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Producing gestures establishes a motor context for procedural learning tasks

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ABSTRACT

Recent research presented evidence that producing gestures influences learning and knowledge representations. In this study, we investigated whether this beneficial effect of gesturing is increased for procedural learning tasks in that the motor context (i.e. producing gestures) is congruent during the learning and the testing phase. In Experiment 1, participants learned to tie nautical knots with or without producing gestures and were asked to reproduce the knots in the testing phase. Hence, the motor context was congruent for the participants producing gestures in the learning phase and incongruent for the learners that did not produce gestures. Producing gestures during learning improved performance, thus, replicating prior research. In Experiment 2, we manipulated whether participants produced gestures during learning and testing. There were two context-congruent conditions (learning and testing both with producing gestures vs. learning and testing both without producing gestures) and two context-incongruent conditions (producing gestures during learning but not producing gestures during testing vs. not producing gestures during learning but producing gestures during testing). Results showed a context-congruency effect. Performance was higher in the context-congruent than the context-incongruent conditions. We conclude that congruency with regard to the availability of motor information during the learning and the testing phase is an important determinant for successful procedural learning.

1. Introduction

Gesturing helps learning and improves problem-solving (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007; Goldin-Meadow, Cook, & Mitchell, 2009; Ping & Goldin-Meadow, 2008). Gestures are assumed to change basic cognitive processes and knowledge representations by introducing "action into one's mental representation" (Beilock & Goldin-Meadow, 2010, p. 1609). Influences of gestures on cognitive processes have been studied in numerous paradigms. There are studies that examine the role of the semantic overlap of speech and gestures on learning (e.g., Singer & Goldin-Meadow, 2005). Further, studies examining the use of gestures without accompanying speech focus on the role of motor processes on knowledge formation (Cook, Mitchell, & Goldin-Meadow, 2008). In the current manuscript, we concentrate on the latter and test the hypothesis that congruency in the motor context across the learning and the testing phase contributes to the *gesture-superiority effect*. This hypothesis builds on the robust finding that similar contextual information during the learning phase and the testing phase results in superior test performance (Tulving & Thomson, 1973). For the gesture-superiority effect, this implies that producing gestures in the learning phase should be most beneficial if the learners are also required to produce gestures in the testing phase because gestures act as an additional, contextual retrieval cue that is congruent across the learning and the testing phase.

In contrast, contextual information that is only available during learning or testing could hamper performance. If learners are required to produce gestures during the testing phase after they did not produce gestures in the learning phase, the required gestures do not constitute contextual retrieval cues. Further, the production of non-learned gestures during the testing phase may constitute a secondary task that interferes with test performance. But also if learners are required to produce gestures during the learning phase and are not allowed to produce gestures in the testing phase, test performance may be hampered because the learners are not able to use all aspects of their mental representations (including motor information) during testing.

1.1. *The gesture-superiority effect*

The beneficial effect of gestures on learning has been well-established in previous experiments (Broaders et al., 2007; Goldin-Meadow et al., 2009). This is true both for producing gestures oneself during the learning phase (Cook, Yip, & Goldin-Meadow, 2012; Cook et al., 2008) as well as for observing other persons' gestures (e.g., Brucker, Ehlis, Häußinger, Fallgatter, & Gerjets, 2015; Cook, Duffy, & Fenn, 2013).

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Regarding the production of gestures, Cook et al. (2008) showed that instructing children to gesture during math instruction significantly improved learning. In another study, participants producing meaningful gestures while explaining math problems performed better in a secondary task that required them to remember letters that were presented during the explanation task (Cook et al., 2012). In contrast, participants, who were instructed to perform unrelated and thus meaningless hand movements did not show better performance in the secondary task than a control group that was instructed not to move their hands while explaining. The authors conclude that producing meaningful gestures reduces working memory load, thus freeing up cognitive resources for additional processing (Cook et al., 2012). Whereas this study makes an important contribution to explaining the positive effects of gesturing, the secondary working memory task was not related to the nature of the gestures. Hence, the conclusion that meaningful gestures facilitate performance by freeing cognitive resources is based on indirect evidence derived from the participants' performance in a secondary task and not on the participants' actual mastery of the math problem that they had explained while producing gestures.

More direct evidence for the beneficial effects of gesturing on related task performance is provided by Novack, Congdon, Hemani-Lopez, and Goldin-Meadow (2014). These authors investigated whether there were differences regarding the learning benefits of producing concrete actions, producing concrete gestures, and producing abstract gestures in a non-procedural mathematical learning task. With increased abstraction of the gestures from the actual learning contents, generalization of the learned concepts to different tasks improved. The authors explained this observation with a dissociation of the learned contents from the gestures when abstract gestures are produced, so that learners are better able to use their knowledge for new problems, whereas producing concrete actions and producing concrete gestures establishes stronger links between the concrete learning materials and the motor information. This explanation implies that learners link the gestures that they actively produced to their mental representations of the learning materials.

Similarly, Goldin-Meadow et al. (2012) have shown that this also applies to procedural tasks, such as simple mental transformation. In such tasks, participants are presented with two initial shapes and a choice card depicting four shapes (one target shape and three distractor shapes). Only the target shape is composed of the two initial shapes. Participants are asked to point to the target shape on the choice card. Children as young as 6 years, who were instructed to perform a gesture relevant to the task (i.e. mental transformation) improved more than children who were instructed to perform a gesture that was not relevant to the task.

Further, it seems to be important that the produced gestures are compatible with the task that learners are supposed to master in the testing phase. For example, Beilock and Goldin-Meadow (2010) studied problem-solving behavior using the Tower-of-Hanoi task. In an initial trial in that participants tried to solve the task, the smallest disc was the lightest one and the largest disc was the heaviest. After this initial trial, participants verbally described the task using gestures. In the meantime, the weights of the discs were reversed for half the participants, so that the smallest disc was now too heavy to be lifted with one hand. When trying to solve the task again for a second time, it was observed that participants who had used one hand in their gestures describing how they moved the smallest disc took significantly more moves to solve the task when the weights of the discs were reversed. The authors argue that gestures using one hand to move the smallest disc were incompatible with the required movements in the testing phase, in that the smallest disc was too heavy to be lifted with one hand when the weights of the discs were reversed. This finding implies that having similar contexts during the learning and the testing phase is most beneficial because learners may then use all aspects of their mental representations of the learned procedure. In contrast, if the motor information (i.e. using one hand vs. two hands for a procedure) differs between the learning and the testing phase, this may be detrimental for learning.

However, not only producing meaningful gestures, but also observing hands that perform gestures supports learning. For example, observing gestures increased performance in a math task (Cook et al., 2013), when learning about physical phenomena (Fiorella & Mayer, 2016; de Koning & Tabbers, 2013), in a Piagetian conservation task (Ping & Goldin-Meadow, 2008), in a knot tying task (Marcus, Cleary, Wong, & Ayres, 2013), and when learning new vocabulary (Kelly, McDevitt, & Esch, 2009). The beneficial effects of observing other people perform gestures is often attributed to an activation of the mirror neuron system (e.g., Marcus et al., 2013; de Koning & Tabbers, 2013). The mirror neuron system consists of neurons that produce the same pattern of activation when observing an action than when actually performing an action (Rizzolatti & Craighero, 2004). Empirical evidence for the activation of the mirror neuron system in the context of observing gestures is provided by Brucker et al. (2015) who demonstrated that observing meaningful gestures in a video describing different categories of fish movements actually resulted in an increased cortical activation of the mirror neuron system in learners with low visuospatial abilities. Moreover, observing gestures that corresponded to fish movements resulted in more accurate classifications of fish movements for learners with low visuospatial abilities compared to observing random gestures (Brucker et al., 2015). Hence, Brucker and colleagues provide conclusive evidence that observing meaningful gestures results both in an increase of cortical activation and in better learning outcomes.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.learninstruc.2018.07.008.

To sum up, we can conclude that both producing and observing meaningful gestures supports learning (e.g., Brucker et al., 2015; Cook et al., 2008). This effect is explained by introducing additional motor information that may be included in the learners' mental representations as an additional retrieval cue that is more or less associated with the learned contents (Beilock & Goldin-Meadow, 2010; Novack et al., 2014). Consequently, providing a context that actually fosters the use of encoded motor information as a retrieval cue during the testing phase should actually benefit learning.

1.2. The context effect in gesturing

In the previous section, we argued that gestures in the learning phase may provide learners with motor information that can act as an additional retrieval cue in the testing phase. It has long been established that congruent contextual information during the learning and the testing phase benefits performance in memory tasks (Smith & Vela, 2001; Tulving & Thomson, 1973). These studies often used environmental context as a contextual cue, such as physical environment (Godden & Baddeley, 1975), smells (Cann & Ross, 1989), or background music (Balch, Bowman, & Mohler, 1992). In our experiment, we assume that producing gestures during the learning phase may serve a comparable purpose, by establishing a motor context that, if re-activated during the testing phase, may act as a retrieval cue that supports memory for the learned contents. Hence, producing gestures during the learning phase should be most beneficial when learners also gesture during the testing phase. In contrast, if learners rely on the motor information that is activated while producing gestures in the learning phase, but are not allowed to reproduce these gestures in the testing phase, this may hamper learning. Similarly, producing gestures during the testing phase is unlikely to benefit learning if no gestures were produced during the learning phase. This assumption is in line with the *encoding specificity principle* (Hannon & Craik, 2001; Reder, Anderson, & Bjork, 1974) stating that retrieval cues support memory only if they were presented together with the critical information during the learning phase. Moreover, producing gestures for the first time during