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The role of motor imagery in learning via instructions☆

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ABSTRACT

Learning via instructions and learning through physical practice are complementary pathways to obtain skilled performance. Whereas an initial task representation can be formed on the basis of instructions, physically practicing novel instructions leads to a shift in processing mode from controlled processing toward more automatic processing. This shift in processing mode is supposedly caused by the formation of a pragmatic task representation, which includes task parameters needed to attain skilled task execution. In between learning via instructions and physical practice, a third type of learning can be situated, motor imagery. Two experiments are reported that studied the extent to which motor imagery can enhance the application of novel instructions. A procedure was developed in which performance improvement after motor imagery could be measured for behavioral markers of processes underlying response selection (i.e., initiation time of a response sequence) and for behavioral markers of processes underlying movement execution (i.e., completion time of the response sequence). Our results suggest that whereas physical practice improves response selection and movement execution, motor imagery only improves response selection. We propose that motor imagery also leads to a shift in processing mode and to the formation of a pragmatic task representation, albeit a less detailed one as compared to the representation that is formed on the basis of physical practice.

1. The role of motor imagery in learning via instructions

Many people have learned complex skills such as handling computers, cameras and cell phones. In most cases these skills are largely based on instructions, which are provided by manuals or peers. An important advantage of instructions is that they offer a quick route to learning. In contrast to trial-and-error learning in which contingencies are learned gradually over time, learning through instructions appears to be instant (e.g., Cohen-Kdoshay & Meiran, 2007; De Houwer, Beckers, Vandorpe, & Custers, 2005; Liefooghe, Wenke, & De Houwer, 2012; Meiran, Pereg, Kessler, Cole, & Braver, 2015; Wenke, Gaschler, & Nattkemper, 2007). Daily life functioning, however, is not uniquely based on the implementation of instructions alone. Novel instructions will most often be physically practiced before skilled behavior emerges. In some cases, practice can be physical with an instruction being executed overtly several times (i.e., physical practice or PP). However, practice does not necessarily need to be overt and people can engage in a more covert modus of practice, which is not associated with physical movement. Such type of practice is often referred to as motor imagery (MI). While the effect of PP on the application of novel instructions has been documented in a number of studies (e.g., Ruge & Wolfensteller, 2010), not much is known about the impact of MI in this context. Accordingly, the aim of the present study is to investigate the effect of MI and PP in the application of novel instructions.

2. Instructions and physical practice

Ever since the seminal work of Schneider and Shiffrin (1977), physical practice is considered as the prime gateway to automaticity. In recent years, however, an increasing amount of research suggests that novel instructions specifying S-R mappings (e.g., Cohen-Kdoshay & Meiran, 2007; De Houwer et al., 2005; Liefooghe et al., 2012; Meiran et al., 2015; Wenke et al., 2007), but also instructions specifying response-effect contingencies (Theeuwes, De Houwer, Eder, & Liefooghe, 2015) and even No-Go instructions (Liefooghe, Degryse, & Theeuwes, 2016) can also lead to automatic effects. The common hypothesis is that instructions are implemented into a procedural representation, which is kept active in working memory (e.g., Liefooghe et al., 2012; Meiran, Cole, & Braver, 2012) and guides future task execution, possibly by enabling prepared reflexes (e.g., Meiran et al., 2015).

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Ruge and Wolfensteller (2010) propose that the representation formed on the basis of instructions is rather abstract in nature and only includes conceptual stimulus and response codes (see also Liefooghe et al., 2012; Tibboel, Liefooghe, & De Houwer, 2016; Wenke et al., 2007, for similar conclusions). This abstract representation supposedly controls initial performance. The PP of novel instructions, however, is assumed to lead to the formation of a second representation, which the authors label as a pragmatic task representation. This representation is supposed to be more finegrained than the initial representation and includes various parameters that underlie the skilled execution of a task. Evidence for this account comes from a neuro-imaging experiment in which novel S-R mappings were practiced a number times and modulations in behavioral performance and brain activity were measured. Ruge and Wolfensteller (2010) observed that behavioral improvement was associated with a shift in brain activity, such as a decrease in the left inferior junction and an increase in the basal ganglia, more specifically in the caudate nucleus. Such pattern suggests a reduced involvement of executive control following PP. Interestingly, the shift in brain activity started from the very first trial on which the novel S-R mappings had to be applied. Furthermore, Ruge and Wolfensteller (2010) observed that a stronger activation in the lateral pre-motor cortex and prefrontal cortex during the encoding of the novel S-R mappings, predicted enhanced performance improvement during the training phase. This finding led to the suggestion that the formation of a pragmatic task representation can be initiated even before PP, on the basis of MI. As such, the implementation of novel instructions into the actions they specify, may be driven by MI of these instructions.

Ramamoorthy and Verguts (2012) introduced a computational model, which specifies how pragmatic task representations are formed on the basis of PP. Their model supposes the presence of two processing routes. The first route quickly learns novel S-R associations on the basis of instructions, but leads to slow responding. The second route slowly learns novel S-R associations, but elicits fast responses. Ramamoorthy and Verguts (2012) propose that the second route learns S-R associations on the basis of Hebbian learning, following the application of these S-R associations through the first route. Initial task performance is mainly under control of the slow route, with the fast route gradually taking over control after sufficient PP. Simulations indicated that the model of Ramamoorthy and Verguts (2012) is able to account for the results of Ruge and Wolfensteller (2010), but also for other findings such as the instruction-based congruency effect reported by Waszak, Wenke, and Brass (2008) as well as the dissociation between instruction understanding and instruction following (e.g., Duncan, Emslie, & Williams, 1996; Luria, 1966).

The study of Ramamoorthy and Verguts (2012) as well as the study of Ruge and Wolfensteller (2010) support the conclusion that the application of novel instructions quickly improves through PP and that this improvement is underlain by a shift in processing mode. The initial application of instructions is based on an abstract representation, which guides behavior in a slow and controlled manner. PP leads to the formation of a pragmatic task representation and therefore fast processing, which guides behavior in a quick and automatic way. The central question in the present study is whether such shift in processing can be obtained on the basis of MI, which would strengthen the hypothesis that MI is part of the implementation of novel instructions.

3. Motor imagery

MI has received much attention in the past decades (see Guillot & Collet, 2005; McAvinue & Robertson, 2008; Schuster et al., 2011; van Meer & Theunissen, 2009 for reviews). Richardson (1967, p. 95) defines MI as “the symbolic rehearsal of a physical activity in the absence of any gross muscular movements”. Thus, MI is based mainly on the mental simulation of an action under training conditions in which the actual execution of that action is minimal or absent. Although MI is (more) covert in nature, it shares features with PP. Most importantly, it has been found that the time needed to perform a particular action covertly covaries with the time needed to execute an action overtly (e.g. Decety, Jeannerod, & Prablanc, 1989; Decety & Michel, 1989). For instance, Decety et al. (1989) observed that increasing the length of a particular walking distance, not only increases the actual walking time but also the imagined walking time. Neuro-physiological research also demonstrates that overt and covert actions do share similar neural substrates, which led to the hypothesis that covert and overt actions are part of the same continuum, with overt actions being based on covert actions, without covert actions being necessarily translated into overt actions (e.g. Jeannerod, 2001).

In view of the similarity between PP and MI, it is not surprising that beneficial effects of MI have been reported in the acquisition of complex skills, such as typing (Nyberg, Eriksson, Larsson, & Marklund, 2006; Wohldmann, Healy, & Bourne, 2007, 2008), playing music (e.g., Highben & Palmer, 2004; Lim & Lippman, 1991), or even surgical interventions (e.g., Rogers, 2006). However, the extent by which MI improves performance in comparison to PP remains unclear. Whereas it has been asserted that the beneficial impact of MI on performance is smaller than the impact of PP (see Driskell, Copper, & Moran, 1994; Feltz & Landers, 1983 for meta-analyses), other research demonstrated that the effect of MI and PP is equally large and under certain training conditions MI can be even more beneficial than PP (e.g., Wohldmann et al., 2008). Finally, several studies reported that the influence of MI on performance improvement is minimal or even absent (e.g., Corbin, 1967; Shanks & Cameron, 2000; Shick, 1970; Smyth, 1975). These diverging findings are caused by the use of different tasks.

Besides the type of task, the type of performance improvement that is measured within a task also seems of importance. Wohldmann et al. (2007) (see also Wohldmann et al., 2008) argued that more finegrained measures of performance, which separate markers of stimulus encoding and response selection from markers of movement execution, are essential in clarifying how MI improves performance. These authors compared the impact of MI and PP in a digit data-entry task. In such task, participants enter strings of three digits on a computer keyboard. The time needed to enter the first digit is considered as a proxy of stimulus encoding and response selection (i.e., reaction time), whereas the average speed of the subsequent keystrokes is considered as a proxy of movement execution (i.e., movement time, see also Brown & Carr, 1989; Buck-Gengler & Healy, 2001; Fendrich, Healy, & Bourne, 1991 for similar distinctions). In the studies of Wohldmann et al. (2007, 2008) a test phase followed either a training phase consisting of PP or a training phase consisting of MI. Interestingly, these authors observed that MI modulated performance to the same degree as PP. More precisely, practice (PP and MI) reduced the movement time but not the reaction time, which sometimes even increased after practice. The reduction in movement time suggests that MI improves processes related to movement execution. However, the reaction time is more difficult to interpret. On the one hand, this result suggests that MI (as well as PP) does not improve response selection. On the other hand, as Wohldmann and colleagues argue, the reaction time may have been inflated by a shift in encoding strategy. In the early stage of practice, each digit of a string may be encoded and responded to separately. After some practice, participants may encode the digits of a string as one chunk. As a result, stimulus encoding becomes centralized prior to the first key-press, which increases the reaction time and decreases the movement time.

4. The present study

Although MI has been investigated extensively in the context of skill acquisition, relatively little is known about the effects of MI on the application of novel instructions. More specifically, it is not yet clear whether MI can improve the application of new instructions as it is the case for PP (Ruge & Wolfensteller, 2010). Such modulation would