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Mechanisms underlying the beneficial effect of a speaker's gestures on the listener

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ABSTRACT

A well-established literature reveals that a speaker's gestures have beneficial effects on the listener's memory for speech. A main assumption of our investigation is that gestures improve memory through the exploitation of the listener's motor system. We tested this prediction in four experiments in which the participants listened to action sentences uttered by a speaker who either stayed still or accompanied the speech with congruent gestures. The results revealed that when the listeners observed gestures their memory for speech improved (Experiment 1), but loading up the listeners' motor system during gestures observation cancelled the beneficial effect when the motor task involved the same effectors used by the speaker (arms and hands, Experiments 2–3). The beneficial effect of gestures persisted when the motor task involved different effectors (legs and feet, Experiment 4). These results support the assumption of a main involvement of the motor system in the beneficial effect of observed gestures.
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Introduction

Hand gestures are motor actions that often accompany speech and are intertwined with the spoken content (e.g., Kelly, Manning, & Rodak, 2008; McNeill, 1992). A huge literature revealed that gestures are crucial in communication: both for the speaker and for the hearer (see, for a review Goldin-Meadow, 1999; Goldin-Meadow & Alibali, 2013). Also, most relevant to the present investigation, gestures can improve learning and memory in several ways, both when produced and when observed (see, e.g., Cutica & Bucciarelli, 2008; Cutica & Bucciarelli, 2013). Cook, Yip, and Goldin-Meadow (2010) found that producing gestures at learning, spontaneously or on demand, makes the information more memorable. Producing gestures is beneficial also in learning from scientific texts (Cutica, Ianì, & Bucciarelli, 2014; Ianì, Cutica, & Bucciarelli, 2016) and in learning math: requiring children to gesture while learning a new mathematical concept helps them to retain the knowledge they had gained during instructions (Cook, Mitchell, & Goldin-Meadow, 2008).

Although the results of some studies seem suggest that performing gestures affects learning more than observing gestures (e.g., Goldin-Meadow et al., 2012), gestures may have a pivotal function also for the observer. For instance, children are more likely to learn a task when their teacher accompanies the instructions with congruent gestures than when the instructions do not include gestures (e.g., Church, Ayman-Nolley, & Mahootian, 2004; Cook & Goldin-Meadow, 2006; Ping & Goldin-Meadow, 2008), and observing gestures while learning words of a foreign language can improve the level of learning (e.g., Macedonia & Knösche, 2011).

Consistent with these findings, the literature on the so-called *enactment effect* reveals that human memory for action sentences is improved by producing gestures or observing gestures congruent with the action described by the sentences. This effect was formerly detected in 1981 by Cohen: free recall of action phrases like *break the toothpick* was improved when participants, during the learning phase, were asked to perform with gestures the action portrayed in the sentences (*subject-performed task*, SPTs) or when they were asked to observe the speaker performing the action (*experimenter-performed task*, EPTs), as compared to the situation in which the participants just heard or read the sentences (*verbal task*, VTs). The enactment effect has been observed in free recall tasks as well as in recognition tasks (see Engelkamp, 1998), using entire actions sentences as well as single nouns (e.g., Kormi-Nouri, Nyberg, & Nilsson, 1994). Further, the effect has been observed in children (e.g., Thompson, Driscoll, & Markson, 1998) as well as in elderly adults (Feyereisen, 2009).

Although few studies reported an advantage of SPTs on EPTs (e.g., Hornstein & Mulligan, 2004), the beneficial effect of enactment occurs both when the participants themselves perform the

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gestures and when they simply observe the gestures produced by a speaker (Madan & Singhal, 2012). Cohen (1981), during a free recall task, detected no difference between the SPTs condition and the EPTs one, whereas Engelkamp and Zimmer (1997) detected a recall advantage of SPTs over EPTs. However, as Engelkamp and Dehn (2000) argue, this inconsistency in findings could depend on the length of the list of sentences to recall. Taken together, the studies on the enactment effect suggest comparable recall rates in SPTs condition and EPTs condition (Feyereisen, 2009). An important feature of the enactment effect is that, although several action sentences used in the literature involve external objects (e.g., *open a book*, *play the piano*), it is not necessary to show up the real objects in order to detect a beneficial effect on memory (e.g., Mohr, Engelkamp, & Zimmer, 1989): just a *pantomime*, a gesture performed without using real objects, produces the enactment effect. A study of Engelkamp and Zimmer (1997), where real objects were presented both in VTs, EPTs and SPTs conditions, revealed that introducing the real object didn't improve the enactment effect, thereby suggesting that the object component is not a critical factor in the advantage of SPTs and EPTs over VTs.

Although the positive effects of gestures are robust, their interpretation is still controversial. As Feyereisen points out, it is well established that "enactment adds something to the processing of the verbal material to be memorized [...] the problem is to identify what is added" (Feyereisen, 2009, p.374). In particular, a question still waiting for an answer is which mechanisms underlie the beneficial effect of gestures. It has to be excluded an attentional explanation. Indeed, in the enactment effect, as for co-speech gestures (see, e.g., Cutica & Bucciarelli, 2015; Kelly, McDevitt, & Esch, 2009), the beneficial effect of observing gestures depends on their semantic meaning and not by their ability to focus the attention on the word they accompany. In particular, Feyereisen (2006) found that only matching representational gestures facilitated verbal recall, whereas incongruent or beat gestures did not.

In this paper, we test the prediction that observing gestures improves memory through the exploitation of the motor system. This prediction is implied by the assumptions of the mental model theory, our theoretical framework, but it is consistent also with alternative theoretical frameworks.

Theories of the beneficial role of gestures in the enactment effect

There exist several theoretical accounts of the enactment effect, all of them not mutually exclusive. Their focus is on the beneficial effect of subject-performed tasks compared to experimenter-performed tasks and pure verbal tasks (hereafter, SPTs, EPTs and VTs, respectively). Among them, the *episodic integration hypothesis* suggests that enacting action sentences reinforces the episodic relationship between the verb portraying the action and the object noun (Kormi-Nouri, 1995). This process results in a stronger association between action and object: these components are encoded in a single memory unit (see, e.g., Kormi-Nouri & Nilsson, 2001; Mangels & Heinberg, 2006). The *distinctiveness hypothesis* (see, e.g., Engelkamp, 1998) suggests that SPTs increase item distinctiveness because planning and executing actions focuses the encoding on item-specific information. According instead to the *multimodality hypothesis* (see, e.g., Engelkamp, 2001), performing an action requires planning and movement control that provide a motor representation which may be reactivated at retrieval (see also Zimmer, 2001). In this view, the classical effect detectable in SPTs condition should arise from the activation and later on the reactivation of information stored in the motor system, thereby enabling a greater elaboration of the action concept in memory. Consistent with this hypothesis, the amount of visual feedbacks does not affect the beneficial effect of gestures: the SPTs effect is detectable also when the persons are blindfolded during the learning phase (Engelkamp, Zimmer, & Biegelmann, 1993) and conversely, memory is not enhanced when a mirror is situated in front of the participants (Hornstein & Mulligan, 2004). These results suggest that the motor information, rather than the visual one, is crucial for the enactment effect.

The multimodal hypothesis gave rise to a series of investigations, and the assumption that stored information is enriched by sensory and motor information during encoding and retrieval resulted in the *reactivation hypothesis*: the motor processes which took place during the study phase should affect the memory and be regenerated during retrieval. These mechanisms would underly the beneficial effect of gestures in SPTs. Consistent with this assumption several neuroimaging studies suggest that the enactment effect results from the possibility to base retrieval on motor information. For example, a PET study revealed a major involvement of the brain motor areas in the verbal retrieval of phrases that the participants formerly accompanied with gestures (Nilsson et al., 2000): remembering action sentences previously accompanied by gestures engages the motor brain areas. An fMRI study of Russ, Mack, Grama, Lanfermann, and Knopf (2003) detected a crucial role of postcentral right area (BA2) after the SPTs condition compared to the VTs condition. The area B2 is roughly the equivalent of the primary motor cortex detected in Nilsson et al.'s study (2000).

Nyberg et al. (2001) measured and compared the brain activities both at learning and recall in order to investigate more in depth the reactivation hypothesis. They observed a great overlap in brain regions activated in both phases, specifically in the left ventral motor cortex and in the left inferior parietal cortex. Since overlapping regions in motor cortex were activated at both learning and retrieval phases, Nyberg and colleagues concluded that retrieval after enactment in SPTs can depend on motor information and that the function of the motor cortex is not limited to the execution of movements, but it is involved also in non-motor skills (see also Masumoto et al., 2006). In sum, findings in the neurocognitive literature revealing a critical activation of the motor areas during recall or recognition after SPTs condition support the *motor information reactivation hypothesis*.

The role of the motor system within a mental model framework

A central assumption of the mental model theory (Johnson-Laird, 1983, 2006) is that a deep comprehension of a discourse, and the subsequent good recall, is tantamount to the construction of an articulated mental model of the discourse. A *mental model* is an iconic, non-discrete, mental representation that reproduces the state of affairs described in a discourse (see, e.g., Graesser, Millis, & Zwaan, 1997); a model consists of elements, which stand for the entities in the discourse, and the relationship between these elements, which stand for the relationship between the entities. Models encode little or nothing of the linguistic form of the sentences on which they are based, hence the prediction, confirmed by the results of studies in the literature, that individuals recover more information at a semantic level and less information at a verbatim level (e.g., Mani & Johnson-Laird, 1982). In particular, an articulated mental model, compared to a poor mental model, results in a greater number of correct recollections and discourse-based inferences drawn from the information explicitly contained in a given material, along with a poorer retention of the surface information (see, e.g., Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991; Johnson-Laird & Stevenson, 1970).

Bucciarelli (2007) argued that the information conveyed by the speaker's co-speech gestures, represented in a non-discrete format,

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