an actress accompanies the phrases with congruent gestures (gesture condition) and in the other she keeps her hands still (no-gesture condition), always turning her gaze to the camera. In the gesture condition, the actress was instructed to accompany each phrase with a congruent arms' and hands' movement. In other words, she produced a pantomime of the action performed on the object, as mentioned in the phrases. Further, the actress was asked to gesture at the same time in which she started to pronounce the phrases. In the no-gesture condition the actress was instructed to pronounce the phrase keeping her arms still on the knees. In both conditions she was invited to use the same intonation while uttering the phrase. Figure 1 shows two frames from the videos created for the phrase *Rowing a boat*.

Insert Figure 1 about here

The couples of videos devised by Ianì and Bucciarelli (2017) and used in the present study are available on line at: https://osf.io/zw96y/

Also, in each experiment the same two experimental protocols devised by Ianì and Bucciarelli (2017) were used: in Protocol 1 half of the phrases occurred in the gesture condition (number of words in the list of phrases: 42) and the other half in the no-gesture condition (number of words in the list of phrases: 42). In Protocol 2, the phrases occurring in the gesture condition in Protocol 1 occurred in the no-gesture condition, and the phrases occurring in the no-gesture condition in Protocol 1 occurred in the gesture condition. Further, within each protocol the order of presentation of the gesture and the no-gesture condition was counterbalanced. In each experiment, half of the participants were randomly assigned to Protocol 1 and half to Protocol 2. The order of presentation of the phrases within each condition in the protocols was randomized for each participant.

Each experiment was carried out in a single session and in the presence of the experimenter, who invited the participant to sit down in front a desk where a computer was placed (approximately at 7 inches from the desk's border). In Experiment 1a, the instructions in both conditions specified to move the arms and the hands at recall: "Thanks for your participation and for your time. Your task in the experiment is to carefully watch and listen to a series of videos in which an actress utters a series of phrases representing actions. At the end of the last video, when the word 'Now' will appear on the screen, repeat as accurately as you can the phrases you heard. Further, during the recall phase, starting with your hands placed on your knees, please alternately touch with your index fingers a casual point on the table in front of the computer while recalling the phrases. It is important that your movements are continuous and alternate. Please start to move your arms and hands when the word 'Now' appears on the screen and start with an arm's movement (left or right), only after the other hand has come back on the knee. The word 'Now' will remain on the screen for 90 seconds, that is the time you have at disposal for your free recall, and during this time you cannot stop your arms and hands. After 90 seconds the word 'End' will appear on the screen". In Experiment 1b, the instructions were identical, except for the secondary motor task: "During the recall phase, starting from the sitting position, please alternately stretch your legs in front of you and touch with only your heels the floor. It is very important that your movements are continuous and alternate. Start with a leg's movement (left or right) only after the other leg has come back to the starting position. Please start to move your legs and feet when the word 'Now' appears on the screen and until the word 'End' appears". The participants were told that the order of the phrases recalled did not matter, and that they could repeat twice the same phrase. The experimenter showed the motor movements requested and specified that this motor secondary task should stop at the end of the recall phase. The experimenter was sitting down behind the participants, but in a position (approximately at 45 degrees) where he was able to check and keep track of the correct performance of the motor secondary task.

Recollections were coded as in Ianì and Bucciarelli (2017), according to the following schema.

- *Literal recollection*: a phrase recalled exactly in its literality.
- *Paraphrase*: a phrase recalled using different words or different prepositions, but with the same meaning of the original phrase. Examples include phrases recalled paraphrasing some elements: plural/singular (*beating an egg* instead of *beating eggs*), article (e.g., *throwing the stone* instead of *throwing a stone*), verb (e.g., *washing a window* instead of *cleaning a window*).

All the other types of recollection were considered errors:

- *Erroneous recollection*: a recollection inconsistent in meaning with any of the original phrases, e.g., the phrase *listening to music*, absent from the list of phrases, or the phrase *throwing a basketball* which is a blending of two original phrases, *throwing a stone* and *dribbling with a basketball.*

The paraphrases were considered correct recollections, along with the literal recollections, because mental models might lead participants to remember a greater number of information at the semantic level compared to the verbatim level (see, e.g., Cutica & Bucciarelli, 2008).

Results

The data of participants who did not perform correctly the secondary task were not coded and therefore excluded from the analyses. In Experiment 1a, two participants did not start the motor task when the word “Now” appeared on the screen, one participant interrupted the motor task when he started to speak, and one participant performed the motor task moving at the same time both his arms and hands, thereby not performing alternate movements. There were no outliers; none of the participants recalled a number of correct recollection 2 standard deviations above or below the mean, in at least one experimental condition. In Experiment 1b, two participants did not perform alternate movements and there was an outlier. Therefore, we analysed the data of twenty-eight of the thirty-two participants in Experiment 1a and those of twenty-nine of the thirty-two participants in Experiment 1b. Table 1 illustrates the mean scores for types of recollection in the two experimental conditions of the experiments.

Insert Table 1 about here

A 2x2 mixed ANOVA, with Gesture (gesture vs. no-gesture) as within subjects variable, Group (arms/hands vs. legs/feet) as between subjects variable and correct recollections as dependent variable, revealed that the main effect of Group was not significant ($F(1,55) = .11$, $p = .74$, $\eta_p^2 = .00$), while the main effect of Gesture was significant ($F(1,55) = 5.59$, $p = .02$, $\eta_p^2 = .09$). Importantly, the Gesture condition by Group interaction was also significant ($F(1,55) = 6.75$, $p = .01$, $\eta_p^2 = .11$). Post hoc tests indicated that correct recollections were greater in the group moving legs and feet than in the group moving arms and hands in the gesture condition (t test: $t = -2.42$, $p = .02$, Cohen’s $d = .64$), but not in the no-gesture condition (t test: $t = 1.22$, $p = .23$, Cohen’s $d = .29$). Crucially, correct recollections were greater in the gesture condition compared to the no-gesture condition in the group moving legs and feet (t test: $t = 3.45$, $p = .002$, Cohen’s $d = .64$), but not in the group moving hands and arms (t test: $t = .17$, $p = .87$, Cohen’s $d = .03$).[1] We detected no significant effects for literal recollections, paraphrases and errors.

[1] Identical results were obtained carrying out mixed-effect logistic regression, implemented with the glmer() function from the lme4 package (version 1.1-14; Bates et al., 2017) in the R statistical programming environment. A model including Gesture and Group as fixed factor of interest, and Subjects and Item as fixed random effect with the maximal structure of random effects supported by the design (Barr, Levy, Scheepers & Tily, 2013) detected the same Gesture*Group significant interaction ($ß = .65$, $SE = .26$, $z = 2.46$, $p = .01$). The model specification was: Recalled ~ Gesture*Group + (1+Gesture|Subjects) + (1+Gesture*Group|Item). This analysis has been performed using the optimizer “bobyqa” to prevent non-convergence problems. Identical results were obtained also when carrying out non-parametric analyses.

Overall, the results confirmed our predictions: the speaker's enactment of phrases did not improve memory in the listeners who moved, at recall, their hands and arms (Experiment 1a), but it did improve memory in the listeners who, at recall, moved their legs and feet (Experiment 1b). A comparison of the results of our Experiment 1b with those in Experiment 1 of Ianì and Bucciarelli (2017), in which the participants stayed still at recall, revealed that accuracy was greater in the gesture condition compared to the no-gesture condition when participants, at recall, moved their legs and feet or stayed still. In particular, the advantage of the gesture condition was similar in the two : a mean of 8.6 (SD = 1.6) and 7.5 (SD = 2.0; t test: $t = 3.09$, $p = .005$, Cohen's $d = .62$) in Experiment 1 of Ianì and Bucciarelli (2017) and a mean of 8.4 (SD = 1.5) and 6.9 (SD = 1.8; t test: $t = 3.45$, $p = .002$, Cohen's $d = .64$) in Experiment 1b. However, the results of our Experiment 1a revealed that the gesture condition had no advantage on the no-gesture condition when, at recall, the participants moved their arms and hands. Figure 2 illustrates the means of correct recollections by the participants in the three studies, as a function of the gesture and the no-gesture condition.

Insert Figure 2 about here

Discussion and Conclusion

Previous research has revealed that the listener's motor system plays a crucial role *at encoding* in the EPTs enactment effect; the aim of our investigation was to explore its role at *retrieval*. The participants in our experiments observed videos in which an actress uttered action phrases in two conditions: in the gesture condition she accompanied them with congruent gestures, in the no-gesture condition she stayed still while uttering the phrases. The task of the participants was to recall as many phrases as they could. At recall, the participants performed a concurrent motor task: in Experiment 1a they moved their arms and hands (i.e., same effectors moved by the actress in the gesture condition) and in Experiment 1b they moved legs and feet (i.e., different effectors from those moved by the actress). The results of our experiments, along with those obtained by Ianì and Bucciarelli (2017) with the same experimental material, support the assumption that the listener's motor system plays a crucial role on memory trace retrieval in the

EPTs enactment effect. The speaker's enactment of phrases improved memory in listeners who stayed still at recall (Experiment 1 in Ianì & Bucciarelli, 2017), but it did not improve memory in listeners who moved their arms and hands at recall (our Experiment 1a), whereas it continued to improve memory in listeners who moved their feet and legs at recall (our Experiment 1b).

The results of the present investigation are consistent with findings in the neuroscientific literature revealing that premotor regions contributing to action production and action understanding have a similar *somatotopic organization*, and premotor area activations during action observation play a *causal role in the understanding* of actions (Michael et al., 2014). For example, the results of studies on foreign word learning accompanied or not with iconic gestures parallel our results in that they evidence a main role of the motor system at recall in the beneficial effect of gestures. In particular, the participants in a study of Macedonia, Muller and Friederici (2011) observed and performed either iconic or meaningless gestures associated with the words while learning novel words. Later on, during a word recognition task, their brain activity was registered using fMRI. The results showed that iconic gestures at learning enhanced memory for new nouns, and most importantly for the present investigation, there was a brain activation in the premotor-cortex during the recognition of words previously encoded through iconic gestures; for nouns encoded with meaningless gestures there was the activation of a network associated with cognitive control. Since the participants kept their arms still at recognition, the authors concluded that the "activity in the premotor cortex results from the resonance of the network established during learning" (Macedonia et al., 2011, p. 993).

A skeptic could argue that our results are not new as studies in the literature have revealed that when people are not free to gesture (as in our Experiment 1a) they have difficulties in lexical retrieval (see, e.g., Frick-Horbury & Guttentag, 1998). However, although gestures play a pivotal role in lexical retrieval at recall (see also Ianì, Cutica & Bucciarelli, 2016), the lexical retrieval paradigm would assume that restricting hand gestures should impair performance in Experiment 1a (where participants could not spontaneously gesture during recall because their arms and hands were involved in action) irrespective whether the phrases were encoded with or without a speaker's gesture, while no such impairment should be in place in Experiment 1b where participants could use their hands during the recall of phrases (because they were only moving their legs and feet). Therefore, if the lexical retrieval explanation would be correct we should have observed the main effect of Group, that actually we did not.

Globally considered, the results of the present investigation are relevant for understanding the reconstructive processes of memory, observable above all in retrieval processes. As Roediger, Wixted and Desoto (2012) have suggested, since remembering is reconstructive, the retrieval processes are crucial, and one of the main problem of the classical “trace theories” is having completely ignored the retrieval processes, thereby considering memories as “fixed and lifeless” (Bartlett, 1932). Classically, the studies on retrieval processes have highlighted the crucial role of high-cognitive processes: humans integrate memories in a coherent description, in a way that strongly depends upon the nature of the cues the individual has, and upon the instructions about retrieval (see, e.g., Roediger et al., 2012). Our results suggest that also low-level processes like those involved in performing a motor secondary task can affect retrieval: the participants’ movement at retrieval can interfere with their memory for the verbal material associated to a specific sensorimotor experience. These results are also in line with the so-called *sensory reactivation hypothesis* or *reinstatement hypothesis* (for a discussion see Schacter, Chamberlain, Gaesser & Gerlach, 2012), according to which cortical regions activated at encoding of a given stimulus are also active at memory tests for the same stimulus (Nyberg, 2002). The most relevant contribution of the present investigation is the evidence in favour of the crucial role of the motor system not only in the EPTs enactment effect, as shown by previous research, but also in the SPTs enactment effect.

A main limitation of our study is that it disregards the importance of demonstrating the relevance of the motor system in the enactment effect through the detection of a double dissociation (see, e.g., Shebani & Pulvermuller, 2013). Future studies could explore this possibility for EPTs. In particular, loading up motor system with a secondary motor task involving hands and arms at recall should cancel the enactment effect for phrases accompanied by hands' and arms' gestures, but not for phrases accompanied by legs' and feet's gestures congruent in meaning with the action phrases (e.g., the gesture of kicking a ball accompanying the phrase "Kicking a ball"). Vice versa, loading up motor system with a secondary motor task involving legs and feet at recall should cancel the effect for phrases accompanied by legs' and feet's gestures, but not for phrases accompanied by arms' and hands' gestures.

An interesting open and more general question is whether the motor system is involved in the retrieval process of an event in which another person was performing an action, the typical kind of memory involved in eyewitnesses' reports (e.g., remembering a mugging). It has been already demonstrated that remembering an autobiographical event relies on the same sensorimotor information that were activated when the event was experienced (for a review see Dijkstra & Post, 2015). Specifically, Dijkstra, Kaschak and Zwaan (2007) found that remembering an autobiographical event in a body position congruent with the body position of the original experience (e.g., lying down in a recliner when recalling the last dental treatment) compared to an incongruent position (i.e., different from the original) facilitates the access and the retention of the memory (Dijkstra et al., 2007). That finding suggests that the motor-based information is used to simulate and reconstruct the original experience in an autobiographical memory. If our results go beyond the enactment paradigm, we could expect that the motor-based information is used also to simulate and reconstruct the action of another person. Then, a secondary motor task at recall should interfere also with such memories.

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The experimental material used in this paper is archived at the following database:

https://osf.io/zw96y/

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Disclosure statement

The authors report no conflicts of interest.

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Appendix

The phrases used in the experiments (translated from Italian) and their mean rating on a 7-points Likert scale in the normative study by Ianì and Bucciarelli (2017).

1_Rowing a boat 5.7

2_Conducting an orchestra 5.2

3_Playing the violin 5.1

4_Dribbling with a basketball 5.0

5_Playing the piano 4.9

6_Cleaning a window 4.7

7_Driving the car 4.6

8_Painting a painting 4.4

9_Ironing a shirt 4.4

10_Beating eggs 4.3

11_Wringing out the clothes 4.3

12_Throwing a stone 4.2

13_Getting shampoo 4.2

14_Polishing silver 4.0

15_Hammering a nail into the wall 4.0

16_Brushing the teeth 4.0

17_Creaming the body 4.0

18_Laying some blocks one above another 3.9

19_Sewing by hand 3.7

20_Typing 3.7

21_Hugging someone 3.7

22_Shooting with the gun 3.5

23_Rolling up the ball of yearn 3.5

24_Sharpening a knife 3.5

(a) (b)

Figure 1. The actress utters the phrase *Rowing a boat* in the gesture (a) and in the no-gesture (b) conditions.

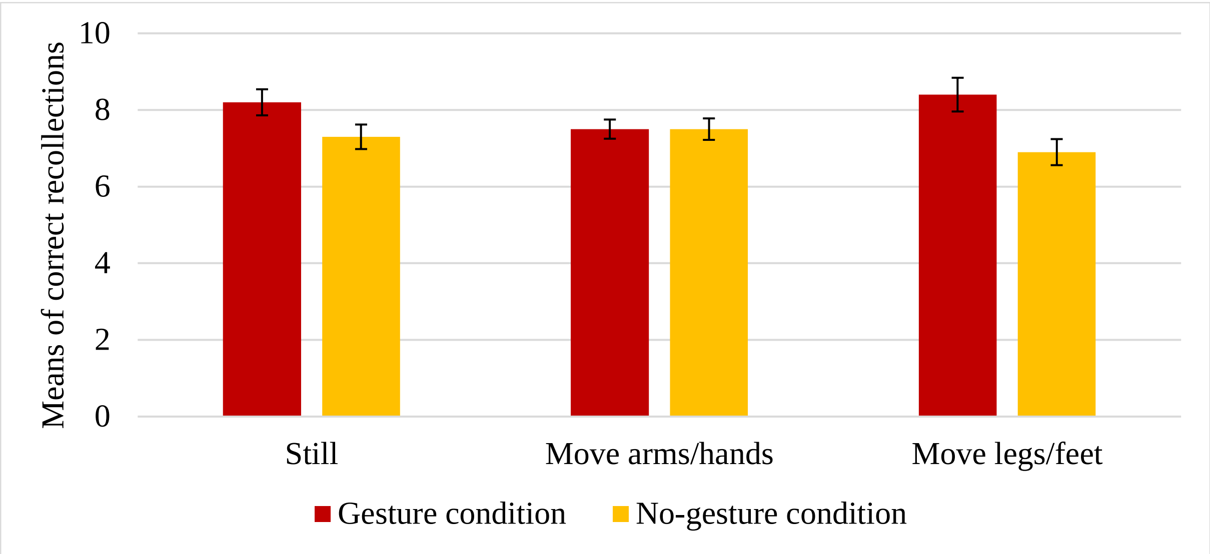

Figure 2. Means of correct recollections by participants who, at recall, stay still (from Ianì & Bucciarelli, 2017), move arms and hands (our Experiment 1a), move legs and feet (our Experiment 1b), as a function of the experimental conditions.

Experiment	**Condition**	**Type of recollection**			
		Literal	Paraphrases	Correct (Literal+Paraphrases)	Errors
1a – move arms/hands (N = 28)	Gesture	5.4 *(1.7)*	2.1 *(1.4)*	7.5 *(1.3)*	0.3 *(0.7)*
	No-Gesture	5.3 *(2.1)*	2.3 *(1.2)*	7.5 *(2.3)*	0.4 *(0.6)*
1b – move legs/feet (N = 29)	Gesture	5.6 *(1.5)*	2.8 *(1.4)*	8.4 *(1.5)*	0.1 *(0.3)*
	No-gesture	4.9 *(1.9)*	2.0 *(1.1)*	6.9 *(1.8)*	0.3 *(0.5)*

Table 1. Means (and standard deviations) of types of recollection in the gesture and the no-gesture conditions as a function of the experiment.