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Automatic effects of instructions and practice

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CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

INTRODUCTION

No one would probably read the present chapter, if she or he was not instructed in some way to do so… Supervisors, members of the guidance committee, or jury members, all have been instructed to read and critical assess the different chapters of the present thesis. Although we cherish the idea of "free will", our behavior is largely determined by instructions and rules, which specify what to do, when to do it and how to do it. Instructions are everywhere! The central position instructions take in our lives in part follows from the unique human ability to assimilate novel information and adapt our behavior on the mere basis instructions. We learn to handle our new camera on the basis of a manual. We learn to take the correct amount of medication on the basis of a prescription. We can find a grocery store in a new city just by following verbal directions. Instructions provide a quick route for ontogenetic adaptation, which can circumvent trial-and-error learning.

Instructions also constitute an essential part of psychological research. In many experiments participants are asked to execute novel task-rules, which are simply instructed at the beginning of the experiment. The ease by which participants can execute these novel rules is astonishing. However, at the present time the dynamics underlying our ability to learn on the basis of instructions have only recently received some attention. According to Cole, Bagic, Kass and Schneider (2010), one of the main reasons of why learning through instructions has been overlooked for a long time, is the fact that a single task execution invalidates the novelty of that task. As we will see later on, investigating (automatic) effects of instructions calls for elaborate and complex experimental procedures, which intend to rule out the contribution of overt practice. Nevertheless, research on the implementation of novel instructions is establishing itself as a central domain in the quest to understand the processes underlying our ability to engage in goal-directed behavior (e.g., Verbruggen, Mclaren & Chambers, 2014). The overall goal of the present thesis is to add novel insights in the effects of instructions. In the current chapter, we first provide an overview of the different procedures and findings that form the basis of the current thesis. Second, the current theoretical accounts on instruction implementation are discussed. Third, the aim and research questions of the present thesis are introduced.

RELEVANT FINDINGS

At the present time, research on instructions can be divided into two main lines. On the one hand, research has been conducted on instructions specifying a particular response strategy. Such research is related to the topic of implementation intentions (e.g., Gollwitzer, 1933; 1999), which are defined as self-regulatory strategies in which a mental link is created between a pre-specified future situation and a desired goal-directed response on the basis of instructions (Cohen, Bayer, Jaudas, & Gollwitzer, 2008, p. 12). An interesting finding in this research context is that instructions can lead to the attenuation of automatic interference effects (e.g., Cohen et al., 2008; Miles & Proctor, 2008). For instance, Cohen, et al. (2008) investigated the impact of implementation intentions on the Simon effect (Simon & Rudell, 1967). In a typical Simon task, participants make a left or right response to a stimulus feature that is not related to the stimulus location, such as color (e.g., If green, press left; if bleu, press right). Critically, stimuli can be presented at the left or the right side of the screen. The Simon effect refers to the observation that performance is enhanced when the task-irrelevant stimulus position matches the response position (compatible trial) in comparison to when they mismatch (incompatible trial). Cohen et al. (2008) instructed participants to respond as quickly as possible on incompatible trials and observed a reduction in the Simon effect. Using a similar procedure, Miles and Proctor (2008) demonstrated that instructing to respond quickly to compatible trials increased the Simon effect. However, when these “respond-fast”-instructions were assigned to a particular response (e.g., the right response key) and not to a particular trial type (e.g., compatible), performance on this particular response-key was enhanced and this irrespective of the trial compatibility.

Although these studies do indicate that instructions can have a powerful effect on behavior, such manipulations do not offer “pure” measures of instructions. Indeed, in this type of experiments the particular response strategy that is instructed is also frequently applied. As such, the contribution of overt practice cannot be excluded. The second line of research, more stringently excluded the contribution of overt practice, and focuses on automatic effects of instructed Stimulus-Response (S-R) mappings that were never practiced overtly before (for a review, see also Meiran, Cole & Braver, 2012). Cohen-Kdoshay and Meiran (2007, 2009) investigated automatic effects of instructed S-R mappings in a single-task context by adapting a Flanker task (Eriksen & Schultz, 1979). In a Flanker task, a target is surrounded by distractor stimuli (i.e., flankers). These flankers can point towards the same response than the target stimulus (compatible trial) or point towards a different response (incompatible trial). A flanker-compatibility effect is indicated by better performance on compatible than on incompatible trials. To investigate if there could be a flanker compatibility effect on the basis of instructions, Cohen-Kdoshay and Meiran (2007, 2009) presented participants with a new stimulus-set and a new pair of category-to-response mappings at the beginning of each experimental (mini-) block. These authors observed a flanker-compatibility effect early after the onset of the instructions (Cohen-Kdoshay & Meiran, 2007) and even on the very first trial following the instructions (Cohen-Kdoshay & Meiran, 2009). The presence of a flanker-compatibility effect on the very first trial following the instructions, indicates that instructed S-R mappings can lead to a flanker-compatibility effect even though they were never executed before. Additionally, Cohen-Kdoshay and Meiran (2007, Experiment 4) investigated whether this instruction-based flanker-compatibility effect could be observed when working memory was loaded. These authors observed that the addition of working-memory load eliminated the instruction-based flanker compatibility effect. These and other findings (Cohen et al., 2008; Meiran & Cohen-Kdoshay, 2012) suggest that the presence of instruction-based congruency effects is a function of working-memory capacity.

Wenke, De Houwer, De Winne, and Liefooghe (in press) adapted the procedure of Cohen-Kdoshay and Meiran (2007, 2009) to compare instruction-based flanker compatibility effects with experience-based flanker compatibility effects. In half of the blocks, the experience-based blocks, all stimuli could appear as targets and as flankers. In the other half of the blocks, instructed-flanker blocks, only two stimuli served as targets, whereas the other two appeared only as flankers. Wenke et al. (in press) observed a flanker compatibility effect for the merely instructed and a larger flanker-compatibility effect for the applied S-R mappings. Furthermore, the size of the instruction-based flanker-compatibility effect decreased with task practice, whereas the size of the experience-based flanker-compatibility effect remained equally large. Wenke et al. (in press) attributed this decrease to a selective strengthening of the S-R associations that were executed overtly, whereas the associations formed on the basis of the merely instructed S-R mappings weakened because they never had to be executed.

Although studies concentrating on instruction-based flanker effects are very promising, other studies investigated to which extent automatic effects of merely instructed S-R mappings can be generalized across different tasks. Waszak, Wenke, and Brass (2008, see also Brass, Wenke, Spengler, & Waszak, 2009) compared an instruction-based task-rule congruency effect with an execution-based task-rule congruency effect. A task-rule congruency effect is a robust effect in task-switching studies (for reviews see, Kiesel et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe & Verbruggen, 2010). In task switching, participants frequently switch between two tasks such as a color task and a shape task. A task-rule congruency effect can be observed if the two tasks share stimuli (e.g., colored shapes) and responses (e.g., a left and a right response). The task-rule congruency effect refers to the finding that reaction times are shorter when both stimulus features point toward the same response than when both features point toward a different response. In the study of Waszak et al. (2008), two tasks were used with each task containing four S-R mappings. Importantly, some of the S-R mappings were merely instructed and never applied overtly. Within this procedure, Waszak et al. (2008) only observed an experience-based task-rule congruency effect but not an instruction-based task-rule congruency effect.

The study of Waszak et al. (2008) suggests that instruction-based congruency effects cannot generalize across different tasks. However, the task-switching procedure used in these studies may have been too complex to observe such effects. In view of the finding that instruction-based congruency depends on working-memory capacity (Cohen-Kdoshay & Meiran, 2007; Meiran & Cohen-Kdoshay, 2012), the presentation of eight S-R mappings may have been too demanding. Indeed, less taxing procedures were successful in obtaining instruction-based congruency effects across two tasks. This was the case in a study by De Houwer, Beckers, Vandorpe and Custers (2005). In a primary task, participants responded to arrows pointing to the left or the right, or to the words LEFT and RIGHT. In order to so, participants had to say the non-words 'bee' and 'boo' aloud. For instance, participants were asked to say 'bee' to left-pointing arrows as well as the word LEFT and 'boo' to right-pointing arrows as well as the word RIGHT. However, between the instructions and the execution of this primary task, participants performed a secondary task. This secondary task was a location-irrelevant task in which participants were asked to respond to the color of a square with the same non-word responses (e.g., say 'bee' to green squares and 'boo' to blue squares). Crucially, these squares appeared either at the left or the right side of the screen (i.e., irrelevant stimulus position). A such, the left-right stimulus location and the left-right meaning the non-word had acquired via the task instructions of the primary task (e.g., 'bee'- left; 'boo'-right) could match (compatible trial) or not (incompatible trial). Performance was better on compatible than on incompatible trials, an effect indicating that the irrelevant stimulus locations in the secondary task automatically biased performance on the basis of the unpracticed instructions of the primary task.

Wenke and colleagues (Wenke, Gaschler & Nattkemper, 2007; Wenke, et al., 2009) also developed a procedure with two embedded tasks. In each mini-block, participants received a pair of arbitrary S-R mappings (e.g., if P press left; if Q press right) of a letter task. Before these mappings had to be executed, a single trial of a secondary task, the size task, was presented. In this size task, participants were presented with two adjacent letters that differed in font size. Participants were asked to judge whether the biggest letter was presented on the left or on the right by pressing a central response-key once or twice. For instance, if the bigger letter appeared on the left (e.g., P-q), the central response-key had to be pressed once and if it appeared on the right (e.g., p-Q), the central response-key had to be pressed twice. Importantly, the same letters were used in both tasks. When the left-right position of the letters was compatible with the left-right response locations assigned to these letters by the S-R mappings of the letter task, participants were faster than when the stimulus location in the size task was incompatible with the response locations assigned in the letter task (e.g., q-P). Importantly, this effect was not present when no-go cues frequently signaled that the letter task was not going to be presented (Wenke et al., 2009). Wenke et al. (2009) concluded that frequent presentation of no-go cues discouraged participants to implement the S-R mappings of the letter task prior to the presentation of the size task. Taken together, the studies of Wenke and colleagues also successfully show that instructions can lead to automatic effects when being task irrelevant.

Taken together, the findings of De Houwer et al. (2005) and Wenke et al. (2007, 2009) suggest that instruction-based congruency effects can be observed across two tasks (for a similar argument, see Liefooghe et al. 2012). However, the nature of these effects is not entirely clear (see Meiran et al., 2012; Liefooghe, Wenke, & De Houwer, 2012). More specifically, the question arises whether these effects are actually based on the automatic activation of a task-irrelevant response. In the studies of Wenke et al. (2007, 2009), responses during the size task (pressing a button once or twice) were unrelated to the instructed S-R mappings (e.g., press left for *P*; press right for *L*). Hence, these studies only offer indirect evidence for the activation of task-irrelevant responses. The study of De Houwer et al. (2005) may provide more direct evidence However, their results in part rely on the overlearned relation between the left–right location of the stimulus and the novel left–right meanings of the responses “bee” and “boo” that were learned through the instructions of the primary task. As such, their results are based on the Simon effect (for a review, see Simon, 1990). Therefore it could be questioned whether instructions might directly elicit response activation because it could be argued that in the study of De Houwer et al. (2005) there is only a semantic S-S overlap between the non-words and the location might be sufficient. The response activation then are a consequence of the overlearned associations. .

In response to these concerns, Liefooghe et al. (2012, 2013) introduced a procedure that was developed to offer additional evidence that instruction-based congruency effects across two tasks are related to the automatic activation of task-irrelevant responses. In this procedure participants were presented with several runs, each consisting of two tasks: *the inducer task and the diagnostic task*. In the inducer task, participants received two arbitrary S-R mappings, each assigning the identity of a stimulus to a left or a right response (e.g., If ‘X’, press left; if ‘Y’, press right). Before executing the inducer task, the diagnostic task was performed in which the same stimuli and responses were used as in the inducer task. In the diagnostic task, participants decided whether a stimulus was presented in italic or upright, again by pressing a left or right response-key (e.g., upright, press left; italic, press right). Liefooghe, Wenke, and De Houwer (2012) observed an instruction-based task-rule congruency effect in the diagnostic task based on the instructions in the inducer task. Because the diagnostic task was performed immediately after the presentation of the instructions of the inducer task and because each run comprised novel S-R mappings, the conclusion was drawn that the congruency effect observed in the diagnostic task was based on the merely instructed S-R mappings of the inducer task. Furthermore, the instruction-based task rule congruency effect could only be observed when participants were required to execute the S-R mappings of the inducer task, but not when these mappings had to be recalled or recognized (Liefooghe et al., 2012, Experiment 2). This dissociation indicates that instructions can only elicit automatic effects when participants intend to apply the instructed S-R mappings. In a follow-up study, Liefooghe et al. (2013) showed that the instruction-based task-rule congruency was only present when participants actively prepared for the inducer task. For example, Liefooghe et al. (2013; Experiment 2) informed participants about the response deadline of the inducer task. For runs with an early response deadline (one second) an instruction-based task-rule congruency effect was observed, whereas no congruency effect was observed for the late response deadline (five seconds). These findings led to the hypothesis that the instruction-based congruency effects is, most probably, based on the automatic response activation that results from task-irrelevant instructions. Yet, more direct evidence for this hypothesis will be presented in the present thesis.

Taken together, procedures using embedded tasks do seem to indicate that instruction-based congruency effects can be obtained across two tasks (De Houwer et al., 2005; Liefooghe et al., 2012; 2013; Wenke et al., 2007, 2009). Although the procedure of Liefooghe et al. (2012, 2013) is at the core of the present thesis, we must acknowledge that recent criticisms have arisen against its use. Indeed, a potential concern raised by Meiran, Pereg, Kessler, Cole, and Braver (in press a), is that participants may confuse the diagnostic task with the inducer task and apply the inducer task during the diagnostic task. It could be argued that even such a single misapplication is sufficient to form S-R associations, which might subsequently bias performance in the diagnostic task (Logan, 1988). As a result, the instruction-based congruency effects obtained in the procedure of Liefooghe et al. (2012, 2013), may be inflated by genuine congruency effects. In response to this potential problem, Meiran et al. (in press a; see also Meiran, Pereg, Kessler, Cole, & Braver., in press b) recently developed a new procedure which is similar to the procedure of Liefooghe et al. (2012), but offers additional control to avoid task misapplication. The critical difference between the procedure of Meiran et al. (in press a, in press b) and the procedure of Liefooghe, et al. (2012) resides in the nature of the diagnostic task. In the procedure of Meiran et al. (in press a, in press b), participants are presented with two S-R mappings of the inducer task. Participants are instructed to perform the inducer task when the corresponding stimuli are presented in a green square. Prior to the presentation of this green square a diagnostic phase is inserted that consists of a certain number of trials. On each trial, one of the two stimuli of the inducer task appear, but now in a red square. Participants are supposed not to perform the inducer task on these trials (i.e., no-go) and simply press a single response key to move on to the next trial. This response is referred to as the “next” response. The crucial manipulation is that this next response is part of one of the two S-R mappings used in the inducer task. In other words, it could be the left response-key of the inducer task or the right response-key. Due this overlap and the presence of “irrelevant” stimuli (i.e., the stimuli of the inducer task) in the diagnostic phase, Meiran et al. (in press a, in press b) were able to calculate an instruction-based compatibility effect on the basis of the “next” response. Because participants were not required to perform an actual task in the diagnostic phase, Meiran et al. (in press b) argued that task misapplication was very unlikely in their procedure. However, as we will discuss in the closing chapter of the present thesis, such procedure may entail additional problems. In addition, some of the experiments conducted during the current PhD project suggest that the task-misapplication problem in the Liefooghe et al. (2012) procedure may not be as dramatic as initially thought.

ACCOUNTS OF INSTRUCTION IMPLEMENTATION

The research discussed in the previous section indicates that instruction-based congruency effects are subject to two important boundary conditions. First, instruction-based congruency effects disappear when working memory is taxed too heavily (Cohen-Kdoshay & Meiran, 2007, 2009; Meiran & Cohen-Kdoshay, 2012). Second, instruction-based congruency effects are only observed when participants intend to apply the instructed S-R mappings (Liefooghe et al., 2012) and when they actively prepare themselves to execute these instructed S-R mappings (Liefooghe et al., 2013; Wenke et al., 2009). These boundary conditions suggest that the implementation of instructed S-R mappings lead to the formation of functional S-R associations, which are represented in working memory. Some researchers specified the processes involved in the implementation of instructions in terms of the working-memory model of Oberauer (2001, 2002, 2009), which is an elaboration of earlier work by Cowan (1988).

Oberauer (2009, 2010; see also Anderson & Lebiere, 1998; Logan & Gordon, 2001) proposes a distinction between declarative and procedural working memory. Whereas declarative working memory is involved in representing semantic and episodic knowledge, procedural working memory is responsible for the acquisition and control of the procedures that guide our behavior in a goal-directed manner (Eichenbaum & Cohen, 2001; Mishkin, Malamut, & Bachevalier, 1984; Schacter & Tulving, 1994; Squire & Knowlton, 2000 Ullman, 2004). In line with the initial proposals of Cowan (1988), both working-memory systems are conceived as being embedded in long-term memory. Common to both systems is the activated long-term memory (ALTM), which is consists of temporarily activated long-term memory information. ALTM is conceptualized as an associative network of representations through which activation spreads automatically. ALTM has virtually no capacity limit. Yet, some representations in ALTM will be more active than others. For declarative information, the most active representations are supposed to enter the Direct-Access (DA) region of working memory. In contrast to ALTM, the DA is capacity limited. The counterpart of the DA in procedural working memory is the Bridge. The Bridge supposedly maintains all parameters necessary to perform a particular task (i.e., a task-set).

Independently of one another, Liefooghe et al. (2012) and Meiran et al. (2012) both situated the implementation of instructions within the model of Oberauer (2009). Liefooghe et al. (2012) argued that when a task is prepared for, the instructions of that task, which are initially represented in declarative working memory, are translated into a functional representation in procedural working memory (see also, Brass, et al., 2009; Meiran et al., 2012). When an instruction does not have to be executed, but only remembered for future recall, this instruction remains in a declarative format. Meiran et al. (2012) proposed a more fine-grained account of how instructions are implemented. These authors argue that instructed S-R associations are assumed to be represented in the Bridge in the form of a temporal binding (see also Wenke et al., 2007, 2009) between preexisting representations in ALTM, such as stimulus and response codes. Once such representation is formed, stimuli can unintentionally activate a specified action in a reflex-like manner (i.e., a prepared reflex, Exner, 1879; Hommel, 2000). The studies by Liefooghe et al. (2013) and Wenke et al. (2009) indicate that such binding will only take place when participants are encouraged to prepare for an upcoming task on the basis of its instructions. This supports the hypothesis of Meiran et al. (2012) that representing information in the Bridge is effortful and is likely to be avoided. Meiran et al. (2012) also make an important difference between S-R associations formed on the basis of instructions and S-R associations formed on the basis of overt practice. They assume that overt practice leads to the formation of S-R associations in long-term memory (see also Logan, 1988). Accordingly, effects of merely instructed S-R mappings are related to the Bridge, while effects of practiced S-R mappings are based on representations in ALTM. This idea is supported by the observation that instruction-based congruency effects seem to depend on working-memory capacity (Cohen-Kdoshay & Meiran, 2007; Waszak, et al., 2008), whereas no such limitations have been observed for experience-based congruency effects (e.g., Kessler & Meiran, 2010; Kiesel, Wendt, & Peters, 2007).

The hypothesis that instructions and practice lead to distinct representations has also been supported by a fMRI study of Ruge and Wolfensteller (2010). These authors investigated the effect of practice on newly instructed S-R mappings. On each run, four new S-R mappings were instructed and practiced for 32 trials (eight trials for each mapping). These authors observed a strong performance improvement with practice. This improvement was accompanied with a shift in brain activity (i.e., an increase the left inferior fontal junction and a decrease in the basal ganglia). Ruge and Wolfensteller (2010) concluded that instruction implementation leads to formation of an abstract representation, which only includes conceptual stimulus and response information (see Liefooghe et al., 2012; Wenke et al., 2007, for similar conclusions). When these instructions are practiced, a second more fine-grained representation is formed, which includes different parameters that lead to the skilled execution of a task. In line with these proposals, Ramamoorthy and Verguts (2012) developed a computational model that focuses on the acquisition and transfer of instructed mappings. The model of Ramamoorthy and Verguts (2012) assumes the presence of two routes.

In the first indirect route, instructions can be rapidly learned. The second direct route, gradually picks up the regularities implemented by the indirect route. Control transfers from the indirect route to the direct route, which accounts for practice effects. This model successfully simulated data patterns from the instruction literature, such as the findings of Ruge and Wolfensteller (2010) and of Waszak et al. (2008).

Finally, we mention research which also offered additional insights on the brain areas involved in the implementation of instructions. Hartsta, Kuhn, Verguts and Brass (2011) measured brain activity using fMRI while participants were asked to implement new S–R mappings or new object–color (O–C) mappings. Hence, a dissociation could be made between different types of instructions. Furthermore, the novelty of these instructions was manipulated. A network of brain areas (i.e., the pre-premotor dorsal, M1, and intra parietal sulcus) dissociated between S-R and O-C mappings, irrespective of whether these mappings were new or practiced. In addition, one brain area was sensitive to the novelty of instructions, the left inferior frontal junction, but its modulation was independent of the instruction type (i.e., S-R or O-C mapping). Hartstra et al. (2011) concluded that the inferior frontal sulcus plays an important role in instruction implementation by underlying the decision, which modality specific areas are needed to perform the upcoming task. Hence, the implementation of instructions results from an interplay of brain areas that are in general sensitive to novel information and brain areas that are specific to the type of mapping regardless whether the mappings was practiced or not. In a follow-up study, Hartstra, Waszak and Brass (2012) investigated whether the brain areas involved in creation of S-R associations and brain areas involved in response preparation could be dissociated. To this end, a procedure was developed in which instructions were divided into two components. The first component was the relevant stimulus that participants needed to attend. The second component were the relevant S-R mappings. These components were instructed sequentially in a random order (i.e., response information and stimulus information). This sequential presentation made it possible to differentiate between response-preparation processes and processes that are involved in establishing the connection between the stimulus and the response (i.e., the S-R mapping). The results showed that the left inferior frontal sulcus was engaged in the formation of the association between stimulus and response, while response preparation could be situated in the premotor cortices, the pre-supplementary motor and the anterior intra parietal sulcus. Harstra et al. (2012) concluded that the left inferior frontal sulcus is crucial to form an S–R mapping based on verbal instructions, because of its role in integrating stimulus and response information.

THE CURRENT PHD THESIS

The overall aim of the current thesis is to provide further insights into the effects of instructions. On the one hand, we further investigate the characteristics of instruction-based congruency effects. This was done in a first research line, which encompasses Chapters 2, 3, and 4. On the other hand, we further investigated how effects of instruction overt practice are related to each other. This line of research was pursued in Chapters 5 and 6. We briefly highlight both lines of research

Instruction-based congruency effects

In the first research line, three chapters are presented. In Chapter 2, we investigate the strength of instruction-based congruency effects relative to congruency effects that are based on previous learning. To this end, we examine the interaction between instruction-based congruency effects and a stimulus-response compatibility effect that is thought to be based on pre-established long-term S-R associations, namely the Simon effect. More specifically, we investigated whether instruction-based congruency can counteract the Simon effect (Simon & Rudell, 1967). To investigate this, an adapted version of the procedure of Liefooghe et al. (2012, 2013) was used in which the inducer task referred to spatially incompatible S-R mappings (e.g., if the stimulus is presented on the right, press the left-key) and the diagnostic task was a Simon task. We observed that spatially incompatible S-R mappings that were never applied overtly before were sufficient to eliminate the Simon effect. In Chapter 3, we addressed a fundamental question about instruction-based congruency effects, namely whether they indeed reflect the automatic activation of responses on the basis of instructions. As we discussed above, this is a critical issue for research on instruction implementation. However, only indirect evidence is available for this hypothesis. In Chapter 3, this issue was directly investigated by measuring lateralized readiness potentials in the procedure of Liefooghe et al. (2012, 2013). The results of Chapter 3, indicated that irrelevant instructions can lead to automatic response activation. In Chapter 4, we investigated whether automatic effects of instructions are limited to S-R mappings. To this end, another type of relationship was investigated, namely response-effect (R-E) contingencies. A R-E contingency specifies the contingency between a particular response and the effect it elicits in the environment. Previous research has provided strong evidence that congruency effects can be obtained on the basis of incidentally learned R-E contingencies (for a review see Shin, Proctor, & Capaldi, 2010). In Chapter 4, we demonstrate that similar congruency effects can be obtained for R-E contingencies that were only instructed.

The Effects of Practicing Novel Instructions

In the second research line, two chapters are presented. Chapter 5 investigates how different types of practice modulates performance on newly instructed S-R mappings. To this end, a novel procedure was introduced, which offered fine-grained measures of performance improvement after physical and mental practice of newly instructed S-R mappings. The results suggest that while physical practice improves both central and peripheral processes of response selection, mental practice only improves central processes. Finally, in Chapter 6 we investigate the differences between instructed and practiced S-R mappings in relation to mental flexibility. Previous research in the task-switching paradigm (see Kiesel et al., 2010; Monsell, 2003; Vandierendonck, et al., 2010, for reviews), indicate that changing S-R mappings lead to a performance cost. Task-switching research, however, for the most part focusses on overtly practiced S-R mappings. In Chapter 6, we tested whether changing merely instructed S-R mappings can also lead to performance costs. The results of Chapter 6 do indicate that this is the case. However, switching overtly practiced S-R mappings leads to additional performance costs.

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RESEARCH LINE 1

INSTRUCTION-BASED CONGRUENCY EFFECTS

CHAPTER 2

ELIMINATING THE SIMON EFFECT BY INSTRUCTION[1]

A growing body of research demonstrates that instructions can elicit automatic response-activations. The results of the present study indicate that instruction-based response-activations can also counteract automatic response-activations based on long-term associations. To this end, we focused on the Simon effect, which is the observation that responding to a non-spatial feature of a stimulus (e.g., color) is faster and more accurate when the task-irrelevant stimulus position matches the spatial position of the correct response. The Simon effect can be eliminated or even reversed when combining a Simon task with an incompatible position task (e.g., press right for left stimuli; press left for right stimuli). The present study demonstrates that the Simon effect is eliminated even after presenting only the instructions of an incompatible position task, without participants having the opportunity to practice that task. Moderate practice of the incompatible task did not add anything to the effect of the instructions. Finally, the instructions of a compatible spatial stimulus-response task did not affect the Simon effect. The present results converge with previous findings indicating that the Simon effect is highly malleable and suggest that stimulus-response associations formed on the basis of instructions can counteract effects of long-term stimulus-response associations.

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[1] Based on Theeuwes, M., Liefooghe, B., & De Houwer, J. (2014). Eliminating the Simon effect by instruction. Journal of experimental psychology: Learning, memory and cognition, 40, 1470-1480.

INTRODUCTION

Although instructions play a seminal role in goal-directed behavior, the translation of instructions into actions has been largely neglected until recently (for a review see Meiran, Cole & Braver, 2012). A key hypothesis is that instructed Stimulus-Response (S-R) mappings can be implemented into S-R associations, which trigger responses when being irrelevant, i.e., instruction-based response activations or IBRA (e.g., Cohen-Kdoshay & Meiran, 2009; De Houwer, Beckers, Vandorpe & Custers, 2005; Liefooghe, Wenke, & De Houwer, 2012; Wenke, Gaschler, Nattkemper, & Frensch, 2009). While IBRA indicate that practice is not a key prerequisite to obtain automatic response effects, research on the functional properties of instructions-based S-R associations is scarce and many advances on our understanding of IBRA are to be made. Accordingly, the present study investigated the relative strength of IBRA compared to automatic response activations that are based on long-term associations.

The Simon effect is a prime example of automatic response activation based on of long-term associations (Simon & Rudell, 1967). In a Simon task, participants make a left or right response to a non-spatial stimulus feature, such as color (e.g., blue, press left; green, press right). The Simon effect corresponds to enhanced performance when the task-irrelevant stimulus position matches the response position (blue stimulus on the left), as when they differ (blue stimulus on the right). Response activation thus results from task-relevant short-term associations between stimuli and responses indicated by task instructions and long-term associations between stimulus and response positions (see Lu & Proctor, 1995 for a review). When short- and long-term associations point toward different responses, responding is hampered. When they converge, responding is facilitated.

Previous research demonstrated that the size and the direction of the Simon effect was malleable (e.g., Marble & Proctor, 2000; Proctor & Lu, 1999; Proctor, Marble & Vu, 2000; Tagliabue, Zorzi & Umiltà, 2002; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000; Vu, 2007). Marble and Proctor (2000; see also Proctor et al., 2000) observed that when intermixing a Simon task with a compatible position task, the Simon effect became larger and when intermixing the Simon task with an incompatible position task, the Simon effect reversed. Tagliabue et al. (2000) observed that the Simon effect did not vary when the Simon task followed a block of a compatible position task, but the Simon effect was eliminated when the Simon task followed 72 trials of an incompatible position task. Similar studies, found a reversed Simon effect reversed after practicing an incompatible position task for 600 (Vu, 2007) or 900 trials (Proctor & Lu, 1999). Recently, Proctor, Yamaguchi, Dutt, and Gonzalez (2013) intermixed a Simon task with a position task consisting of 20% incompatible spatial mapping trials and 80 % compatible spatial mapping trials or vice versa. These authors observed a regular Simon effect, even when 80% of the position task trials was incompatible. Such finding indicates that the long-term associations underlying the Simon effect in itself are not altered by executing an incompatible location task, because if the underlying long-term associations would be modulated, the Simon effect should have been affected when intermixed with 80% incompatible and 20% compatible trials of the position task. Instead, when it is the response activation based on these long-term associations that is counteracted by response activation elicited by the task-irrelevant short-term associations formed during the position task, it is possible that the response activation based on the task-irrelevant short-term associations is not strong enough to counteract the response activation based on the long-term associations resulting in a regular Simon effect.

The present study investigated if IBRA can also counteract the effect of long-term associations in the Simon task. To this end, we examined whether the Simon effect can be modulated by merely instructing S-R mappings of a compatible or an incompatible position task, without letting participants actually execute these mappings. Although it may seem unlikely that such manipulation can overrule the effect of long-term associations, previous research indicated that the execution of incompatible S-R mappings is not a prerequisite to modulate the Simon-effect. Iani and colleagues (2013), for instance, demonstrated that the Simon effect is reduced when participants first observe a block of 300 trials in which an incompatible position task is performed by a computer. Such finding suggests that participants can form S-R associations on the basis of observational learning, which modulate the Simon effect later on. Nevertheless, this does not indicate that S-R associations formed on the sole basis of instructions equally can do so. Yet, other studies indicated that modifying the instructions of a Simon task can lead to changes in the Simon effect. Cohen, Bayer, Jaudas, and Gollwitzer (2008) demonstrated that Simon effects are reduced when participants were instructed to respond quickly on incompatible trials. In analogy, Miles and Proctor (2008) demonstrated that such “respond-fast”-instructions increased the Simon-effect when assigned to compatible trials. Although these studies do reveal the power of instructions, instructions in these cases intended to directly alter participants’ response strategies and the question remains whether IBRA can counteract the effect of long-term S-R associations. Moreover, participants could practice the “respond-fast” instructions throughout the Simon task, thus leaving open to possibility that the effects were due to practice rather than to the instructions

To answer this question, a variant of a procedure introduced by Liefooghe et al. (2012) was used. In their original procedure, participants were presented two tasks that shared stimuli and responses: the inducer and the diagnostic task. In the inducer task, participants received two arbitrary S-R mappings, each assigning the identity of a stimulus to a left or a right response (e.g., If ‘X’, press left; if ‘Y’, press right). Before executing the inducer task, several trials of the diagnostic task were performed. In the diagnostic task, participants decided whether a stimulus was presented in italic or upright, also by pressing a left or right response-key (e.g., upright, press left; italic, press right). Liefooghe et al. (2012) observed that RTs in the diagnostic task were shorter for responses that matched (‘X’ presented upright or ‘Y’ presented in italic) than for responses that did not match the instructed S-R mappings of the inducer task (‘Y’ presented upright or ‘X’ presented in italic). Follow-up research (Liefooghe, De Houwer, &

Wenke, 2013) demonstrated that such instruction-based congruency effect was only observed when participants actively prepared for the inducer task (see also, Wenke et al., 2009). These findings led to the conclusion that when participants intent to apply the inducer task, they prepare for this task by forming functional short-term S-R associations on the basis of the instructed S-R mappings of the inducer task, which leads to IBRA in the diagnostic task (see also Meiran et al., 2012; Wenke et al., 2009).

The question now raises whether IBRA, as measured in the procedure of Liefooghe et al. (2012), can counteract response activations based on long-term associations. This would offer a powerful test of the relative strength of instruction-based S-R associations compared to long-term S-R associations. Accordingly, in the present study, the inducer task was either a compatible or an incompatible position task and the diagnostic task was a Simon task. We measured the impact of the S-R mappings of the inducer task on the Simon effect in the diagnostic task. We included a condition in which the incompatible position S-R mappings of the inducer task were practiced moderately before the execution of the diagnostic task. As such, the added value of moderately practicing incompatible S-R mappings in comparison to the sole implementation of incompatible S-R mappings could be examined.

METHOD

Participants

One-hundred-twenty students at Ghent University participated for course requirements or payment of 4 EURO. Participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment. Participants were randomly assigned to one of four between-subjects conditions: the compatible S-R instructions condition (CI; n=30), the incompatible S-R instructions condition (II; n=30), the incompatible practiced S-R instructions condition (IPI; n=30) and the baseline condition (B; n =30) in which no inducer task was presented, thus offering a benchmark for our manipulations.

Materials

Participants were presented with different runs of trials, which consisted of the inducer task and the diagnostic task. Both tasks shared the same responses and stimuli. The diagnostic task was nested in the inducer task, resulting in the following sequence in each run: (1) instructions inducer task; (2) diagnostic task; and (3) probe trials inducer task (see Figures 1 & 2).

In the diagnostic task participants decided whether a stimulus was presented in green or blue by pressing a left or right key-press. The response assignment in the diagnostic task remained the same during the whole experiment and was counterbalanced across participants.

Table 1
Overview of the S-R mappings of the inducer task of the filler runs and the horizontal-position run in the compatible instructions (CI), incompatible instructions (II), and incompatible practiced instructions (IPI) conditions.

Filler runs		
	Size task	If '§' is presented big on the screen, press left/right If '§' is presented small on the screen, press left/right
	Quantity task	If '§' is presented more than 10 times, press left/right If '§' is presented less than 4 times, press left/right
	Vertical position task	If '§' is presented at the top of the screen, press left/right If '§' is presented at the bottom on the screen, press left/right
Horizontal position run		
	CI	If '§' is presented at the left side of the screen, press left If '§' is presented at the right side of the screen, press right
	II & IPI	If '§' is presented at the right side of the screen, press left If '§' is presented at the left side of the screen, press right

For each run, participants were instructed two new S-R mappings, which indicated how to respond to eight probe trials (four probe trials for each S-R mapping presented in a random order). Two types of runs were created: filler runs and one critical run. In each filler run, the inducer task included different types of S-R mappings, which required responding to either the size, quantity or vertical-position of probe stimuli (Table 1). For each participant one type of filler run was randomly selected and used for a practice run.

In the critical run, the inducer task was either a compatible or incompatible horizontal-position task. In the CI condition, the S-R mappings were compatible. In the II and IPI conditions, the S-R mappings were incompatible (Table 1). In the CI and II conditions, the instructions of the inducer task were followed immediately by the diagnostic task and were thus never practiced. In the IPI condition, participants practiced the inducer task for 100 trials before the onset of the diagnostic task. In the B condition, participants performed only the diagnostic task. Trials in that condition were also separated in different runs.

The run length varied randomly by manipulating the number of trials in the diagnostic task (4, 16, 32 or 48 trials). As such, the onset of the inducer task was relatively unpredictable, which encouraged participants to be constantly prepared to perform the inducer task. For each participant, one run-length was randomly assigned to the practice run and the remaining run-lengths were randomly assigned to the filler runs. In the critical run, the diagnostic task always consisted of 48 trials. The trials in this run were presented in a pseudo-random order with compatible and incompatible trials being equally distributed over the run in four equal subparts, such that predictable response patterns were avoided.

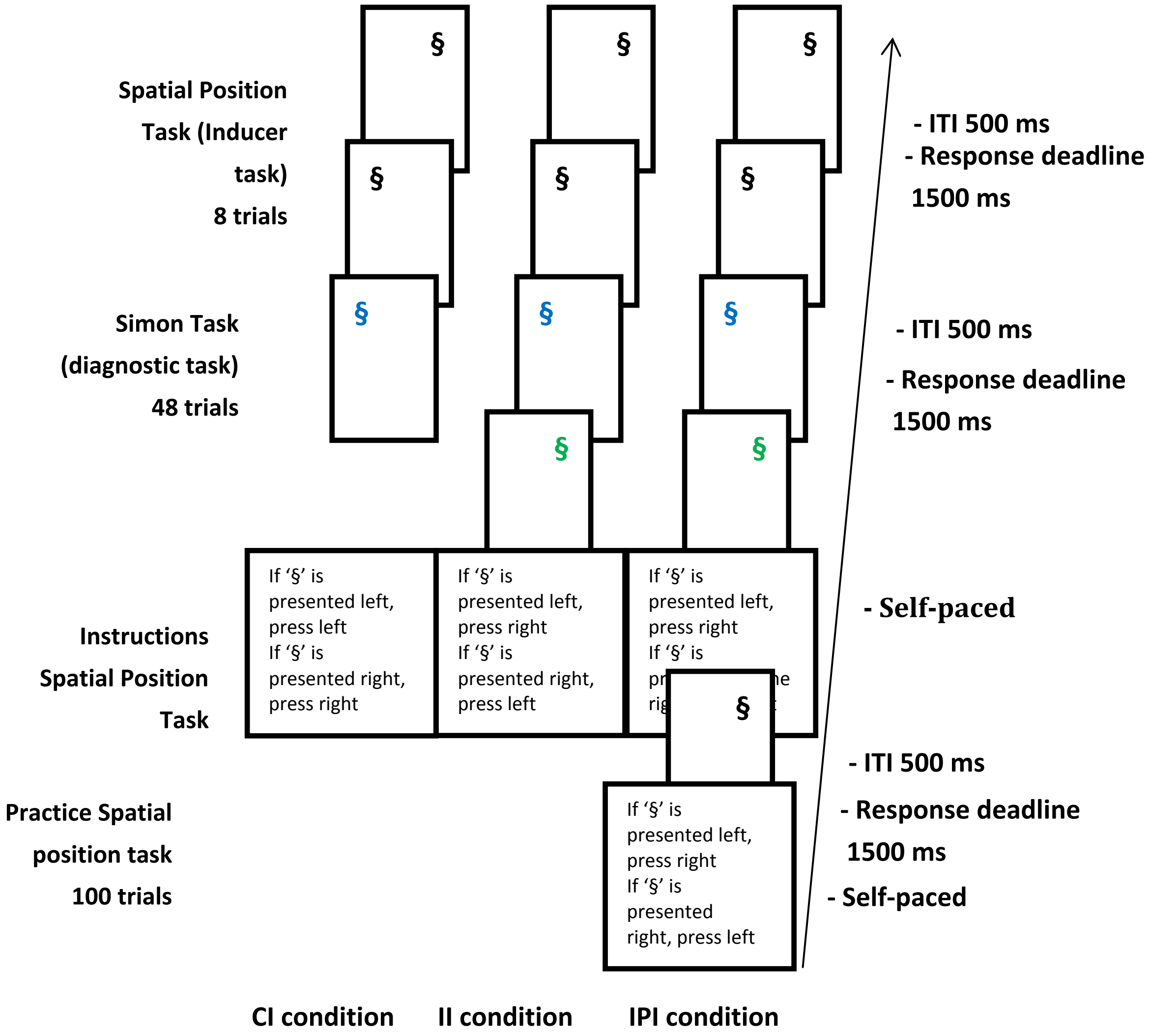


Figure 1. Overview procedure of the different conditions of the horizontal-position run. From left to right the procedure is shown of the compatible S-R instructions condition (CI), the incompatible S-R instructions condition (II), the incompatible practiced S-R instructions condition (IPI).

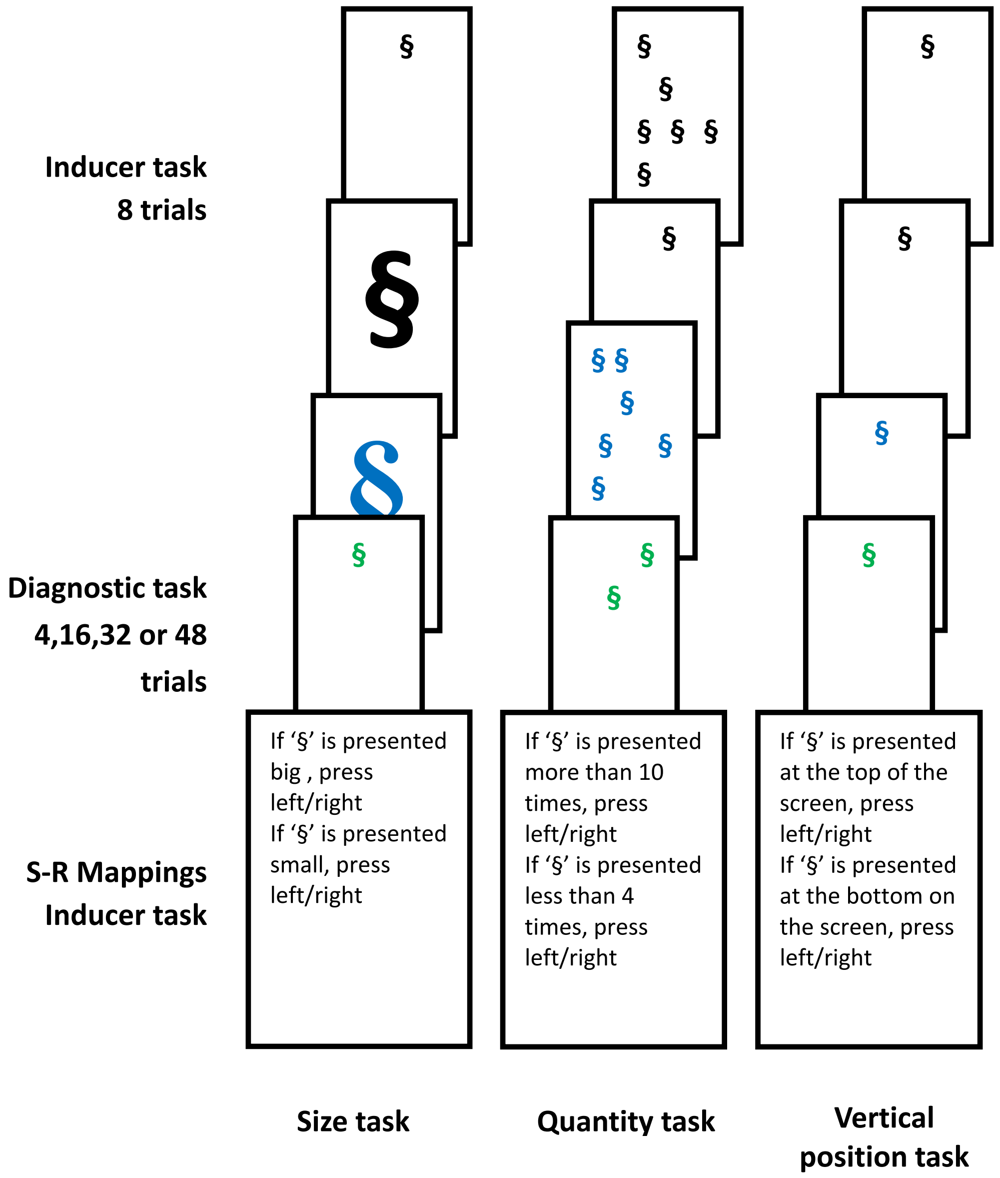
Each run started with a fixation cross in the center of a white screen in Arial font, size 28. The S-R mappings of the inducer task were always presented centrally on the screen, randomly one above the other in Arial font, size 16. Stimuli ('§'-signs) were presented in Arial font, size 36, with the exception of the size task wherein the large stimuli were size 72 and the small stimuli were size 12. For the quantity task, the position and number of stimuli (1,2 or 3 for the small quantity trials and 12,14 or 16 for the large quantity trials) were randomly selected on each trial. For the vertical-position task, stimuli were presented 0.1° above or beneath the screen center . For the horizontal-position task, stimuli were presented 0.2° left or right of the screen center. S-R mappings were presented in Arial font, size 16.

Procedure

Participants were tested individually or in pairs by means of personal computers with a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Main instructions were presented on screen and paraphrased if necessary. Participants were told that for every 10 mistakes during the inducer task, extra runs had to be performed. These extra runs were never presented and this instruction intended to motivate participants in order to perform well.

The experiment started with one practice run. During this practice run participants were monitored by the experimenter who gave additional verbal instructions if necessary. This run was followed by a short break before the test phase started. In this phase, participants first received the three filler runs in a random order (see Figure 2). The sole purpose of the practice and the filler runs was to familiarize participants with the general structure of a run and to experience the unpredictability of the onset of the inducer task, thus encouraging them to remain prepared with respect to this task.

The critical run was always performed last. Both the position task (i.e., inducer task during the critical run) and the Simon task (i.e., diagnostic task during the critical run) were thus never performed before the critical run was administered. Participants were unaware that only the data of this critical run was of main interest.



If '§' is presented big , press left/right
If '§' is presented small, press left/right

If '§' is presented more than 10 times, press left/right
If '§' is presented less than 4 times, press left/right

If '§' is presented at the top of the screen, press left/right
If '§' is presented at the bottom on the screen, press left/right

Figure 2. Overview procedure of the different filler runs. From left to right the procedure is shown for the size task, the quantity task and the vertical position task.

An overview of a critical run, including the time parameters, is presented in Figure 1. In the diagnostic task and the practice trials of the inducer task in the IPI condition, incorrect responses were followed by a red screen for 200ms. In order to minimize the possibility for online learning strategies in the inducer task and thus maximize the need to remember the instructions for the inducer task, no immediate feedback was given on the probe trials of the inducer task. After each run, participants were informed about their performance on the probe trials of the inducer task. Participants received the cumulated number of errors made in the inducer task. The experiment lasted for approximately 5 minutes in the B condition, 15 minutes in the CI and II conditions and 20 minutes in the IPI condition.

RESULTS

One participant in the II condition made 87% errors in the inducer task and was excluded. Five other participants, one each in the CI, II and IPI conditions and two in the B condition, were excluded because they made more than 30% errors in the diagnostic task. Of interest, was the critical run. Analyses of the filler runs are reported in Appendix A.

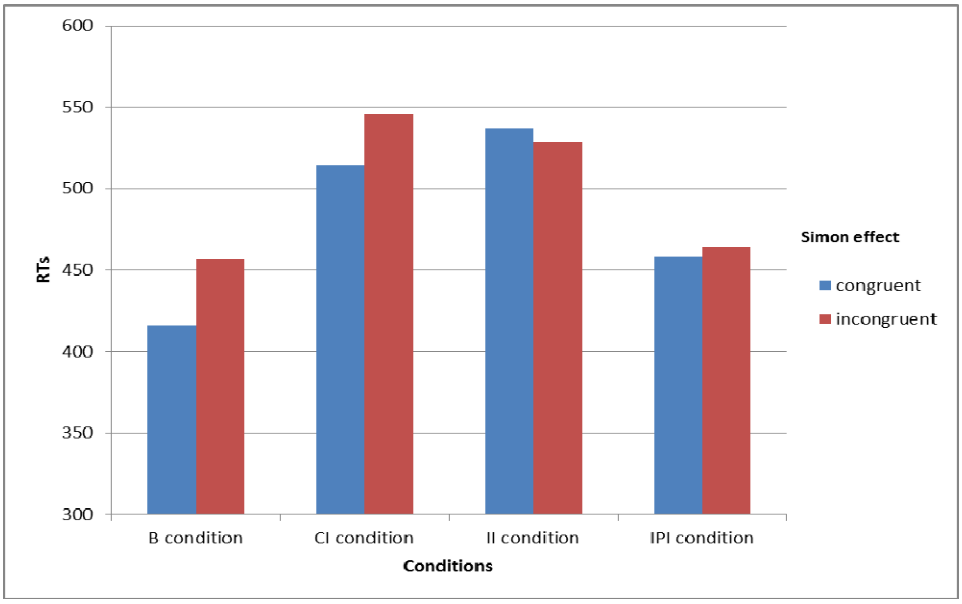


Figure 3. Mean RTs for Simon task as a function of condition.

Diagnostic task

For the RTs, only correct trials were included (data loss 6.3%). For each participant, RTs 2.5 standard deviations above the cell mean were considered outliers (data loss 1.7%). RTs and error rates were subjected separately to a 4

(Condition: B, CI, II or IPI) by 2 (Simon Effect: congruent, incongruent[1]) mixed ANOVA with repeated measures on the last factor. The outcome of this ANOVA is presented in Table 2. Means and standard deviations are presented in Table 3.

Table 2.

Overview outcome ANOVA analyzes.

Diagnostic task	*df1*	*df2*	*F*	*MSE*	η_p^2	*p*
RT						
Condition	3	110	13.74	9814	.27	<.001
Simon Effect	1	110	17.54	1087	.14	<.001
Condition * Simon Effect	3	110	6.75	1087	.15	<.001
Error rates						
Condition	3	110	4.06	.0046673	.10	<.01
Simon Effect	1	110	3.85	.0030052	.03	.0525
Condition * Simon Effect	3	110	9.13	.0030052	.20	<.001
Inducer task						
RT	2	83	5.92	6044	.14	<.01
Error rates	2	83	5.29	.006702	.11	<.01

For RTs (see Figure 3), the interaction between Condition and Simon Effect was significant. In the B condition participants were faster on congruent than on incongruent trials, *t*(27)=6.23, r^2=.60, *p*<.001, denoting a Simon effect. A

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[1] All analyses were also performed with stimulus position and response position separately. Because of word count constrains and also because there were no discrepancies between left en right positions we chose to report a combined factor.

Simon effect was also present in the CI condition , *t*(28)=3.19, r^2=.27, *p*<.01. In the II and the IPI condition, there was no Simon effect, both *t*s<1.

The Simon Effect did not differ between the CI and B condition, *F*<1. The Simon Effect in the B condition was larger than in the II condition, *F*(1,54)=16.70, *MSE*=1206, η_p^2=.24, *p*<.001, and the IPI condition, *F*(1,55)=12.24, *MSE*=709, η_p^2=.18, *p*<.001. The Simon Effect in the CI condition was also larger than in the II, *F*(1,55)=7.89, *MSE*=1466, η_p^2=.12, *p*<.01, and IPI conditions, *F*(1,56)=4.19, *MSE*=1147, η_p^2=.07, *p*<.05.

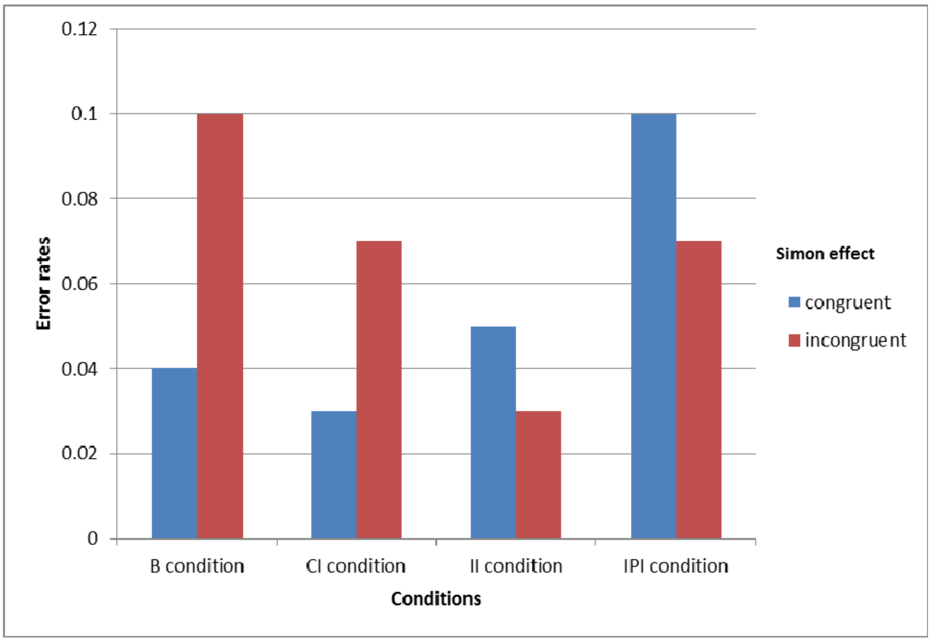

Figure 4. Mean Error Rates for Simon task as a function of condition.

The interaction between Condition and Simon Effect was also significant for the error rates (see Figure 4). A Simon effect was present in the B condition, *t*(27)=4.64, r^2=.44, *p*<.001 and the CI condition , *t*(28)=3.63, r^2=.32, *p*<.01. The Simon Effect was marginally larger in the B condition than in the CI condition, *F*(1,55)=3.58, *MSE*=.002096, η_p^2=.06, *p*=.063. In the II condition, marginally less errors were made on incongruent than on congruent trials, *t*(27)=1.90, r^2=.12, *p*=.067. Hence, a slightly reversed Simon effect was observed. This reversed effect in the II condition differed from the Simon effect in the B condition, *F*(1,54)=23.91, *MSE*=.002180, η_p^2=.31, *p*<.001, and the CI condition, *F*(1,55)=15.01, *MSE*=.0013747, η_p^2=.21, *p*<.001. In the IPI condition no Simon effect was present, $t(28)=1.17, r^2=.05$, $p=.251$.The Simon Effect differed significantly between the IPI and B condition, $F(1,55)=12.83$, $MSE=.004636$, $\eta_p^2=.16$, $p<.001$, and the CI condition, $F(1,56)=6.62$, $MSE=.0038004$, $\eta_p^2=.11$, $p<.05$. There was no difference in Simon Effect between the II and IPI condition, $F<1$.

Inducer task

For each participant, RTs 2.5 standard deviations above the cell mean were considered outliers (data loss 2.4%). RTs of correct responses (data loss: 4%) and error rates were each subjected to a one-way ANOVA with Condition (CI, II or IPI) as a between-subjects factor (see also, Tables 2 and 3). For RTs, there was a main effect of Condition. RTs were shorter in the CI, $t(55)=3.08$, $r^2=.15$, $p<.01$, and the IPI condition, $t(55)=2.86$, $r^2=.13$, $p<.01$, compared to the II condition. For the error rates, the main effect of Condition was also significant. Error rates were lower in the CI condition, than in the II, $t(55)=2.37$, $r^2=.09$, $p<.05$, and the IPI condition, $t(56)=3.53$, $r^2=.18$, $p<.001$. Error rates did not differ between the II and IPI condition, $t<1$.

DISCUSSION

The central finding of the present study is that the Simon effect can be counteracted by the mere instructions of an incompatible position task. Whereas significant Simon effects of similar size were observed in the B and CI conditions, in the II and the IPI conditions no Simon effect was observed. While implementing spatially compatible S-R mappings does not lead to a larger Simon effect, implementing spatially incompatible S-R mappings eliminates the Simon effect, with moderate practice having no added effect to this modulation.

Table 3.

Means results and corresponding standard deviations (between brackets) of the diagnostic and inducer task.

		Simon effect		
Diagnostic Task	Mean	Congruent	Incongruent	Simon effect
RTs				
CI	530(77)	514(81)	546(70)	32*
II	533(86)	537(89)	529(84)	- 8
IPI	461(67)	458(56)	464(78)	6
B	437(65)	416(60)	457(64)	41*
Mean	490(85)	481(86)	499(83)	18
Error rates				
CI	.05(.06)	.03(.06)	.07(.05)	.03*
II	.04(.05)	.05(.06)	.03(.04)	-.02
IPI	.08(.08)	.10(.08)	.07(.08)	-.03
B	.07(.06)	.04(.03)	.10(.07)	.06*
Mean	.06(.07)	.06(.07)	.07(.07)	.01
Inducer task				
RTs				
CI	460(67)			
II	520(81)			
IPI	457(85)			
Error rates				
CI	.00(.00)			
II	.04(.10)			
IPI	.07(.10)			

We suggest that our results provide new information about IBRA (see Liefooghe et al., 2012; 2013). More specifically, the finding that instructed incompatible S-R mappings can eliminate the Simon effect indicates that instruction-based S-R associations trigger IBRAs that have a sufficient strength to counteract the effect of response activations based on long-term associations. The present study thus indicates that the relative strength of IBRA is comparable to the relative strength of response activations based on long-term associations, such that the effect of instruction-based associations can counteract the effect of long-term associations. Note that, in line with Proctor et al. (2013), we do not suppose that IBRA directly modified or suppressed the long-term associations, but only the response activation they elicit in the Simon task.

There are, however, also ways to explain our results without referring to IBRA. With regard to the lack of a Simon effect in the IPI condition, there is even an account that seems as plausible as the IBRA account. A reviewer correctly pointed out that the absence of the Simon effect in the IPI condition could have been due to the operation of long-term associations that were formed as the result of practice rather than to IBRA (Meiran & Kessler, 2008; Yamaguchi & Proctor, 2010). The fact that RTs were shorter in condition IPI than in condition II confirms that practice did have at least some effects in condition IPI. In the following paragraphs, we consider whether also the absence of a Simon effect in the II condition could easily be explained without referring to IBRA.

First, Vu (2007) argued that the modulation of the Simon effect can be based on a general opposite-response strategy rather than on the additional presence of specific short-term associations. This opposite-response strategy is the result of a learning process in which participants have practiced to respond in opposition to intuitively compelling response tendencies. Vu (2007) inferred the presence of such strategy from the finding that when a position task is practiced for 600 trials, the Simon effect is modulated even when the position task and the Simon task are performed on different dimensions (i.e., horizontal vs. vertical). For moderate practice (i.e., 72 trials), the Simon effect is only modulated when the position and the Simon task share the same dimension. The absence of a

Simon effect in the II and IPI condition may thus result from such opposite-response strategy. Yet, as Vu (2007) concluded such general opposite-response strategy is only induced after extensive practice, while in the present study only moderate practice was administered. Accordingly, we believe that the contribution of such strategy to the present results is minimal.

Second, Vu (2007) also argued that cognitive control during a Simon task may be higher after performing an incompatible position task because participants experience conflict during the incompatible position task (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). This increase in cognitive control could reduce of the Simon effect. The reduced Simon effect in the IPI condition could be explained in a similar way because participants in that condition actually performed an incompatible position task before the Simon task. However, it is less likely that the reduction of the Simon effect in the II condition can be explained in this way, simply because participants never performed the incompatible position task and therefore never experienced conflict in this task. One could argue that the mere instruction to perform an incompatible position task leads to an expectation of conflict and in this way increases cognitive control (but see Schmidt, 2013). However, why would participants increase cognitive control on the diagnostic task when expecting a difficult inducer task? One could even argue that participants would relinquish cognitive control during the diagnostic task in order to be better prepared for the difficult inducer task. In any case, we did not find a difference between the II and CI condition in overall performance during the diagnostic task. There were also no other aspects of the participants' general performance that indicated a difference in how the participants approached the diagnostic task in the II condition than in the CI condition. Hence, we have little reason to believe that the reduced Simon effect in the II condition was due to an increase of cognitive control in that condition.

Third, it could be argued that the instructed S-R mappings in the instruction conditions produced an additional load, which increased RTs in the diagnostic task to such an extent that no Simon effect was present in these conditions in the first place. It is well known that Simon effects attenuate with increases in general response speed, suggesting that response activations on the basis of long-term associations are short-lived (e.g., Proctor, Miles, Baroni, 2011). The additional load induced by the instructed S-R mappings may have increased RTs in the instructed conditions to such an extent that response activations based on long-term associations were no longer present in the instructed conditions (II, CI). A close consideration of our design furthermore indicates that the spatial S-R compatibility of instructions is confounded with response congruity in the Simon task. For incompatible S-R mappings, S-R compatible trials are response-incongruent trials, and S-R incompatible trials are response-congruent trials. For compatible S-R mappings, S-R compatible trials are response-congruent trials, and S-R incompatible trials are response-incongruent trials. Accordingly, the effect observed in the CI condition may thus reflect an instruction-based congruency effect, such as previously reported by Liefooghe et al. (2012, 2013), which mimics a Simon-effect. Although a similar Simon effect was present in the B condition, in which no instruction-based response-congruency could come into play, it is still conceivable that the effects observed in both conditions are only superficially similar and underpinned by different processes: IBRA in the CI condition and response activations on the basis of long-term associations in the B condition. Note that even if this hypothesis is correct, our data would imply that IBRA and response activations based on long-term associations are of comparable strength.

Yet, if only IBRA operated in the instructed conditions, the question arises why no effect was present in the II condition, given that the operation of IBRA alone should have led to an effect mimicking a reversed Simon effect. A first possibility is that IBRA does not occur for spatially incompatible S-R instructions. The absence of a Simon effect in the II condition may then reflect the absence of both IBRA and response activations on the basis of long-term associations (because of longer RTs; see above). However, such account would predict the presence of response activations due to long-term associations (and thus a regular Simon effect) on trials with the fastest RTs of the II condition. To test this prediction, we conducted additional bin-analyses on the data of the II condition. The data of the B condition were also subjected to a bin-analyses so that we could compare the Simon effect in the slowest trials of the B condition with the Simon effect in the fastest trials in the II condition. This way, we could control for differences in response speed between both conditions. As can be seen Appendix B, whereas a Simon effect was present in all RT bins of the B condition, a Simon-effect was not present in the II condition, not even in bins in which the overall RT was comparable to that of bins in the B condition. Such a result pattern suggests that the absence of an effect in the II condition is not an artifact of increased response speed. It is, however, in line with the idea that in the II condition, responses were activated both on the basis of instructions and on the basis of long-term associations but in a way that the specific effect of both types of associations was cancelled out.

Although the additional analyses seem to rule out a general slowing-through-load account, it remains possible that incompatible S-R mappings elicited a very specific load, thus leading to the absence of IBRA and response-activation based on long-term associations in the II condition, regardless of response speed. Wühr and Bieble (2011) demonstrated that specifically loading spatial working memory results in the absence of a Simon effect in a horizontal Simon task. In contrast, a verbal load did not influence the horizontal Simon effect. The difference in Simon effect between both instruction conditions was observed even when controlling for differences in general response speed between both conditions. Because it is difficult to exclude this post-hoc explanation in a definite manner, it does hinge upon the assumption that verbal instructions about incompatible S-R mappings can load spatial working memory in a selective manner. Moreover, in order to explain that IBRA did occur in the CI condition, one also has to add the assumption that verbal instructions about compatible S-R mappings do not impose a (similar) load on spatial working memory than verbal instructions about incompatible S-R mappings.

To conclude, our results could be explained without IBRA. Although this will most likely be the case in the IPI condition, the IBRA account stays the most plausible theory to explain the absence or the Simon effect in the II condition. Even though further research is necessary to confirm the IBRA account with even more certainty, this study is the first demonstration that instructing incompatible S-R mappings is sufficient to eliminate the Simon effect. This finding extents our knowledge on the malleability of the Simon effect and undeniably indicates how instructions play an important role in cognitive control.

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APPENDIX A

Mean RTs and Error rates in the filler runs were each subjected to a 3 (condition: CI, II or IPI) by 2 (response congruity: congruent, incongruent) mixed ANOVA with repeated measures on the last factor. Means and standard deviations for each cell of the design are presented in Table A1.

For RTs, the interaction between condition and response congruity was significant, $F(2,83)= 7.75$, $MSE=1129$, $\eta_p^2=.15$, $p<001$. In the II condition, participants were faster on congruent than on incongruent trials, $t(27)=2.86$, $r^2=.23$, $p<.01$, which indicates the presence of a Response Congruity effect. In the IPI condition, responses were faster on incongruent than on congruent trials, $t(28)=2.20$, $r^2=.15$, $p<.05$. In the CI there was no difference between congruent and incongruent trials, $t(28)=1.02$, $r^2=.03$, $p=.314$. There was a main effect of condition, $F(2,83)= 14.23$, $MSE=9869$, $\eta_p^2=.28$, $p<001$. There was no main effect of response congruity, $F<1$. For the error rates, no significant effects were observed (main effect condition, $F(2,83)= 2.17$, $MSE=.0054959$, $\eta_p^2=.05$, $p= .120$; main effect Response Congruity, $F(1,83)= 2.95$, $MSE=.0029074$, $\eta_p^2=.03$, $p= .089$; interaction effect, $F(2,83)= 2.05$, $MSE=.0030052$, $\eta_p^2=.05$, $p= .135$).

The results of the filler runs thus indicate that a response congruity effect was present in the II condition, which supports our hypothesis that the absence of a Simon effect in this condition, results from the competition between instruction-based response activation and response activations on the basis of long-term associations. Nevertheless, some caution is needed in evaluating the importance of these additional analyses. The CI and the IPI condition do not offer parsimonious evidence indicating the presence of a response congruity effect. In addition, it should be noted that the filler runs were presented only as a familiarization of our participants to relatively difficult procedure. Since we cannot be sure if this still has to be regarded as a practice phase these runs were never designed to be analyzed. As a consequence, the lengths of the filler runs were not fully balanced across participants and the number of observations available for measuring a response congruity effect varied for each participants (52 – 96 trails). Conclusions based on the results of the filler runs are thus difficult to make. It should also be noted that the differences in the II and CI condition in these filler trials cannot explain our findings in the critical run.

Table A1.

Means results and corresponding standard deviations (between brackets) of the diagnostic and inducer task in the filler runs.

Diagnostic Task	Mean	Congruent	Incongruent	Response Congruity
RTs				
CI	533(65)	537(69)	529(62)	-8
II	555(84)	540(74)	570(91)	30*
IPI	461(73)	469(78)	452(68)	-17*
Mean	516(84)	515(80)	516(88)	1
Error rates				
CI	.06(.07)	.06(.06)	.07(.07)	.01
II	.06(.06)	.07(.06)	.05(.05)	-.02
IPI	.08(.07)	.10(.06)	.07(.07)	-.03
Mean	.07(.06)	.08(.06)	.06(.07)	-.02

APPENDIX B

RTs in the II and B conditions were divided in three bins. Cells means and corresponding standard deviations are presented in Table B1. We considered bins for which RTs matched in length across both conditions. This was the case for Bin 1 of the II condition, which did not differ significantly in terms of overall RT from Bin 2 in condition B, $t<1$, and for Bin 2 of the II condition which did not differ significantly in terms of overall RT from Bin 3 of condition B, $t(54) = 1.15$, $r^2=.02$, p=.256. A significant Simon effect was present in all three bins of the B condition (i.e., 29ms, 37ms, and 59ms in Bins 1, 2, and 3, respectively). In contrast, for the II condition, no Simon effect was present (i.e.,-10ms, -7ms, and -5ms in Bins 1, 2, and 3 respectively).

As shown in Table B1, the Simon effect in the B condition becomes larger with increases in RTs, a finding at odds with the more common observation that the Simon effect decreases with general speed. However, it has been argued that the decrease of the Simon effect with response speed is malleable. For instance, Hommel (2000) indicated that the temporal characteristics of the Simon effect can be reversed when the relevant stimulus feature is processed faster than the stimulus location. In our experiment, participants practiced the color task extensively before the critical run was presented. In addition, the irrelevant stimulus feature differed in each run (Size, Quantity, Vertical position, Horizontal position). As such, processing of the stimulus color may have been speeded-up considerably compared to the processing of the irrelevant feature. Nevertheless, although the observed pattern deviates from what is commonly observed, it strengthens our main conclusion from these additional analyses: It is unlikely that the absence of effects in the II condition was due to the longer RTs in this condition.

Table B1.

Overview of means of different Bins in both the II and B condition

	Bins		
Diagnostic Task	Bin 1	Bin 2	Bin 3
II			
Congruent	424(65)	513(90)	673(124)
Incongruent	414(62)	506(85)	668(132)
Mean	419(63)	509(86)	668(127)
B			
Congruent	336(47)	404(56)	508(90)
Incongruent	365(47)	441(57)	567(104)
Mean	350(48)	441(59)	567(101)

CHAPTER 3

AUTOMATIC MOTOR ACTIVATION BY MERE INSTRUCTION[1]

Previous behavioral studies have shown that instructions about S-R mappings can influence task performance even when these instructions are irrelevant for the current task. In the present study, we tested whether automatic effects of S-R instructions occur because the instructed stimuli automatically activate their corresponding responses. We registered the lateralized readiness potentials (LRPs) that were evoked by the instructed stimuli while participants were performing a task for which those mappings were irrelevant. Instructed S-R mappings clearly affected task performance in electrophysiological and behavioral measures. The LRP was found to deflect in the direction of the response tendency that corresponded with the instructed S-R mapping. Early activation of the instructed response was observed, but occurred predominantly in slow trials. In contrast, response conflict evoked by instructed S-R mappings did not modulate the N2 amplitude. The results strongly suggest that, like experienced S-R mappings, instructed S-R mappings can lead to automatic response activation, but possibly via a different route

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[1] Based on Everaert, T., Theeuwes, M., Liefooghe, B., & De Houwer, J. (2014). Automatic motor activation by mere instruction. *Cognitive, Affective, and Behavioral Neuroscience, 14,* 1300-1309.

INTRODUCTION

Learning through instructions is a unique human ability that offers a quick route to changes in behavior without the necessity of actual practice. It appears to be based on the implementation of verbal instructions into procedural representations which control responding (e.g., Cohen-Kdoshay & Meiran, 2007; Liefooghe, Wenke & De Houwer, 2012; Meiran, Coles, & Braver, 2012; Wenke, Gaschler, & Nattkemper, 2007). Such view is supported by research demonstrating that merely instructed Stimulus-Response (S-R) mappings, which have never been applied before, can bias responding when being irrelevant. For instance, Liefooghe et al. (2012; see also Liefooghe, De Houwer, & Wenke, 2013) used a procedure in which participants are presented with runs of trials consisting of two tasks: the inducer task and the diagnostic task (Figure 1). Each run starts with the presentation of a novel pair of S-R mappings of the inducer task that indicates how to respond to the identity of a probe stimulus that would be presented later on (e.g., if the probe stimulus is the non-word 'ady', press left). Between the presentation of the S-R mappings and the onset of the probe, several trials of the diagnostic task are presented. Both tasks share stimuli and responses, but in the diagnostic task participants respond to the orientation rather than the identity of the stimuli (e.g., if upright press left; if italic, press right). Liefooghe et al. (2012) observed that RTs in the diagnostic task were faster when the required response in the diagnostic task corresponded to the S-R mappings of the inducer task (i.e., a congruent trial such as 'ady' presented upright, requiring a left key-press), than when it did not (i.e., an incongruent trials such as 'ady' presented in italics, requiring a right key-press). A congruency effect was thus observed that was based only on the instructions of the inducer task. This effect is referred to as the Instruction-Based Task-Rule Congruency Effect (IB-TRCE).

The IB-TRCE and related effects, such as the instruction-based feature-binding effect (Wenke et al., 2007, 2009), the instruction-based Simon effect (De Houwer, Beckers, Vandorpe, & Custers, 2005) or the instruction-based Flanker compatibility effect (Cohen-Kdoshay & Meiran, 2007, 2009; Meiran & Cohen-Kdoshay, 2012), are considered as evidence for the hypothesis that instructed S-R mappings can be implemented into functional S-R associations and this without any practice. Once these S-R associations are established, they can trigger responses even when being irrelevant for the task at hand. In other words, the assumption is made that instructed S-R mappings can lead to Automatic Instruction-Based Response Activation (AIBRA). Although there is consensus that AIBRA underlies many instruction-based effects (see Meiran et al., 2012, for a review), there is only behavioral evidence in support of this explanation. Accordingly, alternative explanations for instruction-based effects which do not call upon AIBRA have also been put forward. For instance, Cohen-Kdoshay and Meiran (2007; 2009) noted that the effects reported by Wenke et al. (2007, 2009) and De Houwer et al. (2005) may reflect interference between the declarative knowledge about different sets of instructions rather than actual AIBRAs. Although Cohen-Kdoshay and Meiran (2007, 2009) and Liefooghe et al. (2012, 2013) offered additional controls to rule out such alternative explanations, until now all evidence is based on the mere existence of the behavioral effects that AIBRA is supposed to explain (e.g., IB-TRCE, instruction-based flanker effect). In the present study, we therefore looked for neurophysiological signs of AIBRA. More precisely, we investigated the EEG signature of the IB-TRCE and focused on an important marker of motor activation: the Laterized Readiness Potential (LRP; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Smulders & Miller, 2013).

It is a well-replicated finding that the preparation of a manual response is accompanied by a negative potential that is maximal over the motor cortex, contralateral to the responding hand (for an overview, see Smulders & Miller, 2013). This LRP is widely accepted as a measure of hand-specific response activation. First, its locus has been shown to lie in the motor cortex (Arezzo & Vaughan, 1975; Eimer, 1998; Gemba & Sasaki, 1990; Okada, Williamson, & Kaufman, 1982; Praamstra, Stegeman, Horstink, & Cools, 1996; Requin, 1985), suggesting that the LRP has strong ties with motor preparation and response activation. Second, the LRP is an extremely valid predictor of motor responses (Gratton et al., 1988). The onset of electromyographic activity occurs reliably when the LRP reaches a certain threshold value. Third, the LRP covaries with a wide array of movement parameters. In paradigms in which the response is precued, for instance, the size of the preparatory LRP, or foreperiod LRP, increases with the number of parameters that is specified about the response to be made (e.g., Leuthold, Sommer, & Ulrich, 1996; Wild-Wall, Sangals, Sommer, & Leuthold, 2003).

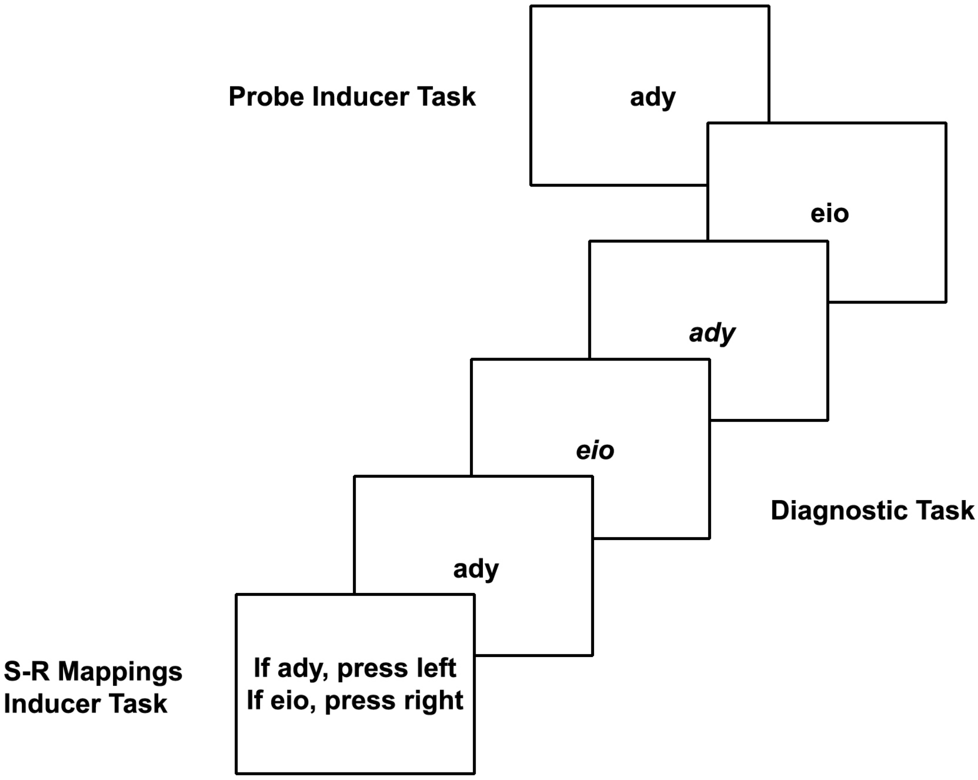

Figure 1. Outline of a run of the inducer task and the diagnostic task.

Importantly for the present purpose, LRPs also allow the measurement of automatic response activations (e.g., Eimer, 1995; 1998; Gratton et al., 1988). This has been demonstrated by studies that relate LRP modulations to S-R congruency effects, such as the Flanker effect (e.g., Gratton et al., 1988), the Simon effect (e.g., De Jong, Liang, & Lauber, 1994), the SNARC effect (e.g., Gevers, Ratinckx, De Baene, & Fias, 2006), and the task-rule congruency effect in task switching (e.g., Umebayashi & Okita, 2010). It is commonly assumed that S-R congruency effects are driven by automatic response activations that are evoked by irrelevant stimuli, stimulus features, or tasks (e.g., Kornblum, Hasbroucq, & Osman, 1990, Hommel et al., 2001). LRP studies on these different S-R congruency effects have revealed modulations of the onset time and amplitude of LRPs as a function of S-R congruency.

Compared to congruent trials, incongruent trials often show an early activation of the incorrect response before the correct response is fully activated (De Jong et al., 1994; Gratton et al., 1988). Furthermore, the onset of stimulus-locked LRPs (SLRPs) is generally later for incongruent trials than for congruent trials. Usually, no such differences are observed when analyzing the onset of the LRP in response-locked segments (LRPRs; Keus, Jenks, & Schwarz, 2005; Masaki, Wild-Wall, Sangals, & Sommer, 2002). These effects on LRP onset demonstrate that S-R congruency mainly affects the duration of the processes occurring before response activation (SLRP onset latency) rather than the duration of response activation and motor programming (LRPR onset latency; Leuthold et al., 1996; Smulders & Miller, 2013).

Taken together, LRP modulations offer a set of valid markers of automatic response activation. We used LRPs to investigate if merely instructed S-R mappings, that have never been applied before can indeed lead to automatic response activations. Such finding has far-stretching consequences for theorization on the implementation of instructions, as it tackles the core of many accounts on instruction implementation, namely that instructions in itself can lead to AIBRA. Accordingly, the present study could provide unique evidence for the hypothesis that instructed S-R mappings can be translated into functional S-R associations even in the absence of any practice. In contrast, failing to find an effect of instruction-based task-rule congruency on the LRP signal would seriously challenge the current consensus in research on instructions, because this would suggest that instruction-based effects have to be explained without calling upon AIBRA.

In order to investigate the hypothesis that merely instructed task-irrelevant S-R mappings can lead to AIBRA, EEGs were measured in the procedure developed by Liefooghe et al. (2012, 2013). We hypothesized that if the mere instruction of S-R mappings of the inducer task leads to AIBRA in the diagnostic task, then the instructed S-R mappings would lead to larger LRPs on congruent trials compared to incongruent trials. Furthermore, the LRPs of incongruent trials are predicted to display an early activation of the incorrect response before the correct response is fully activated. Congruent trials are also thought to evoke LRPs with an earlier onset than incongruent trials in the stimulus-locked segments, as S-R congruency mainly affects the duration of the processes occurring before the onset of the stimulus-locked LRP (Leuthold et al., 1996; Smulders & Miller, 2013).

In addition, S-R congruence is known to evoke a distinct modulation of the EEG signal that could be of interest to the current study. Incongruent trials often evoke a more pronounced N2 than congruent trials. This modulation, peaking approximately 300 ms after stimulus onset at fronto-central sites, is thought to reflect the detection of S-R conflict and likely originates from the anterior cingulate cortex (ACC; Folstein & Van Petten, 2008; Van Veen & Carter, 2002). We therefore investigated whether instruction-based S-R conflict also evokes a larger N2.

METHOD

Participants

Twenty right-handed students at Ghent University (Mage = 23, SD = 6, 17 women) with normal or corrected-to-normal vision signed up for the experiment on their own initiative and without any restriction on the basis of participants' sex (e.g., an equal number of men and women). They were paid €20 to participate in the study. The higher proportion of women in our sample reflects the higher proportion of women students at Ghent University, especially in the Faculty of Psychology and Educational Sciences where the experiment was run.

Stimuli and Materials

A list of 126 three-letter non-words was generated randomly using Wordgen (Duyck, Desmet, Verbeke, & Brysbaert, 2004). For each participant, a set of 63 pairs of non-words was randomly constructed on the basis of this list. These pairs were randomly assigned to 9 blocks, each containing 7 runs. The 7 pairs of each block were randomly assigned to the 7 runs within each block (4 runs with 4 diagnostic trials, 2 runs with 8 diagnostic trials, and 1 run with 16 diagnostic trials.).

In each run, one of the 63 non-word pairs was used for both the inducer task and the diagnostic task. The same left- and right keys (‘a’ and ‘p’ on an AZERTY keyboard) were used for both tasks throughout the entire experiment. In the inducer task, participants responded to the identity of a probe stimulus (a non-word presented in green), on the basis of the instructed S-R mappings. In the diagnostic task, participants decided whether a non-word, presented in black was printed upright or in italic also by either pressing a left or right key. The left-right response assignment in the diagnostic task was counterbalanced across participants.

Each non-word was presented on a white background in uppercase with an Arial bold font and a size of 24 pixels. The instructed S-R mappings were presented in a similar font with a size of 16 pixels and randomly presented one above the other in the screen center, such that a mapping referring to a specific response key could be either on the top line or on the bottom line.

Procedure

Participants were tested individually in a dimly-lit room by means of a personal computer with an Intel Pentium 4 processor and a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Instructions were presented on screen and paraphrased subsequently. Nine blocks of 7 randomly ordered runs were presented with a small break after each block. During each break, feedback was provided about the proportion of errors made on the diagnostic task and the inducer task.

Each run started with the presentation of the S-R mappings of the inducer task. These mappings remained on screen until participants pressed the spacebar or a maximum time of 20 seconds elapsed. Once participants pressed the spacebar, the first non-word stimulus of the diagnostic task was presented after a variable inter-trial interval randomly ranging from 750ms to 1250ms. Each non-word stimulus in the diagnostic task remained on screen until participants responded. Depending on the run length, participants performed 4, 8, or 16 trials of the diagnostic task also with a variable inter-trial interval. Varying the number of trials of the diagnostic task made the onset of the probe stimulus of the inducer task unpredictable, which encouraged participants to be constantly prepared to execute the inducer task (see Liefooghe et al., 2012, 2013). After the last trial of the diagnostic task, the non-word probe of the inducer task was presented. This probe remained on screen until participants responded. A new run with new non-words was automatically initiated after the abovementioned inter-trial interval. Maximum response time was 2000 ms for all responses. Incorrect responses were followed by the Dutch word ‘FOUT’ (‘wrong’) printed in red for 200 ms. The preparation of the participant and the performance of the experiment lasted approximately 30 minutes and 25 minutes, respectively

EEG acquisition and statestical analyses

EEG recording was performed with a Biosemi Active Two System (http://www.biosemi.com), which measured EEGs through 128 Ag/AgCl electrodes that were placed on an elastic cap and positioned according to the ABC positioning system. Two external electrodes were placed on the mastoids to perform an off-line reference of the EEGs to the averaged signal of these electrodes. An additional four electrodes were used to monitor vertical and horizontal eye movements. The EEG signal was sampled at 512 Hz and band-pass filtered offline between 0.03 Hz and 30 Hz with an additional notch filter at 50 Hz to reduce any remaining noise due to AC interference.

Offline computations were performed with Brain Vision Analyzer 2.0 (Brain Products, GmbH, Munich, Germany). The EEG signals were first segmented into broad 2500 ms epochs that were locked to stimulus presentation and aligned to a 200-ms baseline before stimulus onset. Eye-blink artifacts were corrected using the standard algorithm of Gratton, Coles, and Donchin (1983) and remaining artifacts were semi-automatically detected and rejected using a ± 75 µV criterion relative to the baseline. The segments were re-segmented into stimulus-locked epochs and response-locked epochs. The stimulus-locked epochs started 200 ms before stimulus onset and ended 2000 ms after stimulus onset. The response-locked epochs ranged from 650 ms before the response to 350 ms after the response.

The LRPs were calculated separately for each experimental condition. The EEG signals measured in the C3 and C4 electrodes were used to compute the LRP according to the formula proposed by Coles (1989). The ERPs ipsilateral to the responding hand were subtracted from the ERPs contralateral to the responding hand. The resulting waves were subsequently averaged across hands. In the resulting LRP waves, the activation of the correct response relative to the incorrect response is indicated by the amplitude of the signal. Negative waves indicate stronger activation of the correct response compared to the incorrect response, while positive waves indicate stronger activation of the incorrect response compared to the correct response.

LRP amplitudes were assessed using mean amplitudes in intervals that contained the LRP according to visual inspection: 300 to 600 ms after stimulus onset for the SLRPs, and 300 ms before the response until the actual response for the LRPRs. Estimation of the LRP onsets was performed using 2UDF segmented regression (Mordkoff & Gianaros, 2000; Schwarzenau, Falkenstein, Hoormann, & Hohnsbein, 1998) combined with the jackknife method (Miller, Patterson, & Ulrich, 1998; Smulders, 2010; Ulrich & Miller, 2001). The LRP onset in each participant's jackknifed average wave was estimated by fitting two regression lines to the wave using the 'segmented' package in R (Muggeo, 2008). The onset of the LRP was defined as the breaking point between of the two regression lines. To reduce the impact of high-frequency noise on the onset detection, LRPs were low-pass filtered at 7 Hz with a 12 dB octave.

RESULTS

Analyses focus only on the diagnostic task because only performance on this task informs us about AIBRA. The first block of the experiment was considered practice and not included for further analyses. Three hundred and eighty-four trials of the diagnostic task were thus retained (192 congruent and 192 incongruent trials). Only correct trials with RTs not deviating more than 2.5 standard deviation from the cell mean (Ratcliff, 1993) were considered for the analysis. This resulted in the removal of 2.8% of the trials. The artifact rejection on the EEG data led to a further removal of 12.6% of the trials.

Behavioral results

A significant IB-TRCE was observed both in the RTs, *t*(19) = -3.49, *p* = .002, *d* = 0.78, and in the error percentages, *t*(19) = -3.70, *p* = .002, *d* = 0.83. Participants were 17 ms (*SD* = 21 ms) faster in congruent trials (*M* = 646 ms, *SD* = 95 ms) compared to incongruent trials (*M* = 663 ms, *SD* = 90 ms). Similarly, participants made fewer errors in congruent trials (*M* = 3.2%, *SD* = 1.9%) than in incongruent trials (*M* = 5.4%, *SD* = 3.0%).

ERP results

LRP analysis

A clear, significant, LRP emerged for all conditions in both stimulus-locked and response-locked epochs, all *t(*19)'s > 2.59, all *p*'s < .018 (see Figure 2 and Figure 3). Importantly, the mean amplitude of the LRPs for congruent trials was significantly larger than the mean amplitude of the LRPs for incongruent trials in the stimulus-locked LRPs, *t*(19) = 2.52, *p* = .021, *d* = 0.56, and almost significant in the response-locked LRPs, *t*(19) = 2.00, *p* = .060, *d* = 0.45.

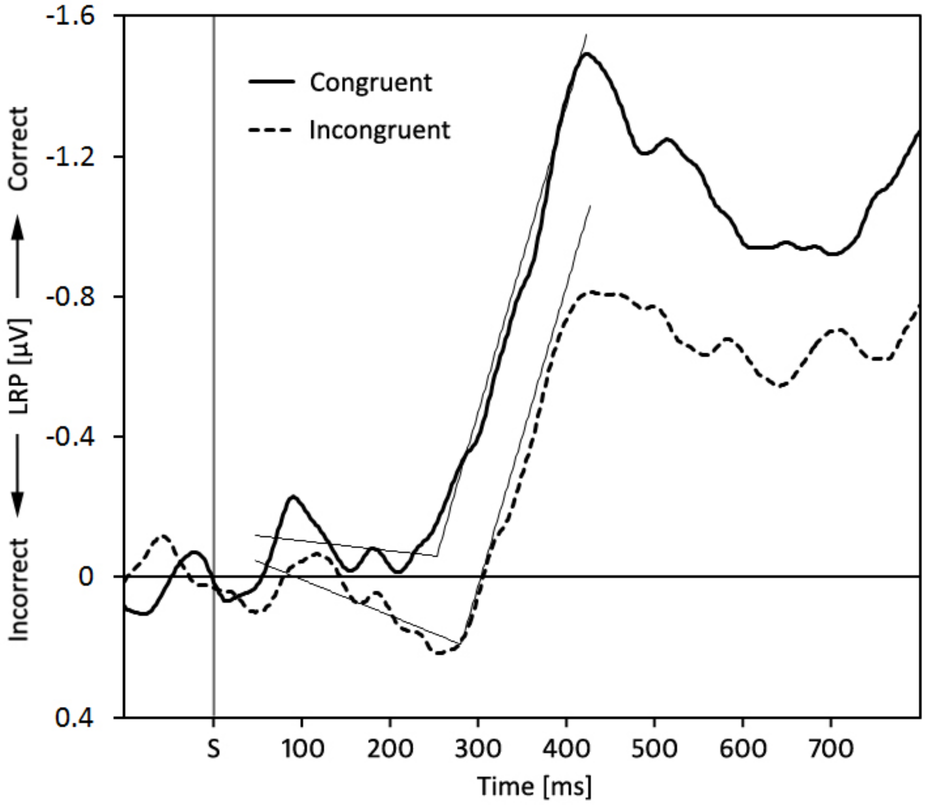

Figure 2. Grand average stimulus-locked lateralized readiness potentials as a function of compatibility. S = stimulus onset. Straight lines indicate the regression lines estimated with the segmented regression procedure. The breaking-points indicate the estimated LRP onset.

The LRP waves also displayed a deflection that is commonly observed in compatibility tasks (e.g., De Jong et al. 1994; Eimer, 1995; Gratton et al., 1988). The stimulus-locked LRP of the incongruent trials was characterized by a small, positive, deflection starting 150 ms after stimulus onset and lasting until 300 ms after stimulus onset. After this initial deflection the LRP shifted toward the correct response. Similarly, response-locked LRPs showed the same dip in activation ranging from approximately 450 ms to 300 ms before the response was given. This deflection suggests a slight activation of the incorrect response on the incongruent trials. We assessed the significance of these dips by segmenting the signal around them into 6 50-ms bins, calculating the mean amplitudes of these bins, and statistically testing them against zero.

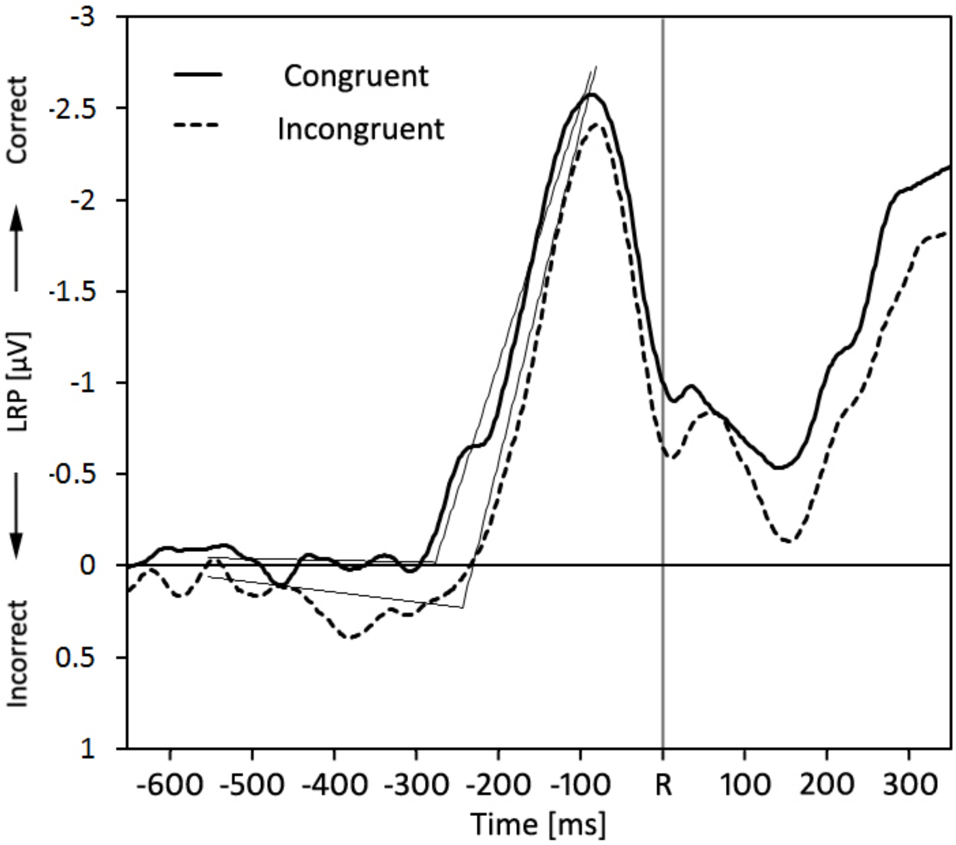

Figure 3. Grand average response-locked lateralized readiness potentials as a function of compatibility. R = response onset. Straight lines indicate the regression lines estimated with the segmented regression procedure. The breaking-points indicate the estimated LRP onset.

The visually present activation dip in the incompatible SLRP did not reach significance, although a slight tendency towards a positive dip was present in the 200 ms to 250 ms bin, *t*(19) = 1.60, *p* = 0.13, *d* = 0.36. In contrast, the activation dip did reach significance in the incompatible LRPR in the -400 ms to -350-ms bin, *t*(19) = 2.42*, p* = 0.03, *d* = 0.54. This difference in significance might be due to the fact that there is considerable variation in RTs. Averaging across trials in which the LRPs did not overlap sufficiently could have made this early activation dip less apparent in the stimulus-locked segments (e.g., Luck, 2005).

To further elucidate these results, we analyzed trials with fast and slow RTs separately by performing a median split on the data. We assumed these data could clarify the earlier results for two reasons. First, effects of S-R congruency might be more pronounced in slow trials because the likelihood that an incorrect response is activated is known to be larger in these trials (e.g., Eder, Leuthold, Rothermund, & Schweinberger, 2012). Second, analyzing fast and slow trials separately reduces the variability in the LRPs amongst the trials, thus leading to clearer LRPs when averaging fast and slow trials (e.g., Luck, 2005; Poli, Cinel, Citi, & Sepulveda, 2010).

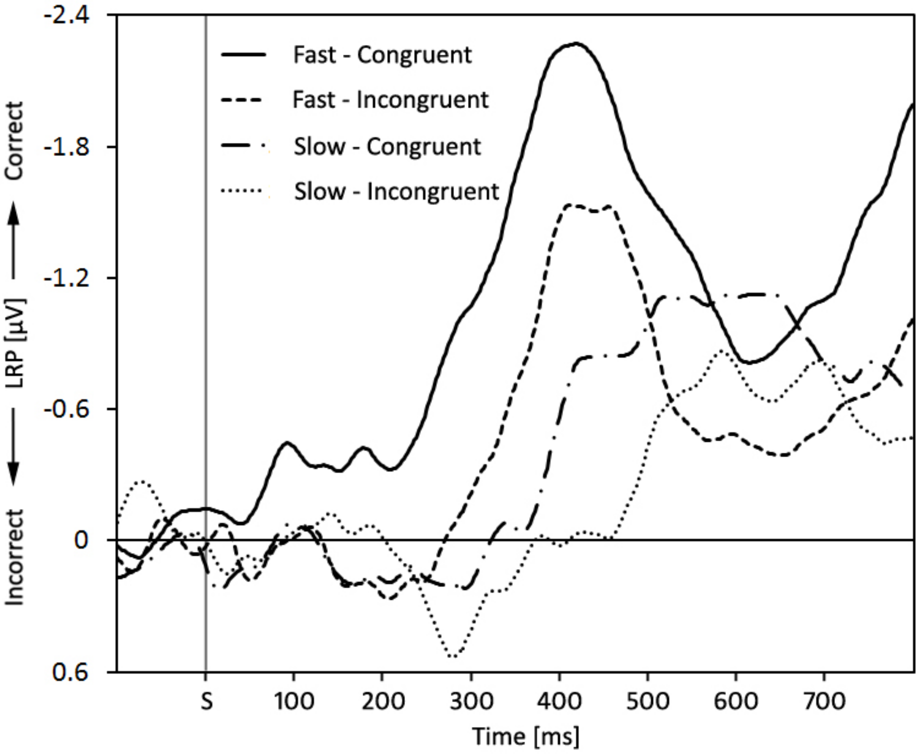

Figure 4. Grand average stimulus-locked lateralized readiness potentials as a function of compatibility and response speed. S = stimulus onset.

In accordance with this line of thought, significant activation dips were found in SLRPs (Figure 4) and LRPRs (Figure 5) for slow trials only, *t*(19) = 2.46, *p* = .024, *d* = 0.55, in the 200 ms to 250 ms bin for the SLRPs, and *t*(19) = 2.14, *p* = .045, *d* = 0.48, in the -400 ms to -350 ms bin for the LRPRs. In the fast trials, only (at best) marginally significant activation dips were found, *t*(19) = 1.51, *p* = 0.15, *d* = 0.34, for the SLRPs, and *t*(19) = 1.66, *p* = 0.11, *d* = 0.37, for the LRPRs. Interestingly, fast congruent trials displayed an early pre-activation of the correct hand in the 50 ms to 100 ms bin in the SLRPs, *t*(19) = 2.39, *p* = .027, *d* = 0.54, that reached marginal significance in the next 2 bins, *t*(19) = 1.81, *p* = .09, *d* = 0.40, and *t*(19) = 2.03, *p* = .06, *d* = 0.45, for the 100 ms to 150 ms bin and the 150 ms to 200 ms bin, respectively. The actual LRP peak started reaching significance only in the 250 ms to 300 ms bin, *t*(19) = 2.98, *p* = .008, *d* = 0.67. A marginal correct-hand pre-activation was found in the fast, congruent LRPRs in the -450 ms to -400 ms bin, *t*(19) = 1.69, *p* = .11, *d* = 0.38.

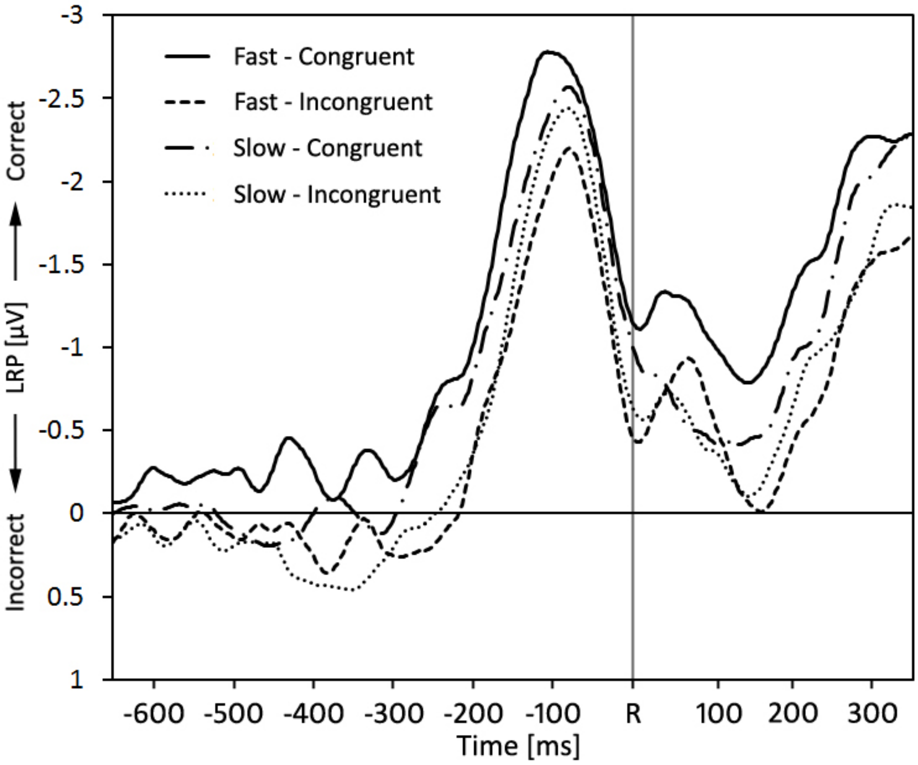

Figure 5. Grand average response-locked lateralized readiness potentials as a function of compatibility and response speed. R = response onset.

The segmented regression analysis on the jackknifed averages yielded clear LRP onset estimates in SLRPs and LRPRs (see Figure 2 and 3 for the regression lines). Although the SLRP onset in the congruent trials (*M* = 256 ms) was earlier than the SLRP onset in the incongruent trials (*M* = 284 ms), the 28-ms difference did not reach significance, *t*(19) < 1. Similarly, the earlier LRPR onset for congruent trials (*M* = -276) compared to incongruent trials (*M* = -240 ms) was not significant, *t*(19) = 1.47, *p* = .16, *d* = .33.

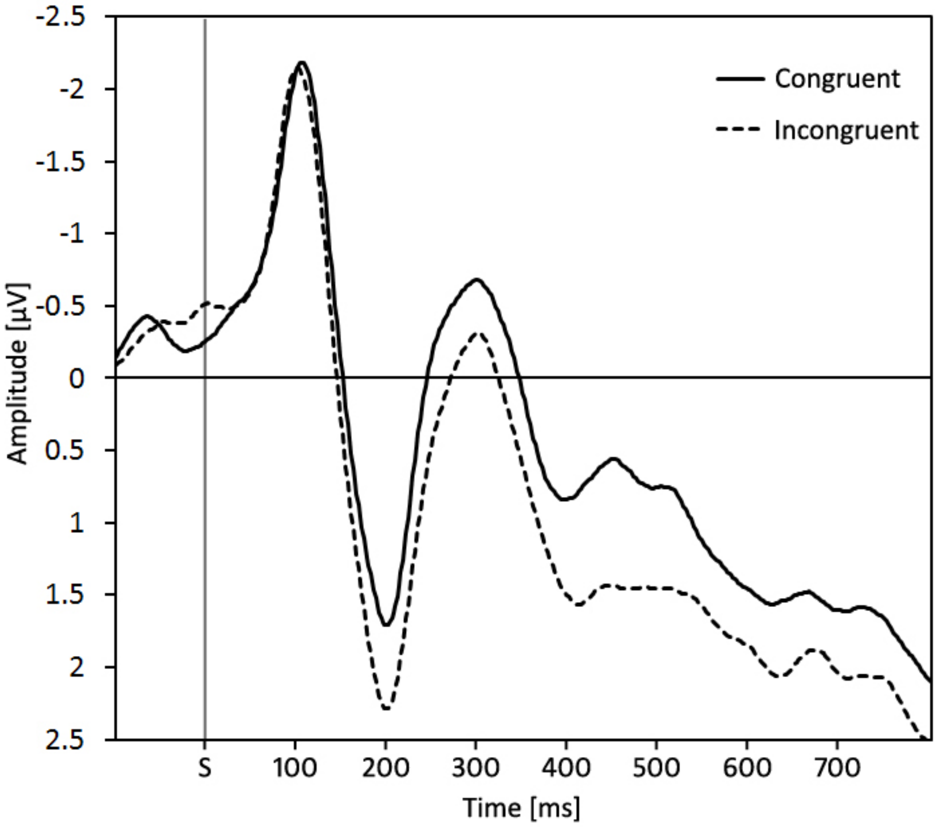

Figure 6. Grand average waveforms at electrodes Fz (C21) and 6 surrounding, more posterior electrodes as a function of compatibility.

Additional analyses

Visual inspection of the data revealed a clear N2 (Figure 6) that peaked between 250 ms and 350 ms after stimulus onset and was maximal at frontal sites (Fz and its surroundings). Analyses of the mean amplitude of this peak in the aforementioned time interval on electrode Fz and the 6 surrounding more posterior electrodes did not reveal any significant differences in N2 amplitude, $t(19) < 1$. No other effects emerged when analyzing fast and slow trials separately, all $t(19)$'s < 1.

S-R congruency can also lead to fluctuations in error-related negativity (ERN), a negative wave following errors that is maximal at fronto-central sites (Falkenstein, Hohnsbein, & Hoormann, 1991; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The error percentage (4.6 %) was too small for a meaningful analysis of this component, however. Only eight participants made at least 6 usable errors, which was not sufficient to elicit a significant ERN at Fz in the 100 ms following an error, $t(7)$ =

1.87, *p* = .10, *d* = 0.75. Unsurprisingly therefore, no significant differences were observed between the ERNs following congruent trials and the ERNs following incongruent trials, *t*(7) < 1.

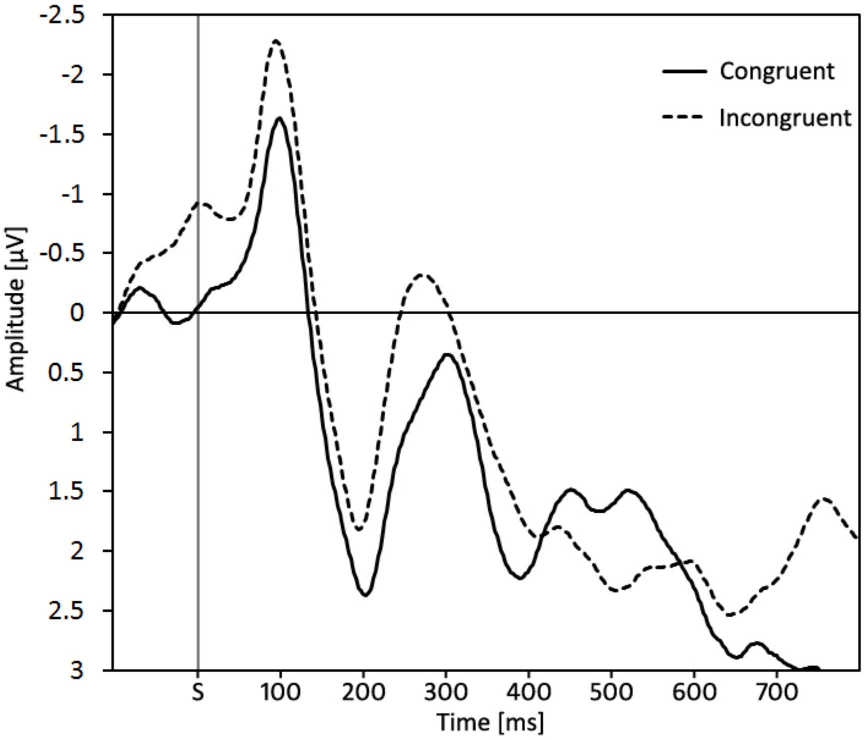

Figure 7. Grand average waveforms of trials following congruent trials at electrodes Fz (C21) and 6 surrounding, more posterior electrodes as a function of compatibility.

DISCUSSION

The current study investigated if responses can be activated automatically as the result of instructions about S-R mappings, a hypothesis which is central in many accounts on the implementation of instructions (e.g., Cohen-Kdoshay & Meiran, 2007, 2009; Liefooghe et al., 2012, 2013; Wenke et al. 2007, 2009). To this end, LRP modulations associated with the IB-TRCE were investigated.

A clear IB-TRCE was present on the RTs and the error rates. Importantly, lower LRP amplitudes were observed on incongruent trials compared to congruent trials suggesting that instruction-based congruency leads to differences in response activation in the motor cortex. These differences were significant mainly in the SLRPs, which suggests that the AIBRA is probably the result of visuo-motor priming evoked by the task-irrelevant stimulus attribute (e.g., Stürmer, Ouyang, Zhou, Boldt, & Sommer, 2013). Such differences in activation that are evoked by the stimulus might become less apparent when averaging the segments aligned to the response. In line with the observed differences in LRP amplitude, the LRPs of incongruent trials displayed an early deflection, showing activation of the response afforded by the solely-instructed inducer task. This deflection was present mainly in the slow trials, as the likelihood of incorrect response activation is larger in these trials.

Analyses of the LRP onsets did not reveal any significant effects of instruction-based congruency on the SLRP onset and the LRPR onset, but the estimation of the LRP onset might not have been optimal in our study. LRP onset latencies are calculated to estimate the point in time at which the activation of the correct response starts. The LRP, however, reflects the relative activation of two responses. Trials in which incorrect responses are activated can therefore obscure the onset estimation of the correct response (e.g., Stürmer et al., 2013). Since we observed clear activation of the responses in line with the irrelevant instructions, our estimates of the LRP onset might not reflect the onset of the activation of the relevant response per se.

The critical difference compared to previous research is that the congruency effect observed in the present study is based on merely instructed S-R mappings that have never been practiced or applied overtly before. In other words, our results offer strong evidence that these effects are based on AIBRA. Neuroimaging studies suggest that a frontal parietal network involved in task-rule implementation might be instrumental for the occurrence of IB-TRCEs (e.g., Hartstra, Kühn, Verguts, & Brass, 2011; Hartstra, Waszak, & Brass, 2012; Ruge & Wolfensteller, 2010). In this network, the inferior frontal sulcus appears to be implicated in the formation of S-R links, while a sizeable part of the network is responsible for the coding of responses in areas related to motor control such as the anterior IPS, premotor cortices and the pre-SMA (Hartstra et al. 2012). Our data suggest that this instruction-related activation in the fronto-parietal network can be sustained over time and even lead to automatic activation in the primary motor cortex during the performance of other tasks.

While the present results indicates that instruction-based congruency effects are associated with modulations in the LRP, as it is the case for execution-based S-R congruency effects, it is important to note that the EEG signatures of both effects also seem to differ. Execution-based task-rule congruency generally leads to variations in the amplitude of the N2 (e.g., Folstein & Van Petten, 2007), while instruction-based task-rule congruency did not seem to evoke such differences. The absence of such an effect does not seem limited to our study. Brass, Wenke, Spengler, and Waszak (2009), for instance, did not observe an effect of interference from instructed S-R mappings on activity in the ACC, the likely source of the fronto-central N2 (Folstein & Van Petten, 2008; Van Veen & Carter, 2002). Conversely, interference from experienced S-R mappings did evoke differences in ACC activation. This contrast might be the result of the different neural pathways that are thought to be involved instruction-based and experience-based performance. While instruction-based task execution is supposedly mediated by the prefrontal cortex, experience-based task execution has been attributed to the basal ganglia (Ramamoorthy & Verguts, 2012) and the posterior parietal cortex (Huang, Hazy, Herd, & O'Reilly, 2013). The prefrontal route allows for fast learning of novel, instructed S-R mappings, and is the supposed source of instruction-based S-R congruency effects. In contrast, repeated task execution triggers a slow learning mechanism in the basal ganglia that eventually bypasses the prefrontal route, which dominates task execution after sufficient practice, and thus might lead to experience-based S-R congruency effects (Ramamoorthy & Verguts, 2012). Such account is in line with the seminal proposals by Logan (1988), who suggested that novel tasks are first processed through a controlled algorithmic route and subsequently available for automatic retrieval.

Previous behavioral research also indicated that instructed and practiced S-R mappings are represented by different components of memory. The common hypothesis is that instructed S-R mappings are translated into a procedural representation such as a task-set (Liefooghe et al., 2012), an event-file (Wenke et al., 2007) or a plan (Meiran et al., 2012) in short-term memory. Such a representation serves the control of actions by representing functional S-R associations that are reflexively triggered when target stimuli are presented (Hommel et al., 2001; Meiran et al., 2012). Importantly, such representation is achieved only for a relatively high degree of task readiness (Liefooghe et al., 2013; Wenke et al., 2009). Whenever preparation demands are too lenient, instruction-based S-R congruency effects are absent. In contrast, execution-based S-R congruency effects, such as the task-rule congruency effect in task switching seem to be independent of task readiness (Yamaguchi & Proctor, 2012) and based on S-R associations in long-term memory (Meiran & Kessler, 2008). While research on instruction implementation undeniable shows that the practice or execution of S-R mappings is not a prerequisite to obtain S-R congruence, practice may still result in a transfer from short-term S-R associations that are formed initially on the basis of instructions to S-R associations in long-term memory.

Execution-based and instruction-based congruency effects thus seem to have different underpinnings which could have led to different modulations of the N2 amplitude. Alternatively, the absence of an effect on the N2 could also be related to the size of the S-R conflict evoked by merely-instructed task-rules. The response activation evoked by irrelevant experience-based task-rules seems to be stronger than the response activation evoked by irrelevant instruction-based task-rules. Evidence for this difference in response strength can be found in the generally larger effect sizes found in experience-based paradigms compared to the instruction-based paradigm used in the current study. Most studies demonstrating the impact of response conflict on N2 amplitude have employed the Eriksen flanker task (Eriksen & Eriksen, 1974), which generally yields behavioral effect sizes larger than the one obtained in our study (IB-TRCE = 17 ms, *d* = 0.78). For instance, the flanker task used in the seminal paper of Coles, Gratton, Bashore, Eriksen, and Donchin (1985) yielded a flanker congruency effect that had an absolute size of 47 ms and a Cohen’s *d* of 3.29. Such large effect sizes are not uncommon for the flanker paradigm (e.g., Bartholow, Pearson, Dickter, Sher, Fabiani, & Gratton, 2005; Hazeltine, Poldrack, & Gabrieli, 2000; Mansfield, van der Molen, Falkenstein, van Boxtel, 2013; Van Veen & Carter, 2002; Yeung, Botvinick, & Cohen, 2004), which might explain why modulations of N2 amplitudes are found more readily using the flanker task. In line with this reasoning, we performed a post-hoc analysis on the N2 amplitudes of the trials following a congruent trial, as congruency effects are usually larger after such trials (Gratton, Coles, & Donchin, 1992). The IB-TRCE in these trials was fairly large on behavioral measures, IB-TRCE = 34 ms, $t(19) = 4.20$, $p < 0.001$, $d = 0.94$, and manifested itself in a marginally significant effect on N2 amplitudes in the expected direction, $t(19) = 1.98$, $p = .06$, $d = 0.44$ (Figure 7). This additional analysis indicates that, under conditions in which the IB-TRCE is larger, significant effects on N2 amplitudes can be observed, as is the case for execution-based congruency effects, such as the flanker effect. Modulation of the fronto-central N2 component, and therefore ACC activation, may thus be more dependent on the size of the conflict rather than the source of the conflict (i.e., instructions or experience).

To conclude, the present study demonstrates automatic motor activation on the mere basis of task-irrelevant instructions. This motor activation indicates that instructions can lead to automatic response activations, an assumption that is at the core of accounts on instruction implementation. Finally, even without considering the different processes underlying the implementation of instructions, the present study offers a very strong proof about the power seemingly irrelevant instructions have on motor behavior.

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CHAPTER 4

CONGRUENCY EFFECTS ON THE BASIS OF INSTRUCTED RESPONSE-EFFECT CONTINGENCIES[1]

Previous research indicated that stimulus-response congruency effects can be obtained in one task (the diagnostic task) on the basis of the instructed stimulus-response mappings of another task (the inducer task) and this without having executed the instructions of the inducer task once. A common interpretation of such finding is that instructed stimulus-response mappings are implemented into functional associations, which automatically trigger responses when being irrelevant and this without any practice. The present study investigated whether instruction-based congruency effects are also observed for a different type of instructions than instructed S-R mappings, namely instructed response-effect contingencies. In three experiments, instruction-based congruency effects were observed in the diagnostic task when the instructions of the inducer task specified response-effect contingencies. On the one hand, our results indicate that instruction-based congruency effects are not restricted to instructed S-R mappings. On the other hand, our results suggest that the representations that mediate these effects do not specify the nature of the relation between response and effect even though this relation was explicitly specified by the instructions.

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[1] Based on Theeuwes, M., De Houwer, J., Eder, A., & Liefooghe, B. (in press). Congruency effects on the basis of instructed response-effect contingencies. *Acta psychologica.*

INTRODUCTION

Although instructions play a vital role in our daily life functioning, little is known about how instructions actually influence behavior. On the one hand, instructions can specify particular response strategies that participants could adopt when performing a particular task. Research in this context has demonstrated, for instance, that instructions specifying the intention to respond particularly fast on certain stimuli could result in the attenuation of automatic interference effects (e.g., Cohen, Bayer, Jaudas, & Gollwitzer, 2008; Miles & Proctor, 2008). On the other hand, instructions can also specify the stimulus-response (S-R) mappings of a task (for a review, see Meiran, Cole, & Braver, 2012). A substantial amount of research focusing on this type of instructions observed that instructed S-R mappings, which have never been executed before, can automatically bias performance when being irrelevant (e.g., Cohen-Kdoshay & Meiran, 2007, 2009; De Houwer, Beckers, Vandrope & Custers, 2005; Eder, 2011; Everaert, Theeuwes, Liefooghe, & De Houwer, 2014; Liefooghe, De Houwer and Wenke, 2013; Liefooghe, Wenke, & De Houwer, 2012; Meiran & Cohen-Kdoshay, 2012; Theeuwes, Liefooghe, & De Houwer, in press; Wenke, Gaschler,& Nattkemper, 2007; Wenke, Gaschler, Nattkemper, & Frensch, 2009; Meiran, Pereg, Kessler, Cole, &Braver, in press; Wenke, De Houwer, De Winne & Liefooghe, in press).

An example of a procedure that has been used for investigating an automatic influence of instructed S-R mappings is provided by Liefooghe et al. (2012). These authors presented participants with different runs of trials on which two tasks had to be performed which shared stimuli and responses: the inducer and the diagnostic task. At the start of each run participants received two novel arbitrary S-R mappings of the inducer task, each assigning a stimulus either to a left or a right response based on the identity of the stimulus (e.g., If ‘X’, press left; if ‘Y’, press right). Before executing the inducer task, several trials of the diagnostic task were performed, on which participants decided whether a stimulus was presented in italic or upright, again by pressing a left or right response key (e.g., upright, press left; italic, press right). After a number of trials of the diagnostic task, a probe stimulus of the inducer task was presented. Liefooghe et al. (2012) observed that performance in the diagnostic task, in terms of speed and sometimes in terms of accuracy, was better on responses that matched with the instructions of the inducer task (e.g., 'X' presented upright or '*Y*' presented in italic) than on responses that did not match with the S-R mappings of the inducer task (e.g., 'Y' presented upright or '*X*' presented in italic). Given that (1) the diagnostic task was performed immediately after the presentation of the instructions of the inducer task, thus prior to the application of these instructions and (2) the inducer task comprised novel S-R mappings on each run, the conclusion was drawn that the congruency effect observed in the diagnostic task was based on the instructed S-R mappings of the inducer task, which were never executed overtly before. Liefooghe et al. (2012, see also Meiran et al., 2012; Wenke et al., 2007) suggested that instruction-based congruency effects indicate that instructed S-R mappings are transformed into procedural associations during task preparation, which automatically trigger response activations when being irrelevant (see, Everaert et al. 2014; Meiran, Pereg, Kessler, Cole & Braver, in press).

Although instruction-based congruency effects have been observed many times in recent years, studies indicated that these effects are subject to several boundary conditions. For instance, instruction-based congruency effects disappear when working memory is taxed too heavily (Cohen-Kdoshay & Meiran, 2007, 2009; Meiran & Cohen-Kdoshay, 2012) and they are only observed when participants intend to apply the instructed S-R mappings (Liefooghe et al., 2012) and actively prepare themselves on the basis of these instructed S-R mappings (Liefooghe et al., 2013; Wenke et al., 2009). Although there is a steady increase in our insights about instruction-based congruency effects, research has focused exclusively on one specific type of instructed relationships, namely S-R mappings. Accordingly, the question arises whether similar effects can be observed on the basis of different types of instructions. The present study aims to make a first step in this direction by investigating to which extent instruction-based congruency effects can be obtained on the basis of instructions specifying the contingency between a particular response and the effect it elicits in the environment (i.e., Response-Effect or R-E contingencies).

Research on action-effect learning has provided strong evidence that congruency effects can be obtained on the basis of previously learned R-E contingencies (for a review see Shin, Proctor & Capaldi, 2010). For instance, Hommel (1996; Experiment 2) first subjected participants to a training phase in which pressing a response key once or twice resulted in the presentation of a left-sided tone or a right-sided tone, respectively. In a subsequent test phase, participants had to respond to the identity of a visual stimulus by pressing the response key once or twice. The left-right stimulus position varied randomly and was irrelevant. Hommel (1996; Experiment 2) observed faster responses when the visual stimulus position (e.g., left) matched with the auditory tone position (e.g., left) that was associated with the response required to the identity of the visual stimulus (e.g., a single key press). Grosjean and Mordkoff (2002) demonstrated that the Simon effect (Simon & Rudell, 1967), a congruency effect between the irrelevant left-right stimulus location and the left-right response location, could be modulated by presenting left-right post-response stimuli, which could either correspond to the response location or not. The Simon effect increased when congruent post-response stimuli were presented and decreased when incongruent post-response stimuli were presented.

Research on action effects is particularly relevant for research on cognitive control as it challenges strict forward models of information processing (e.g., Massaro 1990; Sanders 1980; Sternberg 1969; see Hommel, Müsseler, Aschersleben & Prinz, 2001 for an in depth discussion) by emphasizing the importance of the consequences or expected consequences of a particular action in the environment. Action effects are at the core of influential theories on cognitive control, such as the common coding theory (Prinz, 1990) and the theory of event coding (Hommel, 2009), which elaborate on the ideomotor principle (Herbart, 1825; Lotze, 1852). The ideomotor principle states that actions are activated on the basis of a representation of the effects these actions evoke in the environment. Experiencing an effect that is contingent upon the execution of an action leads to the formation of a bidirectional association between an action and the perceived effect. Based on this R-E association, the activation of the effect automatically leads to the activation of the associated response. Hommel (2009) proposed that a stimulus and a response are integrated into a functional association independently of the order in which the stimuli and responses are experienced (i.e., a stimulus before a response as in S-R contingencies or a stimulus after a response as in R-E contingencies). Within this view, congruency effects based on R-E contingencies are similar to congruency effects based on S-R contingencies (see also, Dutzi & Hommel, 2009; Elsner & Hommel, 2001; Hommel, 2005).

Of interest for the present purpose is a study of Hommel, Alfonso, and Fuentes (2003), which observed that action effects can generalize over words sharing semantic features. In an acquisition phase, the production of a particular response consistently resulted in the appearance of a particular word on the screen. In the test phase, participants responded to words that were semantically associated with the words that were presented as response effects in the acquisition phase. Performance was better when the response to the words in the test phase corresponded with the response preceding the semantically related word in the acquisition phase. This finding suggests that a congruency effect based on R-E contingencies can be obtained with stimuli that never co-occurred with a particular response in the acquisition phase, but that resemble stimuli that were part of a previously learned R-E contingency. Although the findings of Hommel et al. (2003) indicate that direct experience is not a prerequisite to observe R-E contingency effects, the question remains whether instructions about R-E contingencies are sufficient to produce congruency effects, as it is the case for instructed S-R mappings.

The present study offers a more stringent test of the question whether instruction-based congruency effects can be obtained on the basis of instructed R-E contingencies. As mentioned before, this is an important issue as it deals with the boundary conditions of the instruction-based congruency effect as a tool for understanding how instructions moderate behavior. At the same time, the observation of instruction-based congruency effects on the basis of instructed R-E contingencies can offer us additional insights on the nature of the type of representation that mediates these effects. Based on the proposal of Hommel (2009), the observation of an instruction-based congruency effect on the basis of instructed R-E contingencies may suggest that while the associations formed on the basis of instructions do include stimulus and response codes, they do not include a qualification of the particular relation between these codes (i.e., a particular effect is contingent upon a particular response), even though such relation is explicitly specified by the instructions. At the very least, the representation that mediates instruction-based congruency effects must allow for a backward activation of response representations upon the activation of effect representations. A bi-directional response-effect association seems a likely candidate for such a representation.

In order to test whether congruency effects could also be obtained on the basis of instructed R-E contingencies, we used a variant of the aforementioned procedure used by Liefooghe et al. (2012, 2013; see also Everaert et al., in press, and Theeuwes, et al., 2014). In a series of three experiments, the instructions of the inducer task specified R-E contingencies rather than S-R mappings. In Experiments 1 and 2, the inducer task consisted of a grid filled with two stimuli and participants had to remove (Experiment 1) or add (Experiment 2) a particular stimulus such that both stimuli were present an equal number of times in the grid. To this end, participants had to press a left or a right key, which led to the addition or removal of a particular stimulus. In other words, a particular response resulted in a particular effect, namely the addition or removal of a specific stimulus. We will refer to this stimulus as the *effect stimulus*. Each run of trials started with the presentation of two novel R-E contingencies, with each contingency relating a left or right response to a particular effect stimulus. After the presentation of the instructions of the inducer task, participants performed a diagnostic task as outlined above. Importantly, the effect stimuli described in the R-E contingencies of the inducer task were used as stimuli in the diagnostic task. On congruent diagnostic trials, the stimulus and the correct response were part of the same R-E contingency in the inducer task. On incongruent diagnostic trials, the stimulus required a response that was different from the one specified in the R-E contingency of the inducer task. As such, the difference between congruent and incongruent trials could be investigated as in the studies of Liefooghe et al. (2012, 2013), but it was now based on instructed R-E contingencies rather than on instructed S-R mappings. Because it is possible that participants in Experiments 1 and 2 reinterpreted the R-E contingencies as S-R mappings, a third experiment was conducted in which the inducer task was modified such that reinterpretation could not occur. In all three experiments, an instruction-based congruency effect was observed in the diagnostic task. In Experiment 1 the goal of the inducer task was to remove a particular stimulus from a grid filled with two types of stimuli, such that both types of stimuli was presented an equal number of times. To this end, participants were instructed with R-E contingencies, relating a response to an effect stimulus.

EXPERIMENT 1

In Experiment 1 the goal of the inducer task was to remove a particular stimulus from a grid filled with two types of stimuli, such that both types of stimuli was presented an equal number of times. To this end, participants were instructed with R-E contingencies, relating a response to an effect stimulus.

Method

Participants

Twenty-three students at Ghent University participated for a payment of 5 Euro. All participants had normal or corrected-to-normal vision and all were naive to the purpose of the experiment.

Materials

Experiment 1 consisted of different runs each containing two tasks (see Figure 1): the inducer task and the diagnostic task. In each run, both tasks used the same responses (‘A’- and the ‘P’-key on an AZERTY keyboard) and (effect) stimuli. For every run, a pair of effect stimuli was randomly selected from a list consisting of 56 symbols. The symbols used in Experiments 1 and 2 are: “A, B, C, D, E, F, G, H, I, J, K, M, N, O, P, Q, S, T, U, V, W, X, Y, Z, 1, 2, 3, 4, 5, 6, 7, 8, 9, &, L and §”. Each effect stimulus was only assigned once either to a left (‘A’-key) or right response (‘P’-key) in a random fashion. This way two novel instructed R-E contingencies were created for each run, for instance, “the left key removes P” and “the right key removes Q”. The 18 pairs of R-E contingencies were assigned to the three blocks of the experiment, with each block containing six runs of trials R-E contingency instructions were presented in Arial font, size 16 on the screen centre, one above the other. Whether an instructed R-E contingency appeared above or below the screen centre was determined randomly on each run.

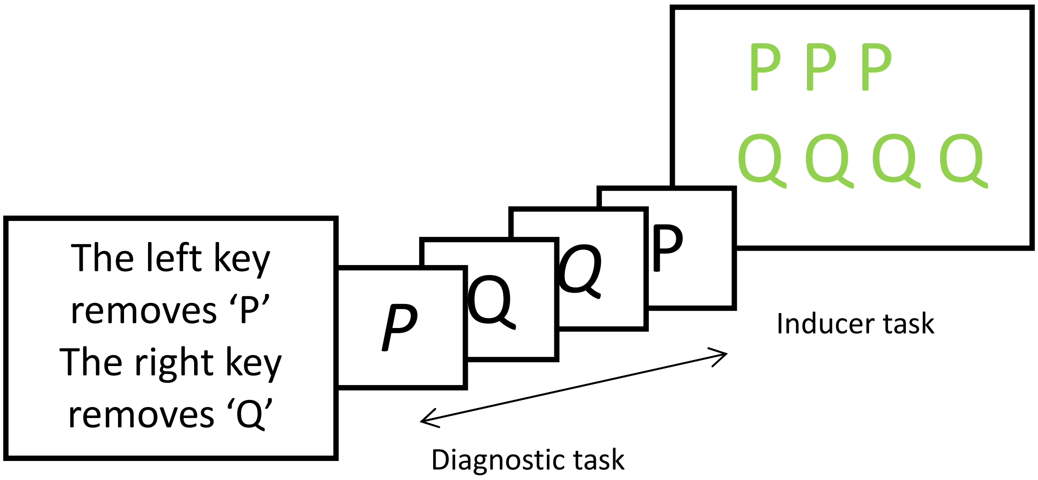

Figure 1. Overview procedure of Experiment 1.

The probe of the inducer task resembled a grid. This ‘grid’ contained the two effect stimuli instructed at the beginning of that run. One effect stimulus was presented four times on the grid. The other effect stimulus was presented three times (see Fig. 1 for an example). All effect stimuli were presented in in Arial font, size 24 resulting in a grid approximately 5cm wide and 3 cm high in the middle of the screen. Whether the most frequent effect stimulus was contingent upon the left or the right key was counterbalanced across runs.

In the diagnostic task participants judged whether a stimulus was printed upright or in italic by pressing the left or right key. The response mapping of this task was counterbalanced across participants. Stimuli in the diagnostic task were presented in Arial font, size 24. In each run, participants performed either 4, 8, or 16 trials of the diagnostic task. The number of diagnostic trials varied randomly across runs such that the onset of the probe of the inducer task was less predictable. This manipulation was intended to encourage participants to be constantly prepared to execute the inducer task (see Liefooghe et al., 2012). Each block consisted of two runs of each run-length. Half of the trials in the diagnostic task required a response that was in line with the R-E contingencies of the inducer task (i.e., congruent trials). On the other half, the response required by the diagnostic task mismatched with the R-E contingency (i.e., incongruent trials). Each run contained an equal number of congruent and incongruent diagnostic trials. The order of both trial types was random. Taken together, participants were presented with three blocks containing 6 runs of trials (2 runs of length 4, 2 runs of length 8, 2 runs of length 16). The first block was considered practice and not included into the analyses. Our design thus consisted of 112 diagnostic trials (56 congruent and 56 incongruent).

Procedure

Participants were tested individually by means of personal computers with a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Instructions were presented on the screen and paraphrased by the experimenter if necessary. The main instructions were followed by a practice block. During this block, participants were monitored and additional instructions were given if necessary. The practice block was followed by two test blocks. After every block there was a brief pause.

A run started with the presentation of the R-E contingencies for the inducer task (e.g., the left key removes ‘P’; the right key removes ‘Q’). These contingencies remained on screen until the participant pressed the spacebar or a maximum time of 20 seconds elapsed. The first trial of the diagnostic task started 750 ms after the removal of the R-E contingencies. The stimulus remained on screen until a response was provided or a response deadline (2000 ms) was exceeded. Incorrect responses were followed by a red screen for 200 ms, before the 750 ms inter-trial interval started. The probe of the inducer task was presented 750 ms after the last trial of the diagnostic task. The goal of the inducer task was to change the display in such a way that both effect-stimuli appeared an equal number of times. Hence, participants had to remove one of the effect-stimuli that was presented four times in the grid. For instance, if the letter P appeared four times in the grid and R-E contingency instructions stated that a P could be removed by pressing the left key, participants had to press the left key. The response deadline was 2000 ms. When participants pressed one of the two keys, the corresponding effect stimulus was removed from the grid. If participants removed the wrong effect stimulus an error message, the word 'FOUT' (wrong in Dutch) was displayed for 200ms. A new run started after 750ms. The experiment took about 20 minutes.

Results

The data of two participants were excluded from further analyses due to excessive error rates. The first excluded participant had an error rate of 50% in the inducer task. The second excluded participant had an error rate of 46% in the diagnostic task.

For the RT analysis, only correct trials of the diagnostic task were included (data loss: 6.5% of all trials). Trials with RTs longer than 2.5 SDs from a participant's mean cell RT were excluded (data loss: 2.6% of the total amount of correct trials). Mean RTs and the proportion of errors were each subjected to a repeated-measures ANOVA with instruction-based congruency (congruent, incongruent) as within-subjects factor.

There was a significant instruction-based congruency effect for the RTs, $F(1,20)=5.03$, $MSE=385$, $\eta_p^2=.20$, $p<.05$, with faster responses on congruent diagnostic trials (M = 532 ms; SD = 66 ms) than on incongruent diagnostic trials (M = 546 ms; SD = 65 ms). This effect was also significant for the proportion of errors, $F(1,20)=6.77$, $MSE=0.0012208$, $\eta_p^2=.25$, $p<.05$, with less errors made on congruent diagnostic trials (M =.05; SD = .04) than on incongruent diagnostic trials (*M* =.08; *SD* = .04). In the inducer task, the average RT was 1033 ms (*SD* = 307 ms) and the average error rate was .08 (*SD* = .27).

Discussion

We obtained a significant instruction-based congruency effect in the diagnostic task: response performance, both in terms of speed and accuracy, was better on congruent diagnostic trials compared to incongruent diagnostic trials. These findings indicate that instruction-based congruency can be obtained on the basis of R-E contingencies, as it is the case for S-R mappings. Nevertheless, a potential concern of Experiment 1 is that participants actually experienced the R-E contingencies during the diagnostic task. Congruent diagnostic trials unfolded in line with the sequence of events specified by the R-E contingencies of the inducer task: the presented stimulus disappeared in response to a key press which – according the R-E contingencies of the inducer task –would remove that stimulus in the inducer task. In contrast, for incongruent diagnostic trials, the stimulus that disappeared when pressing a key, was – according to the R-E contingencies of the inducer task – not the effect stimulus that should disappear when pressing that key. Consider, as an example, that participants are provided with the following R-E contingencies of the inducer task: “The left key removes P; The right key removes Q” and the instructions of the diagnostic task indicate that stimuli printed upright (e.g., P) should be responded to with a left-key press and stimuli printed in italic (e.g., P) should be responded to with a right-key press. On a congruent diagnostic trial, the stimulus ‘P’ could be presented upright and participants respond left following the instructions of the diagnostic task, which causes that stimulus to disappear, ending that diagnostic trial. This sequence of events coincides with the sequence of events specified by the R-E contingencies, namely, “The left key removes P.” On an incongruent diagnostic trial, the stimulus ‘P’ is presented, but now in italic. Following the instructions of the diagnostic task, a right key-press is required and the stimulus ‘P’, which will make that stimulus disappear, again indicating the end of the trial. The sequence of events experienced on these incongruent trials thus is at odds with the sequence of events specified by the R-E contingency, “The left key removes P.” The difference in performance between congruent and incongruent trials in the diagnostic task may thus not only be related to a match/mismatch between the response required in the diagnostic task and the R-E contingencies of the inducer task, but also to a difference in the sequence of events experienced in the diagnostic task and the sequence of events specified by the R-E contingencies of the inducer task. In order to rule out this alternative interpretation, a second experiment was conducted.

EXPERIMENT 2

Experiment 2 was identical to Experiment 1 for the exception that the goal of the inducer task was now to add an effect stimulus to obtain a balanced grid. The instructed R-E contingencies of the inducer task now specified that a particular key-press would make a particular effect stimulus appear on the screen (e.g., the left key produces ‘P’; the right key produces ‘Q’), rather than make it disappear. Accordingly, the sequence of events experienced in the diagnostic task did not coincide with the sequence of events specified by the R-E contingencies, and this both for the congruent and incongruent diagnostic trials. However, as in Experiment 1, the correct responses on congruent diagnostic trials corresponded with the R-E contingencies of the inducer task, while this was not the case for the correct responses on incongruent diagnostic trials. The question was whether the instruction-based congruency effects observed in Experiment 1 could be replicated under such conditions.

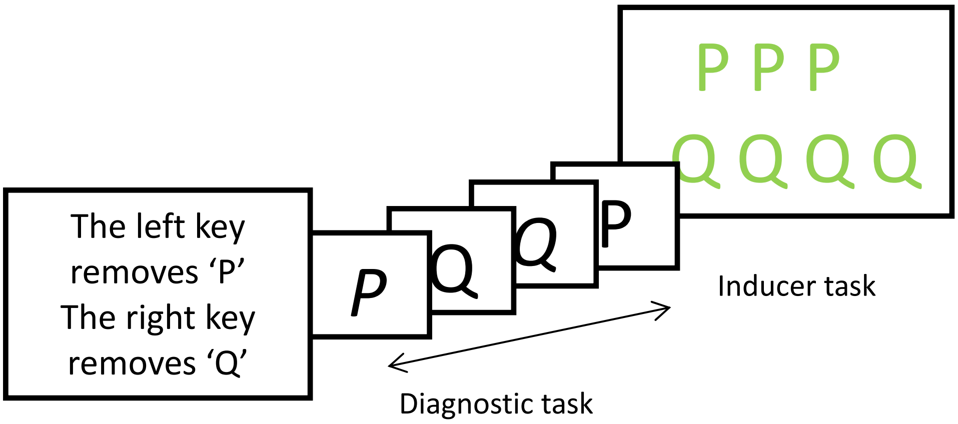

Figure 2. Overview procedure of Experiment 2.

Method

Twenty-one students at Ghent University participated for payment of 5 Euro. All participants had normal or corrected-to-normal vision and all were naive to the purpose of the experiment. Materials and procedure were identical to Experiment 1 with one exception. Instead of removing an effect stimulus in the inducer task, participants were now instructed to add an effect stimulus to balance the grid (see Figure 2). Instructed R-E contingencies (e.g., the left key produces ‘Q’; the right key produces a ‘P’) and error feedback were adapted accordingly. If participants made the correct response, the corresponding effect stimulus now appeared on the empty grid space.

Results

The data of one participant with an error rate of 42% in the inducer task were excluded from further analyses. For the RT analysis, the same exclusion criteria as in Experiment 1 were used (data loss errors: 6.2% of all trials; data loss RTs longer than 2.5 SDs from a participant’s mean cell RT: 2.5% of the total amount of correct trials).

There was a significant instruction-based congruency effect for the RTs, $F(1,19) = 14.21$, $MSE = 2070$, $\eta_p^2=.43$, $p<.01$, with faster responses on congruent diagnostic trials ($M= 634$ ms; $SD = 131$ ms) than on incongruent diagnostic trials ($M =667$ ms; $SD = 134$ ms). There was no difference between congruent ($M =.06$; $SD =.05$) and incongruent diagnostic trials ($M =.07$; $SD =.06$) trials in the proportion of errors, $F < 1$. In the inducer task, the average RT was 1050 ms (SD =290ms) and there was an average error rate of .11 ($SD = .34$).

Discussion

Experiment 2 controlled for a confound between instruction-based congruency and the (mis)match of the sequence of events experienced in the diagnostic task and the sequence of events specified by the R-E contingencies of the inducer task. To this end, the R-E contingencies indicated that key-presses would result into the appearance of an effect stimulus, rather than to the removal of an effect stimulus. Nevertheless, the results of Experiment 2 were partly in line with the results of Experiment 1: responses on congruent diagnostic trials were faster than on incongruent diagnostic trials, indicating an instruction-based congruency effect on the basis of R-E contingencies. In contrast to Experiment 1, the error rates did not indicate the presence of an instruction-based congruency effect. It should be noted, however, that previous research using a similar procedure did also not consistently observe instruction-based congruency effects in the error rates (see Everaert et al., 2014; Liefooghe et al., 2012, 2013). The reason for this is most probably that error rates in the diagnostic task are generally very low and lacking in variance.

Taken together, the results of Experiments 1 and 2 seem to offer a convincing demonstration that instruction-based congruency effects can be obtained on the basis of R-E contingencies. Nevertheless, a crucial difference between the current study and previous research on action effects, is that in the current study the participants were required to actively implement the instructed R-E contingencies. Whereas this contingency was irrelevant in the diagnostic task, it was relevant for performing the inducer task. This contrasts with most research on action effects in which the acquired R-E contingency is never relevant (e.g., Elsner & Hommel, 2001; Hoffman, Sebald, & Stöcker, 2001; Ziessler, 1998). Because the instructed R-E contingencies were relevant in the inducer task it is possible that participants adopted specific strategies with respect to the way in which the R-E contingencies of the inducer task were interpreted. Until now, we assumed that participants interpreted the R-E contingencies of the inducer task as intended, with the stimulus being considered as an effect of a particular response. Alternatively, it could be that participants interpreted the R-E contingencies as S-R contingencies. In view of the goal to balance the number of stimuli in the probe grid of the inducer task, participants first had to infer the identity of the stimulus that had to be removed (Experiment 1) or added (Experiment 2). For instance, when presented with a grid containing four times ‘Z’ and three times ‘Q’ in Experiment 2, participants had to infer that the stimulus ‘Q’ had to be added. In other words, the identity of the stimuli in the grid was of importance in order to decide which key to press.

As a result, participants may have reinterpreted R-E contingencies, such as, “the left key produces P; the right key produces Q”, as S-R mappings, such as “For P, press left key, For Q, press right key.” In other words, participants may have considered the stimuli not as effects of a particular response, but as stimuli to which a particular response had to be made. In short, it is possible that the instruction-based congruency effects observed in Experiments 1 and 2 is based on a re-interpretation of R-E contingencies as S-R mappings. It should be noted, however, that we discouraged such a strategy because in order to perform the inducer task correctly these S-R mappings were not sufficient. Only when additional internally generated rules were kept active in memory, such as ‘react to the stimulus that is presented the least’ (Experiment 2), these S-R mappings were correct. Since it is likely that both reconsidering the instructed R-E contingencies and maintaining additional task rules is effortful, we doubt that participants were motivated to pursue such a complex strategy. Alternatively, participants could have formulated more complex S-R mapping rules for the inducer task. In Experiment 2, for example, such S-R mappings could have been “if two P’s are presented, press left; if two Q’s are presented, press right” or “If there are less P’s than Q’s presented, press left; if there are less Q’s than P’s presented, press right”. In both cases, however, these formulated S-R mappings did not match the events in the diagnostic task in which only one effect stimulus was presented. As a consequence, no response compatibility effect should have been observed. Nevertheless, although we doubt that participants pursued a ‘reinterpretation strategy’ in Experiments 1 and 2, we cannot exclude that such strategy may have contributed to the results obtained in these experiments. We therefore conducted a third experiment for which the reinterpretation of R-E contingencies into S-R contingencies was even less likely.

EXPERIMENT 3

In Experiment 3, a reinterpretation of R-E contingencies as S-R mappings was discouraged by changing the demands of the inducer task in such a way that participants would consistently consider the effect stimuli in every R-E contingency as an effect of a particular response and not as a target to which that response had to be made. In order to do so, novel R-E contingencies of the inducer task were instructed at the beginning of each run, such as “if you press left, ‘P’ appears; if you press right, ‘Q’ appears”. As in the previous experiments, these instructions were followed by a number of trials of the diagnostic task. Finally, the probe of the inducer task started. In this task, the word LEFT or the word RIGHT was presented and participants had to press the left or the right key accordingly. The response to these words resulted in the appearance of an effect stimulus. On half of the runs, the contingency between the produced response and the presented effect stimulus matched with the instructed R-E contingencies (e.g., a left key-press followed by a P) and on the other half of the runs it did not (e.g., a left key-press followed by a Q). Participants had to evaluate as quickly as possible whether the contingencies matched by using a separate set of responses. In short, the responses of the R-E contingencies were made in response to the words LEFT and RIGHT, which thus functioned as target stimuli in this task. In contrast, the effect stimuli never had to be responded to by using the responses described in the R-E contingencies. Reinterpreting the R-E contingencies as S-R mappings thus was unnecessary for Experiment 3.

It should be noted that the inducer task in this experiment requires participants to recall the instructed R-E contingencies. When using instructed S-R mappings, Liefooghe et al. (2012) did not observe instruction-based congruency effects when participants had to recall instructed S-R mappings without having to apply them to a particular stimulus (i.e., when participants had to recognize verbally or visually presented S-R mappings or had to repeat the instructions aloud when a probe was presented). These null effects may suggest that the manipulation used in Experiment 3 is not effective to produce an instruction-based congruency effect. However, a follow-up study by Liefooghe et al. (2013), which demonstrated that a stringent preparation demand is a key prerequisite to observe instruction-based congruency effects. Of most importance to our study were the results of Experiment 2 of Liefooghe et al. (2013) in which an instruction based congruency effect could only be observed with a short response deadline (1500ms) and not when there was a long response deadline (5000ms). Based on these findings we reasoned that the recall conditions used in the study of Liefooghe et al. (2012) may have been too lenient in the sense that participants might not have been encouraged enough to represent the instructed S-R mappings in such a way that instruction-based congruency effects could be observed in the diagnostic task. Accordingly, stringent task demands were imposed on the inducer task of Experiment 3. More specifically, similar to Liefooghe et al. (2013; Experiment 2) participants were encouraged to respond very fast by imposing a strict time window. Moreover, participants were motivated to respond accurately by earning and losing points depending on their response performance.

Method

Twenty-six right-handed students at Ghent University participated for payment of 5 Euros. All participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment. The symbols used in Experiment 3 are: “A, B, C, D, E, F, G, H,I, J, K, M, N, O, P, Q, S, T, U, V, W, X, Y, Z, 1, 2, 3, 4, 5, 6, 7, 8, 9, &, L, §, !, $, à, µ, £, R, {, }, [,], è, ç, ?, ù, :, é, ;,), (and 0”. The diagnostic task was identical to the previous experiments. The inducer task was changed in several ways. First, the R-E contingency instructions now merely indicated that a particular key-press would be followed by a particular effect stimulus (e.g., if the left key is pressed, ‘P’ appears; if the right key is pressed, ‘Q’ appears). Second, the goal of the inducer task was adapted. Participants were now asked to evaluate the correctness of a R-E sequence.

The inducer task started with the presentation of the target word LINKS or RECHTS (the Dutch words for ‘left’ and ‘right’ respectively). Participants responded to the word by pressing the left or the right key, respectively. If either a response deadline of 1500 ms was exceeded or an incorrect response was made, the message ‘press left/right’ appeared above the cue until participants pressed the correct key. Immediately after participants pressed the correct key an effect stimulus appeared and stayed visible for 750ms. Fifty ms after the onset of the effect stimulus the words JA (‘yes’ in Dutch) and NEE (‘no’ in Dutch) appeared above and below the effect stimulus, with JA always above and NEE always below. Participants were asked to evaluate whether the effect stimulus following the response was in line with the instructed R-E contingencies. In half of the runs, the effect stimulus that followed the response was in line with the instructed R-E contingencies. In the other half of the runs, two types of mistakes were included on an equal number of runs. First, the response was followed by the effect to which the other response was linked in the instructions. Second, the incorrect effect stimulus was a new stimulus that had not been previously linked to a response. These ‘new’ effect stimuli were presented to encourage participants to encode both R-E contingencies presented at the beginning of each run.

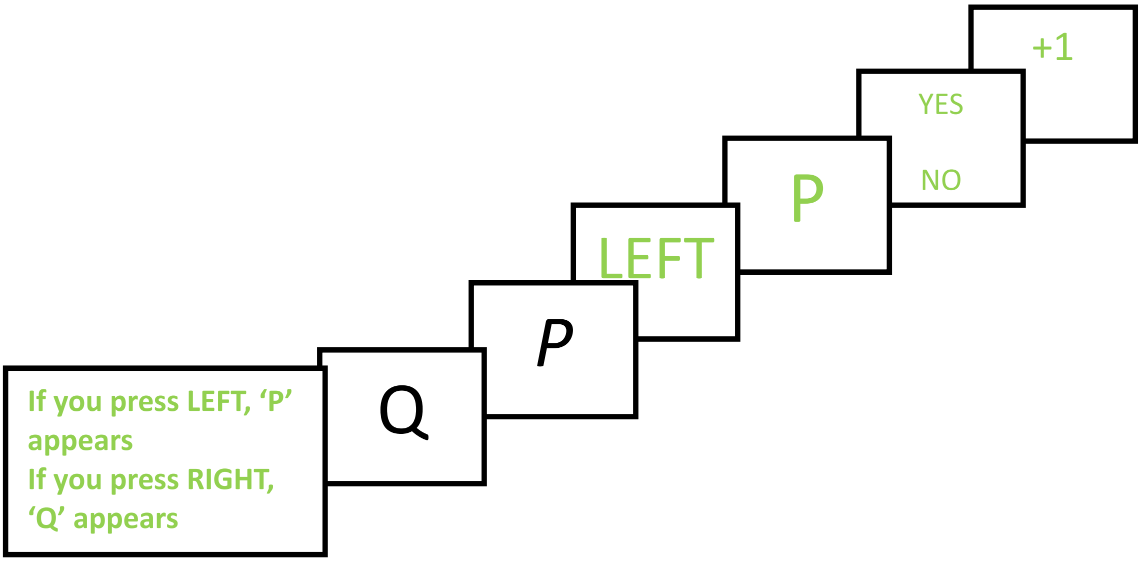

Figure 3. Overview procedure of Experiment 3.

Responses for evaluating the R-E contingency, were made with the middle finger and the thumb of the right hand by using the ‘)’-key and ‘;’-key respectively, on an AZERTY keyboard. Response mappings were identical for all participants: a ‘yes’-response was made with middle finger and a ‘no’-response was made with the thumb. The response deadline was 1500 ms.

Participants were rewarded for a good performance and punished for a bad performance in the inducer task. When both the left/right response to the target word and the yes/no response were correct, participants received one point. If one of both responses was incorrect, a point was subtracted. Feedback concerning the points was presented 50ms after the yes/no response for 750ms. On the top of the screen the point earned or lost during that run was displayed. The total number of points was presented at the bottom of the screen. If the total number of points was positive it was presented in green, otherwise it was presented in red. Finally, because of the complexity of the inducer task an additional practice block was performed at the start of the experiment . This practice blocks consisted of 6 runs. After this practice block there was one practice block with both tasks followed by two test blocks (see the procedures of Experiments 1 and 2). The number of runs and trials during these blocks were identical to Experiment 1 and 2.

Results

The data of three participants who made more than 58% of errors in the inducer task were excluded from further analysis. For the RT analysis, the same exclusion criteria were used as in the previous experiments (data loss errors: 8.6% of all trials; data loss RTs longer than 2.5 SDs from a participant's mean cell RT: 2.7% of the total amount of correct trials).

There was a significant instruction-based congruency effect for the RTs, $F(1,22)=4.70$, $MSE=658$, $\eta_p^2=.18$, $p<.05$, with faster responses on congruent diagnostic trials (M =552 ms; SD = 73 ms) than on incongruent diagnostic trials (M =569 ms; SD = 69 ms). There was also a significant instruction-based congruency effect for the proportion of errors, $F(1,22) = 5.99$, $MSE = .001110$, $\eta_p^2=.21$, $p<.05$, with less errors made on congruent diagnostic trials (M = .07; SD = .05) than on incongruent diagnostic trials (M = .10; SD =.07) trials. In the inducer task, the average RT to the target word was 855 ms (SD =230 ms) and there was an average error rate of .07 (SD = .26). The yes/no response had an average RT of 466 ms (SD= 319) and an error rate of M = .14 (SD = .34). The RTs were measured from the onset of the Yes/No screen.

Discussion

In Experiment 3, the inducer task was adapted in such a way that reinterpreting the instructed R-E contingencies as S-R mappings was completely redundant in order to perform the inducer task. Despite these changes in the task procedures, an instruction-based congruency effect was observed in the diagnostic task, corroborating the results of the previous experiments. Both in terms of response speed and accuracy, performance was superior on congruent diagnostic trials compared to incongruent diagnostic trials. This result confirms the conclusion that instruction-based congruency effects can be obtained on the basis of instructed and actively prepared R-E contingencies.

GENERAL DISCUSSION

The present study investigated whether instruction-based congruency effects could be obtained on the basis of instructed R-E contingencies. To this end, we adapted the procedure used by Liefooghe et al. (2012, 2013; see also Everaert et al., 2014; Theeuwes et al., 2014) in such a way that the instructions of the inducer task now included R-E contingencies rather than S-R mappings. In three experiments, we observed an instruction-based congruency effect in the diagnostic task. It is concluded that instruction-based congruency effects are not only obtained with instructions of S-R mappings but also with instructions of R-E contingencies. The present findings thus indicate that instruction-based congruency effects can be possibly observed on the basis of different types of instructions.

The observation of instruction-based congruency effects on the basis of instructed R-E contingencies suggests that the associations formed on the basis of instructions relate stimulus and response codes, without qualifying the type of relation these codes have. Although the present study did not directly test whether instructed S-R mappings lead to similar unqualified associations, the proposals of Hommel (2009) may lead to the conclusion that this is indeed the case and that associations formed on the basis of instructed R-E contingencies and associations formed on the basis of instructed S-R mappings are similar. An important difference between the present study and previous research on R-E contingencies is that the R-E contingencies of the inducer task are explicitly instructed. In contrast, the congruency effects in previous studies are typically based on contingencies that are experienced between task-relevant responses and task-irrelevant effects and this without explicit instruction of these contingencies (e.g., Elsner & Hommel, 2001). While associations that are unqualified for experienced R-E contingencies may be the result of participants not being explicitly aware of the particular relation these contingencies include, our data suggest that these associations are still unqualified when this relation is explicitly instructed by instructions. Alternatively, it is possible that relational information is encoded in a representation that mediates both experience-based and instruction-based R-E congruency effects but that this propositional representation can operate irrespective of this information (De Houwer, 2014). In other words, it is possible that participants do encode that a response produces an effect (i.e., store a qualified association), but that the presentation of the effect can still result in the retrieval of information about the response without any impact of information about the relation between response and effect (i.e., “produces”). In either case, our results demonstrate that congruency effects based on R-E contingencies are mediated by representations that allow for a backward activation of responses by effects, even when the information about the relation between response and effect is provided explicitly.

In view of research on experienced-based R-E contingencies, the question can also be addressed whether merely instructed R-E contingencies for which the effects are irrelevant for the inducer task, can also lead to instruction-based congruency effects. We have two reasons to believe that instruction-based congruency effects will not arise under those conditions. First, unpublished experiments in our lab indicated that participants do not seem to implement parts of the instructions that are completely irrelevant for performing the inducer task, such as an irrelevant stimulus feature. Second, Liefooghe et al. (2013) demonstrated that participants need to actively prepare for the inducer task in order to observe instruction-based congruency effects, which suggests that instructions are implemented into functional associations only when a stringent demand to do so is imposed (see also, Wenke et al., 2009). In other words, instruction-based congruency is a by-product of task preparation and will thus only extend to information (stimuli, responses, effects) that is needed to prepare and perform a task. This contrasts with experienced-based congruency effects, which have been observed independently of the demand of actively implementing information (see e.g., Yamaguchi & Proctor, 2011, for an example in the context of the task-rule congruency effect). The main distinction between instruction-based and experienced-based congruency effects thus appears to be that instruction-based congruency effects require the active involvement of working memory (see, Liefooghe et al., 2012, 2013; Meiran et al., 2012), while experience-based congruency effects could also be mediated by associations which have already been established in long-term memory (e.g., Hommel, 2005; Meiran & Kessler, 2008, but see Ansorge & Wühr, 2004). Hence, experience-based congruency effects do not require active preparation and can result also from the incidental learning of contingencies that involve task-irrelevant information.

The present study also produced some additional results that are interesting with respect to our understanding of how and when instructions bias performance. First, our results suggest that instruction-based congruency effects can be obtained across tasks that overlap to a lesser degree than was the case in the initial procedures that were used to investigate instruction-based congruency effects. For instance, in the procedure used by Liefooghe et al. (2012, 2013) the goals of the inducer and the diagnostic task were highly comparable, namely judging stimulus identity by pressing a left or right key in the inducer task and judging stimulus orientation of the same stimuli by pressing the same left or right key in the diagnostic task. As Meiran et al. (2012) has pointed out, the effects obtained with such procedures may result from a similarity between the inducer and the diagnostic task, which could trigger participants to inadvertently apply the instructed S-R mappings of the inducer task to the diagnostic task. On the basis of instance theories of automaticity (e.g., Logan, 1988), it could be hypothesized that even a single (erroneously) execution of the instructions of the inducer task during the diagnostic task is sufficient to form S-R associations that bias performance in the diagnostic task. In other words, congruency effects in the diagnostic task may not be based on associations solely formed on the basis of instructions but on associations formed on the basis of actual execution of instructions of the inducer task in the diagnostic task. In the present study, the instructions of the inducer task consisted of R-E contingencies, which were less likely to be erroneously applied to the diagnostic task, as both tasks had very distinct task goals. Yet, as we have discussed before, participants may have reinterpreted the instructed R-E contingencies as S-R mappings in Experiments 1 and 2. A reinterpretation strategy is however implausible for Experiment 3 in which an instruction-based congruency effect was still obtained when participants had only to detect (mis)matches between instructed and experienced R-E contingencies in a modified inducer task. The results of the present study and in particular the results of Experiment 3, thus suggest that instruction-based congruency effects are observed even when the chance of misapplying the instructions of the inducer task to the diagnostic task is minimal.

A second interesting observation in the present study is that the average response speed in Experiment 2 (*M* = 650, *SD* = 133) was slower than in Experiment 1 (*M* = 539, *SD* = 65). This increase in RTs could be related to the fact that in Experiment 2 the sequence of events specified by the R-E contingencies of the inducer task (adding a missing letter) was at odds with the sequence of event shown in the diagnostic task (removal of a stimulus with a button press). This difference is noteworthy, because it may indicate an additional way in which instructions can influence behavior at a time at which those instructions are irrelevant. The difference between Experiments 1 and 2 could suggest that instructions about the sequence of events in one task (the inducer task) can elicit expectancies about the sequence of events in a related task (the diagnostic task). Such finding again indicates that instructions can influence behavior in more than one way.

A final side-note relates to Experiment 3. The results of Experiment 3 indicate that maintaining instructions for future recall may be sufficient to elicit an instruction-based congruency effect but only under very stringent conditions.

This finding is in line with the proposals by Liefooghe et al. (2013), who suggested that instruction-based congruency effects depend on the amount of preparation to execute the inducer task. Experiment 3 suggests that the degree by which participants are prepared with respect to the inducer task is of importance to find instruction-based congruency effects not only when the inducer task requires the application of instructions, but also when the inducer task requires the mere recall of instructions. Clearly, this issue is beyond the scope of the present study and will require additional research.

In summary, contrary to previous studies, who mainly focused on S-R mappings, the present study offered first insights into the implementation of a different type of instructions, namely R-E contingencies. The obtained results suggest that instruction-based congruency effect can be obtained on the basis instructed R-E contingencies. Based on these results, we propose that the implementation of instructions results in a representation that allows for the backward of activation of response representations. Importantly, such representation is formed even though instructions explicitly specified a particular relation. Such finding may suggest that the implementation of the different types instructions, such as S-R mappings or R-E contingencies, may result in similar functional representations, which include bi-directional associations. It becomes clear that future research on instruction implementation, will also need to focus on the communalities and differences between the types of instructions that are implemented.

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RESEARCH LINE 2

THE EFFECT OF PRACTICING NOVEL INSTRUCTIONS

CHAPTER 5

MENTALLY AND PHYSICALLY PRACTICING NOVEL INSTRUCTION: HOW DOES IT HELP?[1]

Recent research proposed that the physical practice of novel instructions leads to a shift in processing mode from controlled processing toward more automatic processing. This shift in processing mode supposedly reflects the formation of a fine-grained task representation, which includes task parameters needed to attain skilled task execution, and this on the basis of an initial representation of the task instructions. The present study investigated to which extent mental practice can also lead to such a shift in processing mode. A procedure was developed, which permitted measurement of the improvement of central processes, such as response selection, and the improvement of peripheral processes involved in response execution. Our results suggest that whereas physical practice improves central and peripheral processes, mental practice only improves central processes. We propose that mental practice can also lead to a shift in processing mode and to the formation of a task representation, albeit a less detailed one as compared to the task representation that is formed on the basis of physical practice

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[1] Based on Theeuwes, M., Liefooghe, B., De Schryver, M., & De Houwer, J. (in preparation). Mentally and physically practicing novel instructions: How does it help?

INTRODUCTION

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 it offers 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., Ramamoorthy & Verguts, 2012). An increasing amount of research suggests that novel instructions, such as Stimulus-Response (S-R) mappings, can very rapidly be implemented into a procedural representation, which underlies the initial performance on a novel task (e.g., De Houwer, Beckers, Vandorpe, & Custers, 2005; Liefooghe, Wenke, De Houwer, 2012; Cohen-Kdoshay & Meiran, 2007, 2009; Wenke, Gaschler, & Nattkemper, 2007).

Daily life functioning, however, is not uniquely based on the implementation of instructions alone. Most often, novel instructions will be 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). Research suggests that the application of novel instructions, such as S-R mappings, is based initially on controlled processes, which are involved in the maintenance and application of the initial representation formed on the basis of instructions (e.g., Liefooghe et al., 2012; Meiran, Cole & Braver, 2012). Ruge and Wolfensteller (2010) propose that this initial representation includes only conceptual stimulus and response codes (see also Liefooghe et al., 2012; Wenke et al., 2007, for similar conclusions). It is assumed that PP leads to the formation of a more fine-grained representation, which includes different parameters driving the skilled execution of a task. Once this second representation is formed, it takes over control in a relatively automatic fashion (Ramamoorthy & Verguts, 2012). In other words, PP leads to a shift in processing mode from controlled processing toward more automatic processing. Such shift in processing mode results in a performance improvement. This improvement can be observed at the level of central processes, such as response selection (e.g., Pashler & Baylis, 1991), but also at the level of peripheral processes, involved in the execution of complex motor responses (e.g., Smith & Collins, 2004).

Although PP is an important factor underlying skill acquisition, practice does not necessarily need to be overt. In some cases, people engage in a more covert modus of practice, which is often referred to as mental practice (MP). MP has received much attention in the past decades (see Guillot & Collet, 2008; Schuster et al., 2011; van Meer & Theunissen, 2009 for reviews). Richardson (1967, p. 95) defines MP as "the symbolic rehearsal of a physical activity in the absence of any gross muscular movements". Thus, MP is based mainly on the mental simulation of an action under conditions in which the actual execution of that action is minimal or absent. While effects of MP on simple tasks are limited or even absent (e.g., Ryan & Simons, 1981,1983; Smith & Collins, 2004, but see e.g., Gentili, Papaxantihis & Pollo, 2006), beneficial effects of MP have been observed in the acquisition of complex skills, such as reading (e.g., Glenberg, Gutierrez, Levin, Japuntich & Kaschak, 2004), 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). Research on such complex activities indicated that whereas PP improves both cognitive and motor processes, MP mainly modulates cognitive processes (e.g., Ryan & Simons, 1981).

Although MP has been investigated in different types of skill acquisition, to our knowledge, the effects of MP on the execution of novel instructions remains to be determined. The question thus becomes to which extent MP can lead to a quick shift in processing mode and the performance improvement this entails. In order to investigate this issue, the present study compared performance after merely implementing newly instructed S-R mappings, performance after the implementation of novel S-R mappings complemented with PP, and performance after the implementation of novel S-R mappings complemented with MP. Such endeavor is of importance, as it can uncover the role of MP in the very early stages of skill acquisition, namely when novel instructions have to be implemented.

In order to ensure observable modulations of performance by both PP and MP, we used complex S-R mappings in which a stimulus was assigned to a sequence of letters that had to be typed on a keyboard (e.g., “if you see the picture of a bridge, press the sequence a-z-e on the keyboard”). The use of such complex response sequences offers the possibility to dissociate between markers of processes related to response selection and markers of processes related to response execution (e.g., Fendrich, Healy & Bourne, 1991; Nissen & Bullemer, 1987; Verwey, 1999). More precisely, performance on the first response of a response sequence is considered as a proxy of processes not only related to the execution of that first response but also of processes related to the selection and retrieval of the whole sequence of responses. In contrast, performance on the subsequent response is supposed to offer an estimation of the time needed for the motor system to carry out responses of a sequence that is already retrieved.

Our procedure was composed of different runs of trials each consisting of a training and a test phase. Each run started with the presentation of two novel S-R mappings, followed by a training phase. After the training phase, the instructions were re-presented, and this was followed by the test phase. In the test phase, each S-R mapping was probed only once. The nature of the training phase varied depending on the condition participants were assigned to. In the PP condition, participants practiced each S-R mapping for ten trials. On each trial, a stimulus was presented and the corresponding response sequence had to be typed. Importantly, a home-key was used, namely the spacebar of the keyboard. Between each typing response, participants had to place their typing-finger back on the home-key. In the MP condition, the same sequence of events occurred, but participants were instructed to mentally imagine that they typed a response, without actually performing that response. They were asked to take their typing-finger off the home-key, imagine to type the required letter and place their typing-finger back on the home-key after the imaginary movement was completed. The use of inter home-key intervals permitted us to compare the time needed to perform imagined and actual typing movements in the training phase (see, Rieger, Martinez & Wenke, 2011, for a similar procedure). Finally, concerned by previous reports suggesting that participants may not engage in MP (Shanks & Cameron, 2000), a manipulation check was added in the PP and MP condition. Namely, a run could either include a response sequence comprising responses that were physically close to the home-key (i.e., close sequences) or responses that were located further away from the home-key (i.e., distant sequences). Given that the time to physically and mentally execute an action are similar (Guillot & Collet, 2005), observing a difference in inter home-key intervals between close and distant sequences in the MP condition offered an indication that participants were involved in MP during the training phase as was intended by our experiment.

The PP and MP conditions were compared with a no practice (NP) condition, in which no practice was possible in the training phase. In the NP condition, only partial S-R mappings were instructed at the beginning of the run (e.g., if “bunny”, press ?-?-?). Participants thus were only given the relevant stimuli. In line with the PP and MP condition, the “training” phase in the NP condition consisted of recurrent presentations of the stimuli at which and participants were asked to press the home-key three times in a row before the next stimulus could appear. In other words, in the NP condition participants experienced the same sequence of events as in the PP and MP condition, but without having any knowledge about the actual S-R mappings. The actual S-R mappings in NP condition were provided at the onset of the test phase.

Based on previous research on the impact of PP and MP, we hypothesized that if PP leads to the improvement of central en peripheral processes (Driskell, Copper, & Moran, 1994), then - when presented with newly instructed S-R mappings - response-selection performance (i.e., performance on the first response of a response sequence) and response-execution performance (i.e., average performance on the subsequent responses of a response sequence) should be improved in the test phase of the PP condition compared to the test phase of the NP condition. Furthermore, if MP only improves central processes and not peripheral processes (Driskell et al., 1994), then the test phases of the NP and MP conditions should only differ with respect to response-selection performance and not with respect to response-execution performance.

METHOD

Participants and Design

Twenty-four students at Ghent University participated for course requirements or payment of 20 EURO. Participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment. All participants performed the NP, PP, and MP condition sequentially in three different blocks. On each run, one S-R mapping comprising a close response sequence and one S-R mapping comprising a distant response sequence was presented. In sum, a 3 (condition: PP, MP, NP) by 2 (phase: Training, Test) by 2 (sequence: close, distant) repeated measures design was used.

Materials

Pictures were selected from the Snodgrass and Vanderwart (1980) picture set. Based on the Dutch-naming ratings of these pictures by Severens, Van Lommel, Ratinckx, and Hartsuiker (2005), 186 pictures were selected with the highest naming-agreement ratings, that depicted an object or an animal with a name with maximal six letters. The stimulus names are presented in the Appendix . Based on this stimulus set, 93 pairs of S-R mappings were created. In each pair, one S-R mapping related a stimulus to a distant response sequence. The other S-R mapping related the other stimulus to a close response sequence. Responses were registered by using an AZERTY keyboard. The distant response sequence consisted of a combination of letters (a, z, e, r, t, y, and u) that were physically distant from the spacebar, which served as the home-key. The close response sequence was a combination of letters that was physically close (w, x, c, v, b, n, and f) to the spacebar. Each response sequence always consisted of three randomly selected letters of the corresponding letter subset and were used only during one run of the Experiment. An illustration of the difference between close and distant response sequences is provided in Figure 1a.

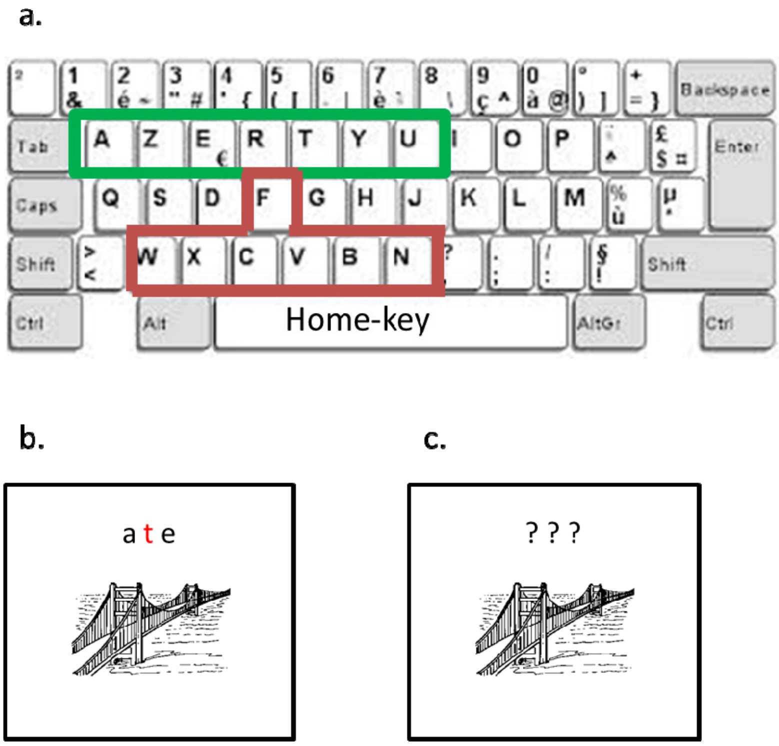

Figure 1. a. Visualization manipulation of typing distances relative to the home-key. Letters in the green area were used for the distant sequences. Letters in the red area were used for the short sequences. b. Example of the display during the test phase and the PP practice phase. c. Example of the display during the NP practice phase.

These 93 pairs of S-R mappings were randomly assigned to the PP, MP, and NP condition. Within each condition, one pair was used for familiarization and the remaining 30 pairs were used for actual measurement. The names of objects and animals were used in S-R mappings that were instructed at the beginning of each run. The corresponding object/animal pictures were used as stimuli in the training and test phase of each run.

In the PP and MP condition, a run started with the presentation of two S-R mappings, followed by a 20-trial long training phase. After the training phase, the instructions were presented for a second time. This was followed by a two-trial test phase. In the training phase of the PP condition, each instructed S-R mapping was physically practiced for 10 times in a random order. On each trial, a picture appeared on the screen and the corresponding letter sequence had to be entered on the keyboard. At the onset of a response sequence, participants were required to keep the spacebar pressed down. They released the spacebar to press the first response-key press and pressed the spacebar afterward. This was repeated for the second and the third response-key press. For instance, when required to enter the sequence a-z-e, participants first released the spacebar, pressed the ‘a’, pressed the spacebar, pressed the ‘z’, pressed spacebar, pressed the ‘e’, and pressed the spacebar. Participants were instructed to press down the spacebar until the next trial. When pressing a letter-key, the corresponding letter appeared on the screen (see Figure 1b). If the letter was correct, it was displayed in black, otherwise it appeared in red. After an incorrect response sequence, the message ‘FOUT’ (wrong in Dutch) was presented, accompanied by the correct response sequence for 500ms. The test phase in the PP condition was identical to the training phase, but now each S-R mapping was probed only once, resulting in a test phase of two randomly ordered trials.

The sequence of events was similar in the MP condition. In the training phase, participants were asked to use the home-key but to enter each letter mentally without actually pressing the corresponding letter-keys. In other words, when required to enter the response sequence a-z-e mentally, participants released the spacebar, imagined that they pressed the ‘a’, pressed the spacebar, imagined that they pressed the ‘z’, pressed the spacebar, imagined that they pressed the ‘e’, and pressed the spacebar again. When a letter-key was pressed physically, an error message was presented saying “do not press the keys”. In order to maximize the similarity with the PP condition, pressing the spacebar resulted in the appearance of the letter that was supposedly entered following the instructions. This way, participants could evaluate their mentally performed movement and a similar degree of feedback was provided in the PP and MP conditions. After the training phase, the instructions were presented a second time, followed by the test phase. In the test phase, participants entered the letter-keys physically as in the PP condition.

In the 20-trial long training phase of the NP condition, no response sequence was instructed at the onset of a run. The letters of the response sequence were replaced by question marks (e.g., if ‘bridge’ press ?-?-?) as placeholders on the S-R mapping instruction screen. Participants were just instructed to press the home-key three times each time a stimulus appeared. This resulted in the appearance of three question marks on the screen (see Figure 1c). After the training phase, the complete S-R mappings were provided (e.g., if ‘bridge’ press a-z-e). This was followed by the test phase, which was the same as in the PP and MP conditions.

The S-R mapping instructions were always presented centrally on the screen, the S-R mappings referring to the close and distant response sequences were ordered randomly one above the other. S-R mappings and feedback messages were presented in Arial font, size 24. When a mistake was made the feedback was printed in red. For each response sequence, a response deadline of 10 seconds was used.

Procedure

Participants were tested individually by means of personal computers with a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). The experiment made use of a cover story, in which participants were told that the muscle activation in their right index finger would be monitored by using a bogus measurement device (see Figure 2). Participants were additionally told that imagining an action leads to small muscle activations, which could be used to monitor whether participants actually engaged in MP as instructed to do. Therefore, a fake electrode, which was wired to the bogus device, was taped onto their right hand (all responses had to be made with the right index finger). In a so-called calibration phase, participants were asked to go from the home-key to two keys (‘a’ and ‘p’) and back and afterwards they had to imagine doing the same movements. This fake electrode remained on the participant’s hand for the whole experiment. This cover story was used to encourage participants to practice the S-R mappings mentally by creating the illusion that we could monitor when they were engaged in MP and that we could dissociate MP from PP. In addition, this fake calibration phase was also used to emphasize the difference between MP and PP so that during the course of the experiment they did not engaged in actual finger movements during the MP practice phase.

Figure 2. Bogus measuring device.

After the calibration phase, the main instructions were presented on screen and paraphrased if necessary. The three conditions (PP, MP, and NP) were administered separately in three different blocks of the experiment, which were counterbalanced across participants. Each condition started with an instruction screen, informing participants about the type of practice (PP, MP, or NP). At the start of each condition, one run was performed as a short familiarization phase during which participants were monitored and additional information was given if necessary. This run was followed by six blocks of five runs, with a small break after each block.

Each run started with the presentation of the complete (PP and MP condition) or partial (NP condition) S-R mappings. After pressing the spacebar or a maximum time of 40 seconds, the training phase started. The training phase consisted of 20 practice trials, 10 for every S-R mapping. Afterwards the S-R mappings were presented (again) for a maximum time of 40 second. Finally, the test phase started, which consisted of two trials, one for each S-R mapping. The interval between the last response of a response sequence and the next stimulus onset was 750ms. For an outline of the procedure see Figure 3. The experiment lasted for approximately two hours.

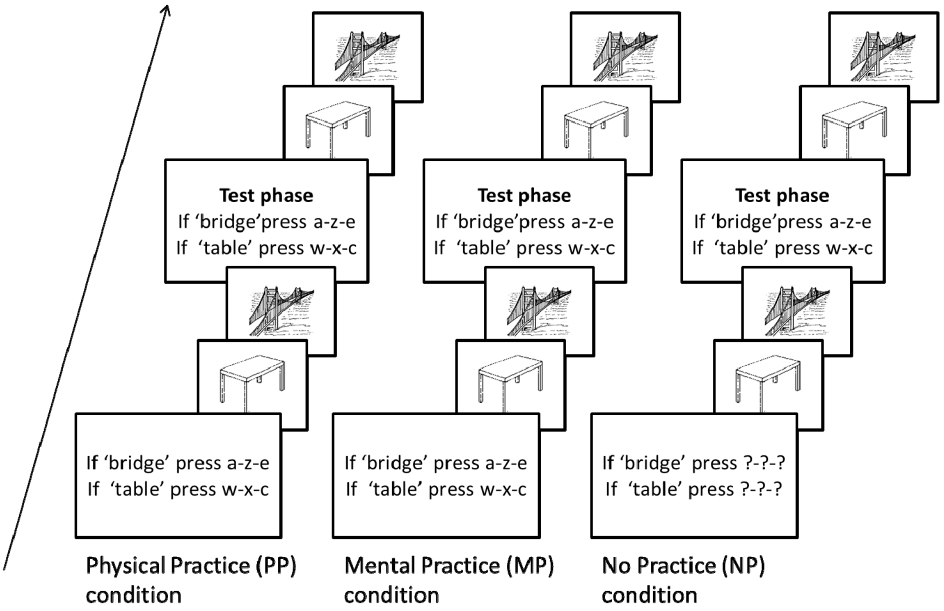

Figure 3. Overview procedure of the different practice conditions.

RESULTS

Training phase

In the training phase, the common dependent measure in all three conditions was the inter-home key interval. Furthermore, errors were not discarded from the PP condition, since no error data were available for the NP and MP condition. In each condition, the inter home-key interval of the first response was considered and the average inter home-key interval of the two subsequent responses. The inter home-key intervals for the first response were defined as the time between stimulus onset and pressing the home-key again after the first response. The inter-home key intervals for the subsequent responses were calculated as the average of the inter-home key intervals for the second and third response which were defined as the time between pressing the home-key before and after pressing the actual response key. Inter home-key intervals longer than 2.5 SDs from each participant's cell mean were excluded. This resulted in a data loss of 2% for the first response and 3% for the subsequent responses. Inter home-key intervals were investigated separately[1] for the first response and the subsequent responses by using two separate crossed linear mixed effects model analyses as implemented in the R package 'lme-4' (Bates, Mächler, Bolker & Walker, 2012). Linear mixed models were used in order to capture the variance accounted for by the use of randomly created response sequence. Therefore, the letters strings used as response sequence (e.g., a-z-e) were considered as random effect factor. Similarly, participants were also considered as a random effect factor. Sequence Type (close sequence, distant sequence) and Condition (PP, MP, NP) were considered as fixed effect-coded factors. The reported *p*-values for the fixed effects are based on a Type III ANOVA using a χ^2-distribution. Contrasts were calculated using dummy coding. Mean inter home-key intervals and corresponding standard deviations are presented in Table 1.

First response

A significant effect of Condition was observed, $\chi2(2)= 44142.84$, $p<.001$. Participants were significantly slower in the PP condition (*M*=1229 ms, *SD*= 348 ms) than in the MP condition (*M*=991 ms, *SD*=460 ms), $\chi2(1)= 3274.80$, $p<.001$, and participants were significantly slower in the MP condition than in the NP condition (*M*=384 ms, *SD*= 265 ms) , $\chi2(1)= 21544.00$, $p<.001$. The interaction between Condition and Sequence Type was significant, $\chi2(2)= 24.67$, $p<.001$. In the PP condition, participants were faster for the close response sequences than for the distant response sequences, $\chi2(1)=7.84$, $p<.01$. The effect of Sequence Type was not significant in the MP condition, $\chi2(1)=2.06$, $p=.151$, and the NP condition, $\chi2<1$. There was no main effect of Sequence Type, $\chi2<1$.

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[1] In principle, the type of response could be entered as a fixed effect in our model, but for reasons of clarity we preferred to treat both types of responses in separate analyses.

Subsequent responses

The effect of Condition was significant, *χ2*(2)= 24108.18, *p*<.001. Participants were significantly faster in the NP condition (*M*= 292 ms, *SD*= 149 ms), compared to the PP condition (*M*= 547 ms, *SD*= 174 ms), *χ2*(1)= 10113.00, *p*<.001, and significantly faster in the PP condition than in the MP condition (*M*= 679, *SD*= 342), *χ2*(1)= 2721.90, *p*<.001. The effect of Sequence Type was also significant, *χ2*(1)= 23.45, *p*<.001. Participants were faster for the close response sequences (*M*=519 ms, *SD*=295 ms), than for the distant response sequences (*M*=492 ms, *SD*=275 ms).

The interaction between Condition and Sequence Type was significant, *χ2*(2)= 160.27, *p*<.001. In the PP condition participants were faster for the close response sequences than for the distant response sequences, *χ2*(1)= 96.20, *p*<.001. Importantly, also in the MP participants were faster for the close response sequences than for the distant response sequences, *χ2*(1)= 9.16, *p*<.01. In the NP condition, the effect of Sequence Type was not significant, *χ2*<1.

Test phase

In the test phase several dependent measures were available in all three conditions. Besides the inter home-key intervals, error rates could also be measured in all three conditions. In addition, the inter home-key intervals could be divided in two components: the *actual response times* and the *return times*. The actual response time was the time needed to enter a particular letter. The return time was the time needed to return from a particular response-letter to the home-key. An illustration of these different timing components is presented in Figure 4. In contrast to the training phase, erroneous responses were now excluded from the different reaction time analyses. This resulted in a data loss of 12%. For each timing component, outliers were identified in the same way as in the training phase. For each analysis, this resulted in the exclusion of approximately 3% of the trials. Means and standard deviations of each analysis are presented in Table 1.

Table 1.

Mean results and corresponding standard deviations of the training and test phase

	First response		Subsequent responses	
Training phase	close sequence	distant sequence	close sequence	distant sequence
Inter home-key interval				
PP	1215 (364)	1242 (331)	516 (167)	579 (175)
MP	998 (467)	985 (454)	669 (328)	688 (355)
NP	385 (270)	383 (261)	292 (143)	293 (142)
Test phase				
Inter home-key interval				
PP	1064 (272)	1084 (243)	491 (142)	562 (146)
MP	1324 (516)	1393 (557)	596 (194)	677 (200)
NP	1467 (707)	1524 (766)	615 (210)	677 (184)
Actual response times				
PP	835 (254)	817 (217)	263 (103)	295 (107)
MP	1036 (455)	1054 (461)	317 (112)	351 (103)
NP	1170 (664)	1197 (717)	330 (122)	352 (101)
Return times				
PP	226 (53)	262 (56)	226 (53)	266 (55)
MP	285 (95)	324 (99)	276 (93)	320 (105)
NP	290 (96)	327 (93)	282 (105)	322 (96)
Error rates				
PP	.02 (.14)	.02 (.15)	.03 (.16)	.04 (.19)
MP	.05 (.21)	.03 (.18)	.07 (.26)	.04 (.19)
NP	.18 (.39)	.19 (.39)	.24 (.42)	.20 (.41)

Inter Home-key Intervals

First response.The effect of Condition was significant, $\chi2(2)= 507.24$, $p<.001$. Participants were significantly faster in the PP condition ($M= 1074$ ms, $SD= 258$ ms) than in the MP condition ($M= 1359$ ms, $SD= 538$ ms), $\chi2(1)= 237.96$, $p<.001$, and participants were significantly faster in the MP condition than in the NP condition ($M= 1496$ ms, $SD= 737$ ms), $\chi2(1)= 49.21$, $p<.001$. The effect of Sequence Type was also significant, $\chi2(1)= 9.42$, $p<.01$. Participants were faster for the close response sequences ($M= 1271$ ms, $SD= 539$ ms) than for the distant response sequences ($M= 1319$ ms, $SD= 578$ ms). There was no significant interaction, $\chi2(2)= 1.95$, $p=.377$.

Subsequent responses. The effect of Condition was significant, $\chi2(2)= 519.93$, $p<.001$. Participants were significantly faster in the PP condition ($M= 526$ ms, $SD= 149$ ms) than in the MP condition ($M= 637$ ms, $SD= 201$ ms), $\chi2(1)= 369.12$, $p<.001$ and the NP condition ($M= 646$ ms, $SD= 200$ ms), $\chi2(1)= 391.26$, $p<.001$. The difference between the MP condition and the NP condition was not significant, $\chi2(1)= 2.47$, $p=.116$. The effect of Sequence Type was also significant, $\chi2(1)= 148.69$, $p<.001$. Participants were faster for the close response sequences ($M= 563$, $SD= 190$) than for the distant response sequences ($M= 635$, $SD= 186$). There was no significant interaction, $\chi2(2)= 2.40$, $p=.302$.

Actual Response Times

First response. Only the effect of Condition was significant, $\chi2(2)= 243.05$, $p<.001$. Participants were significantly faster in the PP condition ($M=826$ ms, $SD= 237$ ms) than in the MP condition ($M=1045$ ms, $SD= 458$ ms), $\chi2(2)= 168.81$, $p<.001$. Participants were significantly faster in the MP condition than in the NP condition ($M= 1184$ ms, $SD= 691$ ms), $\chi2(2)= 60.54$, $p<.001$ There was no effect of Sequence Type, $\chi2<1$, nor was there a significant interaction, $\chi2(2)= 1.97$, $p=.373$.

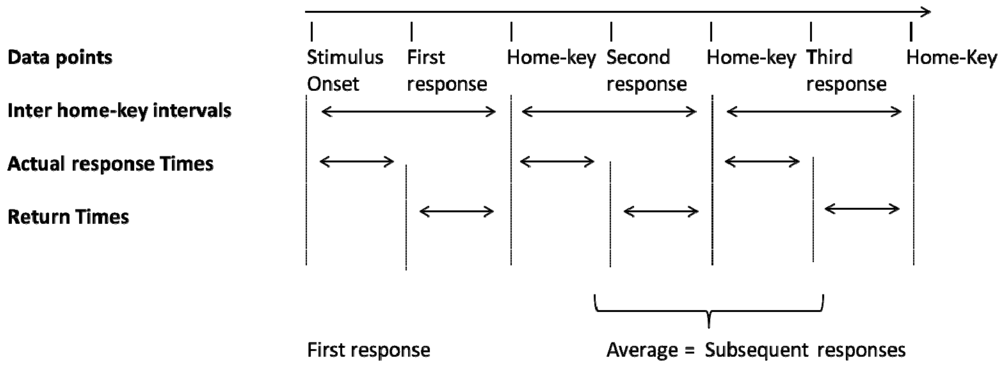

Figure 4. Overview of the timing components. All timing components were calculated separately for the first and subsequent responses. Importantly, the timing components for the subsequent responses were the average of the second and third response. For the first response, the inter home-key intervals were defined as the time between stimulus onset and pressing the home-key again after the first response. Similarly, the actual response times were measured from stimulus onset until the first response key was pressed. For the subsequent responses both the inter home-key intervals and actual response times started from pressing the home-key after the previous response. For the return times the measurement of the first and subsequent responses were the same, namely the time between the pressing of the actual response and returning to the home-key.

Subsequent responses. The effect of Condition was significant, *χ2*(2)= 327.03, *p*<.001. Participants were significantly faster in the PP condition (*M*= 279 ms, *SD*= 106 ms) than in the MP condition (*M*= 335, *SD*= 108), *χ2*(1)= 225.04, *p*<.001 and the NP condition (*M*= 341 ms, *SD*= 112 ms), *χ2*(1)= 252.64, *p*<.001. The MP condition did not differ significantly from the NP condition, *χ2*(1)= 2.89, *p*=.089. Furthermore, the effect of Sequence Type was also significant, *χ2*(1)= 61.05, *p*<.001. Participants were faster for the close response sequences (*M*= 301 ms, *SD*= 115 ms) than for the distant response sequences (*M*= 331, *SD*= 107). There was no significant interaction, *χ2*(2)= 2.81, *p*=. 245.

Return Times

First response. The effect of Condition was significant, *χ2*(2)= 770.82, *p*<.001. Participants were significantly faster in the PP condition (*M*= 244 ms, *SD*= 58 ms) than in the MP condition (*M*= 305 ms, *SD*= 99 ms), *χ2*(1)= 563.92, *p*<.001, and the NP condition (*M*= 309 ms, *SD*= 96 ms), *χ2*(1)= 562.61, *p*<.001. There was no significant difference between the MP and NP condition (*M*= 309 ms, *SD*= 96 ms), *χ2*(1)= 1.59, *p*=.208. The effect of Sequence Type was also significant, *χ2*(1)= 157.68, *p*<.01. Participants were faster on the close response sequences (*M*= 265 ms, *SD*= 88 ms) than on the distant response sequences (*M*= 302, *SD*= 90). There was no significant interaction, *χ2*<1.

Subsequent responses. The effect of condition was significant, *χ2*(2)= 599.41, *p*<.001. Participants were significantly faster in the PP condition (*M*= 246 ms, *SD*= 58 ms) than in the MP condition (*M*= 298 ms, *SD*= 102 ms), *χ2*(1)= 427.71, *p*<.001 and the NP condition (*M*= 302 ms, *SD*= 103 ms), *χ2*(1)= 449.64, *p*<.001. The difference between the MP and NP condition was not significant, *χ2*(1)= 2.54, *p*=.110. The effect of Sequence Type was significant, *χ2*(1)= 264.83, *p*<.001. Participants were faster for the close response sequences (*M*= 259 ms, *SD*= 92 ms) than for the distant response sequences (*M*= 301 ms, *SD*= 89 ms). The two-way interaction was not significant, *χ2*(2)= 1.07, *p*=.585.

Error rates

First response. The effect of Condition was significant, *χ2*(2)= 331.53, *p*<.001. Participants made less errors in the PP condition (*M*= .02, *SD*= .14) than in the MP condition (*M*= .04, *SD*= .20), *χ2*(1)= 3.94, *p*<.05, and less errors were made in the MP than in the NP condition (*M*= .18, *SD*= .39), *χ2*(1)= 215.55, *p*<.001. The effect of Sequence Type and the interaction between Condition and Sequence Type were not significant, *χ2*<1 and *χ2*(2)= 1.27, *p*=.531 respectively.

Subsequent responses. For the subsequent responses, a trial was only considered as a correct trial when both the second and third response was correct. In all other cases the trial was regarded as an error trial. Furthermore, no distinction was made between answering incorrectly on one or on both responses. The effect of Condition was significant, *χ2*(2)= 356.53, *p*<.001. Participants made less errors in the PP condition (*M*= .03, *SD*= .18) than in the MP condition (*M*=.06 , *SD*= .23), *χ2*(1)= 4.54, *p*<.05, and less errors were made in the MP condition than in the NP condition (*M*= .22, *SD*= .41), *χ2*(1)= 230.48, *p*<.001. The effect of Sequence Type was also significant, *χ2*(1)= 4.45, *p*<.05. Participants made less errors in the distant response sequences (*M*= .09, *SD*= .29) than in the close distance sequences (*M*= .11, *SD*= .31). There was no interaction between Condition and Sequence Type, $\chi 2(2)= 5.18$, $p=.075$.

DISCUSSION

The current study investigated the influence of MP and PP on the execution of newly instructed S-R mappings. Participants were instructed with S-R mappings comprising response sequences of three response letters. In a training phase, these mappings were practiced physically (PP condition), mentally (MP condition), or not practiced (NP condition). Because participants in the PP and MP condition were instructed to press a home-key after each (physical or mental) key press, performance in the practice phase of these conditions could be compared by looking at the timing of the home-key presses. The influence of these three types of training was measured also in a post-training test phase. The use of response sequences enabled us to investigate test performance on the first response and the subsequent responses separately. Based on previous research using response sequences (see Fendrich, et al., 1991; Nissen & Bullemer, 1987; Verwey, 1999), we assumed that performance on the first response is indicative of central processes such as response selection, while performance on the subsequent responses is a proxy of more peripheral processes involved in response execution, such as motor execution.

Let us start with a discussion of the performance during the training phase. During the training phase, performance was measured using the inter home-key interval. Of crucial importance was the effect of sequence distance on the length of the inter home-key intervals. In the PP condition, the effect of sequence distance was significant for both first responses and subsequent responses: close response sequences were associated with shorter inter home-key intervals than distance response sequences. Importantly, in the MP condition the effect of sequence distance was significant for the subsequent responses. Although participants did not actually enter the response-letters, inter-home key intervals were shorter for close response sequences than for distant response sequences. This finding suggests that participants did engage in a form of MP, which does incorporate parameters of physical properties, such as the distance between the home key and the response letters.

Performance in the test phase was measured by using the inter home-key intervals, the actual response times, the return times and the error rates. These dependent measures converge toward the same conclusions. For the first response of the response sequence, PP led to a better performance than MP and MP led to a better performance than no practice. For the subsequent responses, PP improved performance compared to MP and no practice. However, performance after MP did not differ significantly from performance following no practice, albeit an improvement was observed in terms of error rates. Taken together, the results of the test phase suggest that while PP leads to improvement both at the level of the retrieval and execution of newly instructed S-R mappings, MP mainly leads to an improvement in the retrieval of newly instructed S-R mappings.

The main question of the present study was whether MP can also result in a quick shift of the mode in which novel instructions are processed, as it is the case for PP (e.g., Ruge & Wolfensteller, 2010; Ramamoorthy & Verguts, 2012). Based on previous research on instruction implementation (e.g., Liefooghe et al., 2012; Meiran et al., 2012), it can be hypothesized that performance in the NP condition was probably mainly based on the operation of controlled processes involved in the maintenance and application of an initial representation of the instructions. Within the experimental conditions we used, these processes led to a particularly slow and error-prone performance. In line with the proposals of Ruge and Wolfensteller (2010), the improvement in performance induced by PP, suggests that a second, more fine-grained, representation was formed on the basis of PP, which quickly took over control. Within this framework, the impact of MP can be interpreted in two ways. First, it can be assumed that MP also leads to the formation of a second representation. The finding that the effect of MP was situated mainly at the level of central processes, suggests that the representation formed on the basis of MP is less fine-grained than the representation formed on the basis of PP. The representation formed on the basis of MP includes less task parameters that are needed to attain a skilled task execution. This would suggest that these task parameters are represented on the basis of learning experiences that are uniquely related to overt task execution, such as senso-motoric experiences (e.g., Lotze & Halsband, 2006; Mulder, Zijlstra, Zijlstra, Hochstenbach,2004; Rieger, 2012) or experiencing errors (e.g., Rieger et al., 2011). Alternatively, it could be argued that MP does not lead to the formation of a second representation. In such view, the beneficial effect of MP is not related to a shift in processing mode, but to an enhancement of the processes involved in the maintenance and application of the initial representation that is formed on the basis of instructions. Although we cannot exclude such account on the basis of the present results, the many existing demonstrations that MP can lead to long-term performance improvement (e.g., Clark ,1960; Jarus, Ratzon, 2000 ; Mc Bride & Rothstein, 1979; Wohldmann et al., 2007), challenge the idea that MP would not result in the formation of long-term representations.

The present conclusions on PP and MP are based on the assumption that performance on the first and the subsequent responses are mapped on different types of processes. Performance on the first response was considered as a marker for central processes. Performance on the subsequent response was considered as a marker for peripheral processes. It is clear that such distinction should be more nuanced. Indeed, we cannot rule out that performance on both types of responses may be contaminated by different types of processes (see also, Wohldmann et al., 2007, 2008). In other words, performance on the first response mainly reflects central processes and performance on the subsequent response mainly reflects peripheral processes. Our conclusions are thus constrained by this limitation. Nevertheless, the return times we measured are most probably uniquely related to a motor processes, as they simply indicate the speed by which the home-key is reached after responding. Return times indicated faster performance on the PP condition compared to the MP and NP condition. However, the MP and NP condition did not differ significantly. This pattern of results thus strengthens the conclusion that MP mainly impact central processes and not peripheral processes.

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APPENDIX

Overview of words used as stimuli in Dutch:

Aap, ananas, anker, appel, asbak, auto, baard, bad, bal, ballon, banaan, bank, bed, been, beer, beker, berg, bijl, blad, blik, bloem, boek, bom, boom, boot, bord, brief, bril, broek, brood, brug, bureau, bus, cactus, clown, cowboy, dak, das, deur, dokter, doos, douche, draak, duif, duim, duivel, eend, eikel, emmer, eskimo, ezel, fiets, fles gebit, geest, geit, geweer, gewei, gieter, gitaar, glas, haai, haak, hak, hamer, hand, harp, hart, heks, helm, hert, hoed, hoef, hond, huis, iglo, jas, jojo, kaars, kaas, kam, kameel, kanon, kast, kerk, kers, kikker, kip, koe, kok, konijn, koning, kooi, kraan, kreeft, kroon, kruis, kussen, ladder, lama, leeuw, lepel, maan, mais, mand, masker, meisje, mes, mixer, muis, muur, neus, oog, oor, paard, pan, pauw, peer, pet, piano, pijl, pijp, pincet, puzzle, racket, radijs, radio, regen, ring, robot, rugzak, schaap, schaar, schelp, schoen, sigaar, sjaal, slak, slang, slee, spin, spook, ster, stoel, strik, stuur, taart, tafel, tak, tand, tank, tent, tijger, tol, tomaat, ton, touw, trap, trein, uil, vaas, varken, vinger, vis, vlag, vlieg, vlot, voet, vork, vos, vuur, wiel, wolk, worst, wortel, zaag, zadel, zak, zebra, zon, zwaan, zweep.

CHAPTER 6

THE COST OF CHANGING MERELY INSTRUCTED AND PRACTICED S-R MAPPINGS[1]

The present study investigated the performance costs induced by changing merely instructed S-R mappings and overtly practiced S-R mappings. To this end, a procedure was developed in which changes in both types of S-R mappings could be directly compared by measuring different performance costs. The results indicate that changing merely instructed S-R mappings mainly induces a general cost in processing. Changing overtly practiced S-R mappings results into additional performance costs, which seem to be based on the automatic retrieval of S-R associations that are formed through overt practice. Our results, furthermore, suggest that these S-R associations only include abstract stimulus and response codes, such that the additional performance costs associated with changing overtly practiced S-R mappings can transfer across different response effectors.

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[1] Based on Theeuwes, M., & Liefooghe, B. (submitted). The cost of changing merely instructed and practiced S-R mappings.

INTRODUCTION

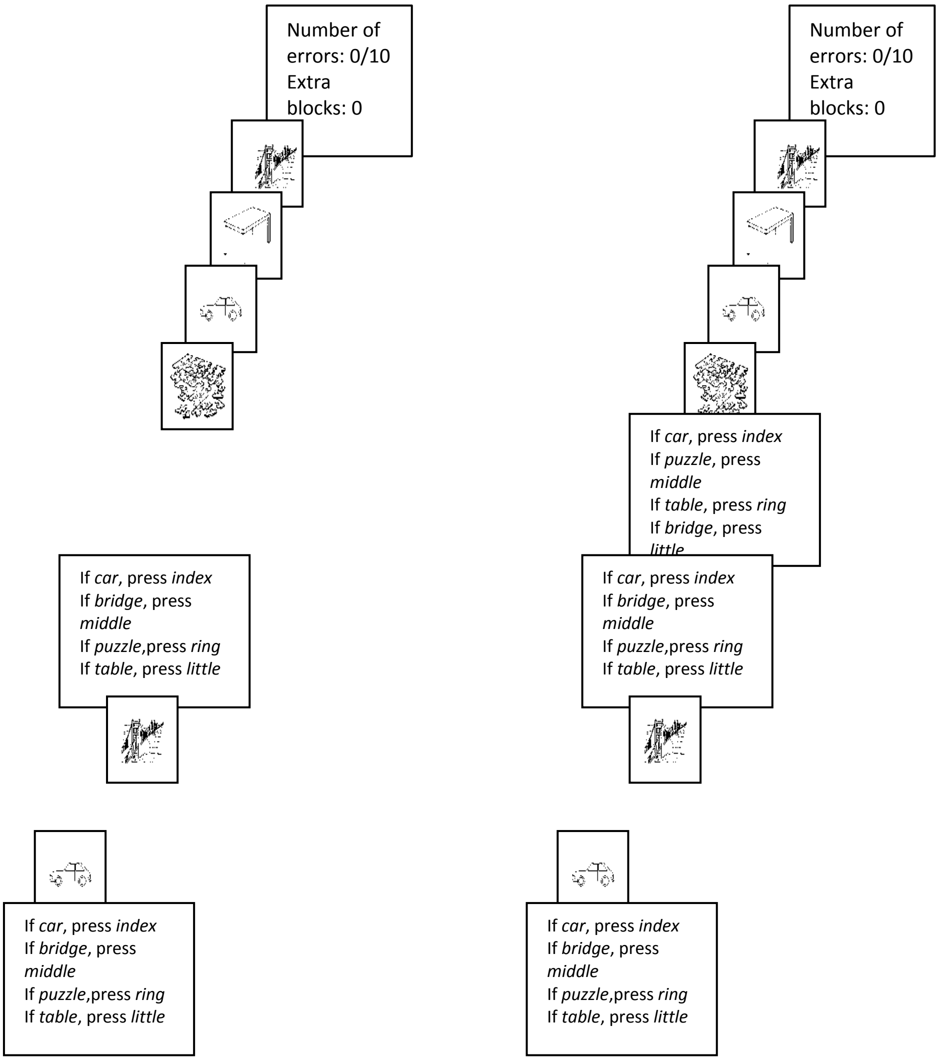
Instructions play a seminal role in daily life functioning by specifying how and when to respond to different demands in our environment. In many situations instructions can be considered as the basis on which a particular skill is subsequently built through the repeated overt practice of the instructed actions. In recent years, a substantial amount of research focused on the implementation of novel instructions. A central idea in this line of research is that instructed Stimulus-Response (S-R) mappings that have not been practiced or executed overtly before, can be implemented into a task-set, which includes functional S-R associations (e.g., Liefooghe, Wenke, & De Houwer, 2012; Meiran, Cole & Braver, 2012). Support for this hypothesis comes from the observation that automatic response activations can be obtained on the basis of task-irrelevant S-R mappings that have only been instructed and never been practiced overtly before (e.g., Cohen-Kdoshay & Meiran, 2007, 2009; Everaert, Theeuwes, Liefooghe, & De Houwer, 2014; Liefooghe, De Houwer and Wenke, 2013; Liefooghe, et al., 2012; Meiran, Pereg, Kessler, Cole & Braver, 2014; Theeuwes, Liefooghe, & De Houwer, 2014; Wenke, Gaschler, Nattkemper & Frensch, 2009).

At the present time, research focusing on the implementation of instructions assumes that instructions always remain valid over the course of a task. However, it is reasonable to assume that the validity of an instruction can change during the course of a task. Although changes in the validity of instructions has been neglected in research focusing on the implementation of novel instructions, this issue is at the core of a well-known paradigm in cognitive psychology, namely task switching (see Kiesel et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe & Verbruggen, 2010 for reviews). Task switching research focuses on performance in multi-task situations, which require frequent switches between two or more tasks. The general strategy to investigate the different components of task switching performance (see for instance, Braver, Reynolds, & Donaldson, 2003; Koch, Prinz, & Allport,2005; Kray & Lindenberger, 2000; Rubin & Meiran, 2005) is to compare performance on pure lists each containing one task with a list in which both tasks are present (mixed lists). This mixed list contains both task repetitions (same task on trial n-1 and trial n) and task switches (different task on trial n-1 and trial n). A first cost in performance that can be discerned in such design is the alternation cost or global switch cost. This cost is indexed by the difference in performance between the pure lists and the task switches in the mixed list (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Spector & Biederman, 1976). The alternation cost supposedly relates to an increase in the general load associated with the mixed list, such as increased working memory demands, increased degree of effort, and the use of a more conservative response criterion (Meiran, 1996; Rogers & Monsell, 1995; Ward, 1982).

A second marker of switch performance that can be obtained in such situation is the mixed-list cost. This cost reflects the difference between performance on the pure lists and performance on the task repetitions in the mixed list. The mixed-list cost is a more fine-grained measure of performance, as it relates to task-repetition performance in a context in which no switches can occur and situations in which frequent switches are present. Rubin and Meiran (2005) proposed that, in contrast to the alternation cost, the mixed-list cost does not reflect increased demands on working memory, but rather the competition between task sets in a mixed list. These authors demonstrated that the mixed-list cost relates to processes involved in the decision of which task to perform in a mixed list, a decision which is made both on task repetitions and task switches.

Finally, the bulk of research on task switching focused on a third component of task switching performance known as the local switch cost. This component is corresponds to the difference in performance between task repetitions and task switches within a mixed list. On the one hand, the switch cost has been interpreted in terms of the representation of task-sets in working memory. Some accounts suggest that the switch cost reflects processes that are involved in the reconfiguration or retrieval of a task-set (e.g., Rogers & Monsell, 1995, Meiran, 1996). These processes operate on task switches but not on task repetitions, which results into a switch cost. Other accounts suggest that the switch cost reflects the influence of a previously activated task-set. On task switches, this task-set is irrelevant and interferes with performance on the current trial (e.g., Allport, et al., 1994). On task repetitions, this task-set is still relevant and supposedly facilitates performance on the current trial (e.g., Sohn, & Anderson, 2001). On the other hand, switch costs are still observed when ample time is provided between two trials in a mixed list. This residual switch cost does not seem to be related to task-set representations in working-memory functioning, but are interpreted in terms of competing S-R associations that are formed in long-term memory through practice. Wylie and Allport (2000; see also Allport & Wylie, 2000; Koch & Allport, 2006) proposed that participants form specific S-R associations in long-term memory when executing a particular task. These associations are then automatically retrieved when being irrelevant in the context of another task.

Taken together, research on task switching identified different costs in performance associated with the demand to switch between tasks. On the one hand, the alternation cost, which is a proxy of increased effort and working memory load (Meiran, 1996; Rogers & Monsell, 1995; Ward, 1982). On the other hand, the mixed-list cost and the local switch cost, which are more fine-grained indices of task-set competition and long-term memory retrieval of associations. Switching between tasks, however, can be reinterpreted as switching between sets of instructions, which are valid in one situation and not in another. From the perspective of research focusing on the implementation of instructions, the question thus becomes what performance costs will occur when changing instructions that have not yet been applied overtly before? In order to investigate these research questions, we developed a novel procedure that not only permitted us to measure the cost in performance elicited by changing instructed S-R mappings that were never practiced overtly before, but also to determine whether practice adds to those effects. The latter issue is particularly important given the lack of studies that directly compare learning via instructions and learning via practice (see, Wenke, De Houwer, De Winne, & Liefooghe, in press for an exception). Within the current context, a crucial difference between instructed and practiced S-R mappings, is that the execution of practiced S-R mappings rely on the automatic retrieval S-R associations that were formed in long-term memory through practice (e.g., Logan, 1988). In contrast, current evidence suggest that instructed S-R mappings can only lead to the formation of a task-set in working memory (Cohen-Kdoshay & Meiran, 2007; Waszak, Wenke, & Brass, 2008). The question thus arises, to which extent these different representations lead to differences in performance when changing S-R mappings.



Number of errors: 0/10 Extra blocks: 0

If *car*, press *index*
If *bridge*, press *middle*
If *puzzle*,press *ring*
If *table*, press *little*

If *car*, press *index*
If *bridge*, press *middle*
If *puzzle*,press *ring*
If *table*, press *little*

Number of errors: 0/10 Extra blocks: 0

If *car*, press *index*
If *puzzle*, press *middle*
If *table*, press *ring*
If *bridge*, press *little*

If *car*, press *index*
If *bridge*, press *middle*
If *puzzle*,press *ring*
If *table*, press *little*

If *car*, press *index*
If *bridge*, press *middle*
If *puzzle*,press *ring*
If *table*, press *little*

Same Set Run

Different Set Run

Figure 1. Illustration of the procedure used in Experiment 1.

Our procedure consisted of different runs or mini-blocks each containing two parts, a training and a test phase. An overview of a run is presented in Figure 1. Each run started with the presentation of a set of four novel S-R mappings, which we refer to as Set 1 instructions. Subsequently, a training phase of 40 trials was performed. Only two of the four instructed S-R mappings were practiced. Thus, after this training phase, two S-R mappings were overtly practiced and two S-R mappings were not. Following the training phase, the Set 1 mappings were presented for a second time. In half of the runs, which we refer to as the Same Set Runs, the test phase started directly after the second presentation of Set 1 instructions. In the test phase, participants were asked to execute all four S-R mappings of Set 1 only once. In the other half of the runs, which we call the Different Set Runs, a novel set of S-R mappings was introduced prior to the test phase. We refer to this set as Set 2 instructions. Set 2 comprised three new S-R mappings and only one S-R mapping of Set 1. Whereas Set 1 instructions were valid in the test phase of the Same Set Runs, Set 2 instructions were valid in the test phase of the Different Set Runs. In other words, while Same Set Runs comprised only one set of instructions (Set 1), Different Set Runs comprised two sets of instructions (Set 1 and Set 2), with Set 1 being valid in the training phase and Set 2 instructions being valid in the test phase. Set Runs comprised two sets of instructions (Set 1 and Set 2), with Set 1 being valid in the training phase and Set 2 instructions being valid in the test phase.

In analogy to task-switching research, our procedure permitted to investigate different costs of performance when changing merely instructed S-R mappings (i.e., Set 1 S-R mappings that were not practiced overtly before) and overtly practiced S-R mappings (i.e., Set 1 S-R mappings that were instructed and overtly practiced). These different costs are represented in Figure 2. First, Same Set Runs can be considered as pure lists in which one set of instructions remains valid whereas Different Set Runs can be considered as mixed lists in which two sets of instructions are present, with each set being valid at a particular time. The difference in performance in the test phase of Same Set Runs and the Different Set Runs is therefore an analogue of the alternation cost and accounts for changes in performance associated with the introduction of a new set of instructions (i.e., Set 2). Observing such *set change cost* would indicate that introducing a novel set of instructions leads to increased effort and working memory demands (Meiran, 1996; Rogers & Monsell, 1995; Ward, 1982). Of quintessential importance is the question whether such set change cost can also be observed for S-R mapping that have not yet been overtly executed before. Prior research did not address this question because all S-R mappings were practiced throughout the experiment. A second way to examine task switching in our procedure is by focusing on those S-R mappings that did not alter between the training and the test phase. Performance on these S-R mappings can be compared between the test phase of Same Set Runs and the test phase of Different Set Runs. We refer to this difference as the *mixed set cost* because it is an analogue of the mixed list cost in earlier task switching studies. It offers an index of how the repetition of one S-R mapping is impacted when all other S-R mappings are changed. In line with the proposals of Rubin and Meiran (2005), it can be considered as a proxy of processes involved in the decision of whether a new or an old S-R mapping should be applied in a context in which new and old S-R mappings co-occur. Again, of crucial importance is whether such mixed set cost is present for merely instructed S-R mappings. Finally, within the Different Set Runs, the difference in performance between unchanged and changed S-R mappings could also be measured. In analogy to the local switch cost, we refer to this cost as the *mapping switch cost*. This particular cost is informative about possible differences in performance between mapping repetitions and mapping switches.

EXPERIMENT 1

Experiment 1 aimed to answer three main questions. First, can we find a set change cost for merely instructed S-R mappings? Second, can we find a mixed set cost for merely instructed S-R mappings? Third, can we find a mapping switch cost for merely instructed S-R mappings? Importantly, for each of these three effects (set change cost, mixed set cost, and mapping switch cost) we also examined whether the cost differs for the merely instructed compared to the overtly practiced S-R mappings.

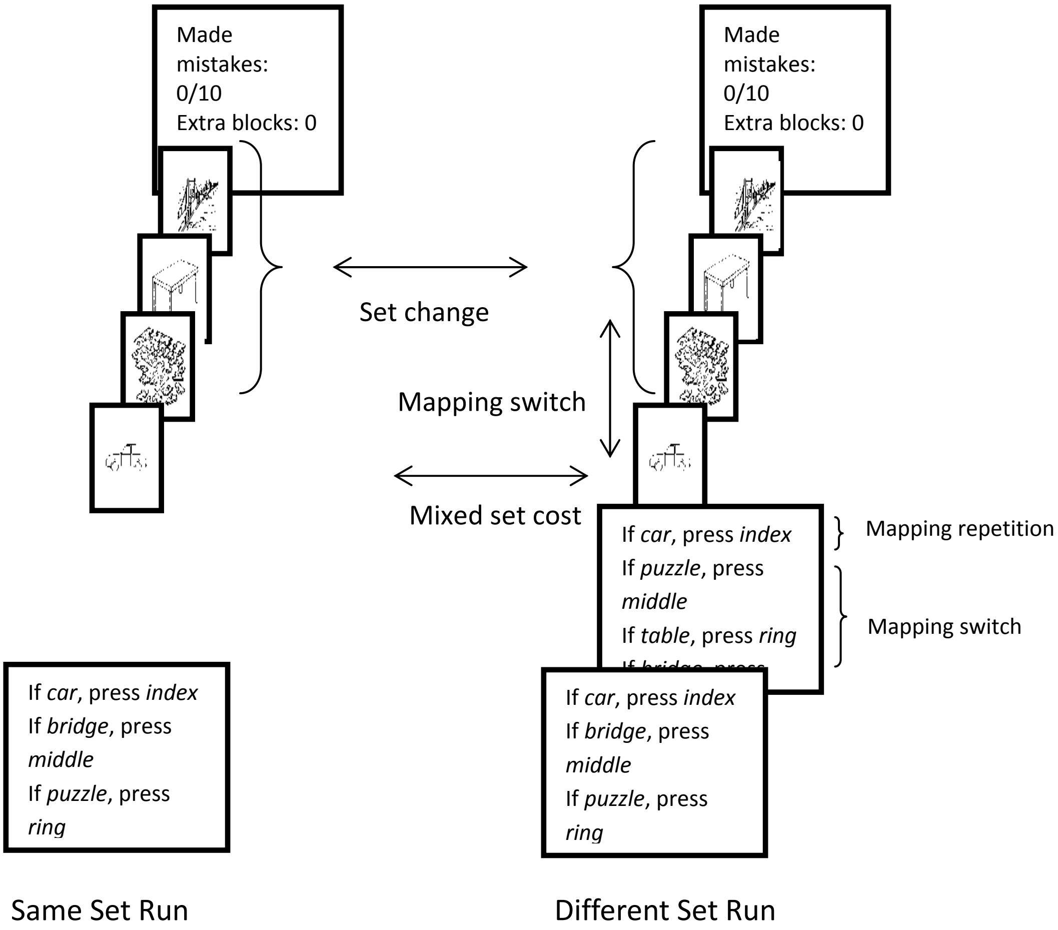


Figure 2.Illustration of the different performance costs that were measured.

Method

Participants

Thirty-seven students at Ghent University participated for either course requirements or payment of 8 EURO.

Materials

Pictures were selected from the Snodgrass and Vanderwart (1980) picture set. Based on the Dutch-naming ratings of these pictures by Severens, Van Lommel, Ratinckx, and Hartsuiker (2005), 200 object-names and object-pictures were selected. For each participant, these objects were randomly assigned to 50 sets of (Set 1) instructions. Each set was only used once in the experiment and contained four S-R mappings. Each S-R mapping related a specific object to a particular finger (e.g., If ‘car’ press index finger; If ‘bridge’ press middle finger; If ‘puzzle’ press ring finger; If ‘table’ press little finger). In the Different Set Runs, a new set of S-R mappings (Set 2) was created. Three S-R mappings were changed by reassigning the objects a different finger (e.g., If ‘puzzle’ press index finger; If ‘car’ press middle finger; If ‘bridge’ press ring finger). One S-R mapping remained unchanged (e.g., If ‘table’ press little finger). On half of the Different Set Runs, the unchanged S-R mapping was practiced in the training phase of the run. On the other half, the unchanged S-R mapping had not yet been applied overtly before.

In the instructions sets, the S-R mappings included object-words. The S-R mappings were presented in written form, by using Arial font, size 16. During the training and test phases, the corresponding object-picture was used. The object-picture was presented in a virtual square of 300 by 300 pixels. For each set of instructions, the four S-R mappings were presented on four lines: the S-R mapping referring to the index finger was on the top line, the S-R mapping referring to the middle finger was on the second line, the S-R mapping referring to the ring finger was on the third line, and the S-R mapping referring to the little finger was on the fourth (bottom) line. This order of presentation was fixed. Responses were registered by using an AZERTY keyboard: index finger, ‘H’; middle finger, ‘U’; ring finger, ‘I’; and pink ‘L’.

Procedure

Participants were tested individually or in groups of two or three by means of personal computers with a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Instructions were presented on screen and paraphrased if necessary. To motivate participants to perform to the best of their ability, participants were told that for every 10 mistakes during the test phase an extra block had to be performed. In reality, these extra blocks were never executed. The experiment consisted of one practice block containing two runs and six experimental blocks each containing eight runs. Each block was followed by a small break. In each block, half of the runs were Same Set Runs and the other half were Different Set Runs.

An overview of a run is presented in Figure 1. Each run started with a fixation cross in the middle of the screen for 2000 ms to clearly separate different runs. Hereafter, the Set 1 instructions were presented for maximum time of 30 seconds or until participants pressed the spacebar. After this first presentation, the training phase started. This phase consisted of 40 trials. Only two of the four S-R mappings were practiced in this phase (e.g., If ‘car’ press index finger; If ‘bridge’ press middle finger). Each S-R mapping was practiced for twenty trials. The presentation order was random. On each trial, an object-picture was presented at the screen center until participants pressed the corresponding key or a maximum response time of 2000ms elapsed. Incorrect responses were followed by a 200ms long red screen. The inter-trial interval was 750ms. The training phase was followed by a second presentation of the Set 1 instructions, again for a maximum time of 30 seconds or until the participant pressed the spacebar. In the Different Set Runs, this second presentation was followed by the presentation of the Set 2 instructions (i.e., three changed S-R mappings + one unchanged S-R mapping) for maximum 30 seconds or until participants pressed the spacebar. After viewing the Set 2 instructions, the test phase started. In the Same Set Runs, the test phase started immediately after the second presentation of the Set 1 instructions. In each run, the test phase consisted of 4 trials (one trial per S-R mapping). The timing parameters were the same as in the training phase. In the test phase, there was no immediate error feedback. After the test phase, a feedback screen was presented, informing participants about their cumulative error scores and if extra blocks had to be performed. The experiment lasted for approximately 75 minutes.

Results

Cell means and corresponding standard deviations are presented in Table 1.

Set Change Cost

We first compare performance on Same Set Runs and Different Set Runs. To this end, performance on the three S-R mappings that changed in the Different Set Runs was compared with performance on three S-R mappings in Same Set Runs, which employed the same response fingers. In order to investigate performance on this subset of S-R mappings, a linear mixed effects model (LME) analysis was conducted with Run Type (Same Set Run, Different Set Run) and S-R Mapping (merely instructed S-R mapping, overtly practiced S-R mapping) as fixed effects as implemented in the R package 'lme-4' (Bates, Mächler, Bolker & Walker, 2012). In all analyses reported in the present study, the grouping variable Participant and the grouping variable Object-Picture were entered as random effects. For all RT analyses in the present study, only correct trials were included and RTs exceeding 2.5 standard deviation above the participants' cell mean were considered as outliers.

For the RTs (data loss: 6%), the main effect of S-R mapping was significant, $\chi 2(1)=28.40$, $p<.001$. Participants were faster on overtly practiced S-R mappings (682ms) than on merely instructed S-R mappings (732ms). The main effect of Run Type was also significant, $\chi 2(1)=119.59$, $p<.001$. Responses were faster on Same Set Runs (657ms) than on Different Set Runs (759ms). S-R mapping and Run Type interacted, $\chi 2(1)=16.88$, $p<.001$. The difference between Same and Different Set Runs was larger for overtly practiced S-R Mappings, $\chi 2(1)=1113.34$, $p<.001$, than for merely instructed S-R mappings, $\chi 2(1)=23.28$, $p<.001$.

For the error rates, the main effect of Run Type was significant, $\chi 2(1)=69.14$, $p<.001$. Less errors were made on Same Set Runs (.02) than on Different Set Runs (.07). The main effect of S-R mapping was not significant, $\chi 2<1$. S-R mapping and Run Type interacted, $\chi 2(1)=6.63$, $p<.05$. The difference between Same Set Runs and Different Set Runs was larger for overtly practiced S-R mappings, $\chi 2(1)=59.32$, $p<.001$, than for merely instructed S-R mappings, $\chi 2(1)=16.47$, $p<.001$.

Mixed Set Cost

Performance on the S-R mapping that remained the same in the Different Set Runs was compared to the S-R mapping in the Same Set Runs that involved the corresponding finger. As for the analysis of the Set Change Cost, an LME with Run Type (Same Set Run, Different Set Run) and S-R Mapping (overtly practiced S-R mapping, merely instructed S-R mapping) as fixed effects was conducted.

For the RTs (data loss: 8%), the main effect of S-R mapping was significant, $\chi2(1)=47.91$, $p<.001$. Participants were faster for overtly practiced S-R mappings (644ms) than for merely instructed S-R mappings (754ms). The main effect of Run Type was also significant, $\chi2(1)=18.93$, $p<.001$, with faster responses in Same Set Runs (664ms) than on Change Set Runs (734ms). The two-way interaction was not significant, $\chi2(1)= 2.56$, $p=. 109$.

For the error rates, only the main effect of Run Type was significant, $\chi2(1)=6.12$, $p<.05$, with less errors on Same Set Runs (.02) than on Different Set Runs (.04). There was no main effect of S-R Mapping, $\chi2<1$ and no interaction, $\chi2(1)=2.25$, $p=.109$.

Mapping Switch cost

In order to investigate the mapping switch cost, we only focus on the Different Set Runs and compare performance between S-R mappings that were the same in Set 1 and Set 2 (mapping repetition) and S-R mappings that were different in Set 1 and Set 2 (mapping switch). To this end, an LME was conducted in which Transition (mapping repetition, mapping switch) and S-R Mapping (overtly practiced S-R mapping, merely instructed S-R mapping) were coded as fixed effects.

Table 1.

Cell means and corresponding standard deviations of Experiment 1.

Diagnostic Task		S-R mapping Merely Instructed	Overtly Practiced
RTs			
Set change cost	Same Set runs	701 (321)	614 (283)
	Different Set runs	765 (355)	754 (372)
Mixed set cost	Same Set runs	719 (352)	611 (289)
	Different Set runs	790 (362)	678 (322)
Mapping switch cost	Mapping repetition	790 (362)	678 (322)
	Mapping switch	765 (355)	754 (372)
Error rates			
Set change cost	Same Set runs	.03 (.18)	.01 (.11)
	Different Set runs	.07 (.25)	.07 (.26)
Mixed set cost	Same Set runs	.03 (.16)	.01 (.09)
	Different Set runs	.03 (.18)	.04 (.20)
Mapping switch cost	Mapping repetition	.03 (.18)	.04 (.20)
	Mapping switch	.07 (.25)	.07 (.26)

For the RTs (data loss: 4%), the main effect of S-R mapping was significant, $\chi 2(1)=19.50$, $p<.001$. RTs were faster for overtly practiced S-R mappings (736ms) than for merely instructed S-R mappings (771ms). The effect of Transition was not significant, $\chi 2(1)=3.02$, $p>.05$. The interaction between S-R mappings and Transition was significant, $\chi 2(1)=11.99$, $p<.001$. Whereas the difference between mapping repetitions and mapping switches was significant for overtly practiced S-

R mappings, $\chi 2(1)=13.16$, $p<.001$, no such significant difference was observed for merely instructed S-R mappings, $\chi 2(1)=1.75$, $p=.185$.

For the error rates, the main effect of Transition was significant, $\chi 2(1)=13.12$, $p<.001$. Less errors were made for mapping repetitions (.04) than for mapping switches (.07). Both the main effect of S-R mapping and the two-way interaction were not significant, $\chi 2s<1$.

Discussion

The results of Experiment 1 can be summarized along the lines of the three main questions of Experiment 1. First, a set change cost was observed both for merely instructed S-R mappings and overtly practiced S-R mappings. An interaction indicated that this set change cost was larger for overtly practiced S-R mappings than for merely instructed S-R mappings. Introducing a novel set of instructions (i.e., Set 2) thus taxes performance and this even for S-R mappings that were only instructed and never applied overtly before. In line with research on task switching this cost probably reflects an increased load on working memory (Meiran, 1996; Rogers & Monsell, 1995; Ward, 1982). Second, a mixed set cost of was present. We did not observe an interaction between mixed set cost and the type of S-R mapping. The presence of this mixed set cost indicates that when participants are presented with a novel set of instructions the decision to repeat a particular S-R mapping is hampered by the presence of novel of S-R mappings. Our data furthermore suggest that this decision is also hampered for S-R mappings that were never practiced overtly before. Third, a mapping switch cost was present for overtly practiced S-R mappings but not for merely instructed S-R mappings. This last observation needs some additional discussion.

As mentioned in the Introduction, the local switch cost has been interpreted in different ways. When two tasks are performed in close succession, the local switch cost is considered to reflect processes involved in the representation of task-sets in working memory (Allport, et al., 1994; Rogers & Monsell, 1995, Meiran, 1996; Sohn, & Anderson, 2001). When ample time is provided between trials, the residual switch cost that remains is considered to be elicited by the automatic retrieval of S-R associations from long-term memory

(Allport & Wylie, 2000; Koch & Allport, 2006; Wylie & Allport, 2000). In view of the procedure we used in Experiment 1, we propose that the mapping switch cost observed in Experiment 1 is also related to the retrieval of S-R mappings from long-term memory. In our procedure ample time was provided between the training and the test phase. In the Different Set Runs, Set 2 instructions were presented for 30 seconds and it is reasonable to assume that processes related to the interference and reconfiguration of task-sets did not come at play anymore during the test phase of these runs. Accordingly, the mapping switch cost that we observed in Experiment 1, can also be qualified as residual. Within this view, the observation that mapping switch costs were only present for overtly practiced S-R mappings makes perfect sense. Indeed, it is commonly accepted that overt practice leads to the formation of S-R associations in long-term memory, while the implementation of S-R mappings without overt practice leads to task-set representations in working memory (e.g., Liefooghe et al. 2012; Meiran et al., 2012). As such, the automatic retrieval of S-R associations from long-term memory can only bias performance for overtly practiced S-R mappings and not for merely instructed S-R mappings, which is reflected in the observation that a mapping switch cost for overtly practiced S-R mappings and not for merely instructed S-R mappings.

EXPERIMENT 2

In Experiment 2, we further investigated the difference between merely instructed and overtly practiced S-R mappings in the context of switching. In Experiment 1, we observed that changing overtly practiced S-R mappings leads to a larger set change cost and a mapping switch cost, with the latter effect not being present for instructed S-R mappings. These additional costs observed for overtly practiced S-R mappings are most probably related to the fact that overt practice leads to the formation of S-R associations in long-term memory. These associations are automatically retrieved later on, which leads to additional interference when new S-R mappings need to be applied. Experiment 2 further investigated the nature of these associations. Previous research on S-R associations in long-term memory indicated that these associations only include abstract stimulus and response codes. Specific features such as response effectors and response modality do not seem to be represented at all or the weight these features receive is negligibly small (e.g., Gade & Koch, 2007; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Hübner & Druey, 2006; Schuch & Koch, 2004). The hypothesis that S-R associations only include conceptual information, raises the question whether the additional costs observed for overtly practiced S-R mappings are restricted to situations in which the training phase and the test phase physically share the same response effectors or whether the effects of practice can also be observed when both phase employ different response effectors. In order to investigate this issue, participants in Experiment 2, used their left hand in the training phase and their right hand during the test phase. The question was whether the pattern of results obtained in Experiment 1, would still emerge in Experiment 2.

Method

Participants

Thirty-six students at Ghent University participated for either course requirements or payment of 8 EURO. None of them participated to Experiment 2.

Materials and procedure

The same materials and procedure was used as in Experiment 1, with the exception of two adjustments. First, the training phase and the test phase now involved different hands. Yet, the same four keys were used in both phases, namely F, G, H, J on an AZERTY keyboard. Participants pressed these response keys with the left hand in the training phase and with the right hand in the test phase. Data of a pilot experiment showed that this procedure was highly confusing for participants when using S-R mappings, which referred to specific response fingers (e.g., index finger, little finger). Accordingly, a second change was made in comparison to Experiment 1. The response keys were labeled with different colors by using stickers. In the instructions of Experiment 2, the response keys were defined as the: the blue-key (’F’-key), the red-key (G’-key), the yellow-key (H’-key) and the green-key (J’-key). The S-R mappings now referred to the color of the response key (e.g., if ‘car’, press RED).

Results

Cell means and corresponding standard deviations are presented in Table 2.

Set Change Cost

For the RTs (data loss: 6 %), the main effect of S-R mapping was significant, $\chi2(1)=8.39$, $p<.01$. Participants were faster for overtly practiced S-R mappings (706ms) than for merely instructed S-R mappings (735ms). The main effect of Run Type was also significant, $\chi2(1)=44.68$, $p<.001$, with faster responses in Same Set Runs (688ms) than in Different Set Runs (755ms). S-R mapping and Run Type interacted, $\chi2(1)=12.65$, $p<.001$. The difference between Same Set Runs and Different Set Runs was larger for overtly practiced S-R mappings, $\chi2(1)=52.33$, $p<.001$, than for merely instructed S-R mappings, $\chi2(1)=4.91$, $p<.05$.

For the error rates, the main effect of Run Type was significant, $\chi2(1)=62.61$, $p<.001$. Less errors were made on Same Set Runs (.03) than on Different Set runs (.08). The main effect of S-R mapping was not significant, $\chi2<1$. S-R mapping and Run Type interacted, $\chi2(1)=5.21$, $p<.05$. The difference between Same Set Runs and Different Set Runs was larger for overtly practiced S-R mappings, $\chi2(1)=51.97$, $p<.001$, than for merely instructed S-R mappings, $\chi2(1)=15.85$, $p<.001$.

Table 2.

Cell means and corresponding standard deviations of Experiment 2.

Diagnostic Task		S-R mapping Instructed	 Practiced
RTs			
Set change cost	Same Set runs	720 (359)	655 (323)
	Different Set runs	751 (365)	758 (397)
Mixed set cost	Same Set runs	737 (355)	670 (350)
	Different Set runs	745 (358)	715 (345)
Mapping switch cost	Mapping repetition	745 (358)	715 (354)
	Mapping switch	752 (365)	758 (397)
Error rates			
Set change cost	Same Set runs	.03 (.18)	.02 (.15)
	Different Set runs	.07 (.25)	.09 (.28)
Mixed set cost	Same Set runs	.03 (.17)	.02 (.14)
	Different Set runs	.06 (.24)	.03 (.17)
Mapping switch cost	Mapping repetition	.06 (.24)	.03 (.17)
	Mapping switch	.07 (.25)	.09 (.28)

Mixed Set Cost

For the RTs (data loss: 7%), the main effect of S-R mapping was significant, $\chi 2(1)=8.42$, $p<.01$. RTs were shorter for overtly practiced S-R mappings (692ms) than for merely instructed S-R mappings (741ms). There was no effect of Run Type, $\chi 2(1)=2.55$, $p=.110$, and no interaction, $\chi 2(1)=1,25$ $p=.263$.

For the error rates, the main effect of Run Type was significant, *χ2*(1)=9.53, *p*<.01. Less errors were made in the Same Set Runs (.03) than in the Different Set Runs (.05). There was also a significant main effect of S-R mapping, *χ2*(1)=4.98, *p*<.05. Participants made less errors for overtly practiced S-R mappings (.03) than for merely instructed S-R mappings (.05). The interaction was not significant, *χ2*(1)=1.40, *p*=.237.

Mapping Switch Cost

For the RTs (data loss: 4%), none of the effects was significant: Transition, *χ2*(1)=2.87, *p*>.05; S-R mapping, *χ2*<1; two-way interaction, *χ2*(1)=1.70, *p*>.1. For the error rates, the main effect of Transition was significant, *χ2*(1)=10.74, *p*<.01, with less errors on mapping repetitions (.05) than on mapping switches (.08). The main effect of S-R mapping was not significant, *χ2*<1. S-R mapping and Transition interacted, *χ2*(1)=6.55, *p*<.05. The difference between mapping switches and mapping repetitions was significant for overtly practiced S-R mappings, *χ2*(1)=17.03, but not for merely instructed S-R mappings, *χ2*<1.

Discussion

The results of Experiment 2 can be summarized as follows. First, as in Experiment 1, we observed a set change cost, which was larger for overtly practiced S-R mappings than for merely instructed S-R mappings. Second, there was no significant mixed set cost for the RTs. In contrast, a significant mixed set cost was observed for the error rates. Third, also the mapping switch cost was not significant for the RTs. However, a mapping switch cost was present in the error rates. An interaction indicated that the mapping switch cost was significant for the overtly practiced S-R mappings, but not for the merely instructed S-R mappings.

Taken together, the results of Experiment 2 only partially replicate the results of Experiment 1. Whereas the set change cost was again obtained on the RTs as well as on the error rates, the mixed set cost and the mapping switch cost were only observed in the error rates. Nevertheless, the pattern observed in the error rates of Experiment 2 was in line with the pattern of results obtained for the RTs in Experiment 1. Although some cautiousness is warranted, the results of Experiment 2 thus offer indications that the practice effects obtained with one set of effectors (i.e., the left hand), transferred to the other set of effectors (i.e., the right hand). This finding suggest that the difference between merely instructed S-R mappings and overtly practiced S-R mappings is based on the formation of S-R associations, which only contain conceptual representations of stimulus and response codes.

GENERAL DISCUSSION

The present study set out to investigate whether changing instructions that were never overtly executed before could lead to costs in performance. Inspired by research on task switching, a procedure was developed, which permitted us to measure different costs associated with the change of merely instructed and overtly practiced S-R mappings: (a) the set change cost, which offers a marker of the general load that is brought on by the introduction of a novel set of instructions; (b) the mixed set cost, which offers a proxy of processes involved in the decision whether a new or an old S-R mapping should be applied; and (c) the mapping switch cost, which is the difference between mapping repetitions and mapping switches. The results of two experiments indicated that the set change cost, measured in terms of RTs and error rates, is larger for overtly practiced S-R mappings, but is also present for merely instructed S-R mappings. The mixed set cost was present for the RTs of Experiment 1 and the error rates of Experiment 2. The mixed set cost did not differ for merely instructed and overtly practiced S-R mappings. Finally, a mapping switch cost was only present for overtly practiced S-R mappings, albeit only in the RTs of Experiment 1 and only for the error rates of Experiment 2.

What do these different markers tell us about the processes involved in changing merely instructed S-R mappings and overtly practiced R mappings? On the one hand, the present results suggest that both for merely instructed and overtly practiced S-R mappings similar processes are involved when these S-R mappings are changed. In line with the interpretation of the alternation cost in task switching (Meiran, 1996; Rogers & Monsell, 1995; Ward, 1982), we propose that the observation of a set change cost for merely instructed S-R mappings relates to the additional load associated with the presence of two sets of instructions in the Different Set Runs compared to the Same Set Runs. It is important to emphasize that the change set cost reflects the impaired performance in the application of the Set 2 S-R mappings. From this perspective, the observation of a set change cost for merely instructed S-R mappings indicates that previously valid set S-R mappings, which were not practiced overtly before, still hamper the application of new S-R mappings. This effect is general in nature and thus presumably reflects increased effort or working-memory load. The finding that the set change cost is larger for overtly practiced S-R mappings, most probably relates to the fact that for overtly practiced S-R mappings an additional source of interference exists, namely the automatic retrieval of S-R associations formed through overt practice. This additional source of interference was isolated to some degree in the mapping switch cost, which was only present for overtly practiced S-R mappings. Finally, the results concerning the mixed set cost suggest that both for merely instructed and overtly practiced S-R mappings, the introduction of a new set of instructions impairs the decision that is made on each trial whether a new or an old S-R mapping should be applied. This decision does not seem to be affected by the fact that an S-R mapping has been practiced overtly or not. In other words, this particular decision does not seem to be affected by the retrieval of previously formed S-R associations.

The present results underline that the implementation of instructions without overt practice and the implementation of instructions followed by additional overt practice lead to distinct representations. Whereas overt practice leads to the formation of S-R associations in long-term memory, the mere implementation of instructions does not. Previous research suggested that instruction implementation leads to a functional representation of S-R mappings in working memory. The observation of set change cost for merely instructed S-R mappings can be interpreted along these lines. The absence of a mapping switch cost for merely instructed S-R mappings, however, may seem at odds with the hypothesis that instruction implementation leads to the formation of a functional representation in working memory. Indeed, the local switch cost, which we consider as an analogue of the mapping switch cost, has been frequently interpreted in terms of processes related to task-set representations in working memory. However, as we mentioned before, such interpretation holds for local switch costs measured in situations requiring rapid switching between different tasks. The procedure used in the present study did not impose such rapid switching. In addition, a major difference between more common task-switching procedures and the present procedure is that our procedure does not include distinct tasks. In contrast, task-switching procedures do employ two (or more) tasks, which have a different goal and relate to different stimulus features. Accordingly, whereas our manipulation relates to sets of instructions, including different S-R mappings, these sets of instructions do not differ with respect to a particular task goal and the relevant stimulus features. In view of these differences, the most proper interpretation of the mappings switch cost is in terms of automatic retrieval of S-R associations.

The results of Experiment 2 also offer additional insights about the difference between overt practice and mere instruction implementation by further exploring the boundary conditions needed in order to observe such difference. Although we must remain careful about the results of Experiment 2 because effects were observed mainly in the error rates rather than the RTs, these results suggest that practice effects are not restricted to situations in which training and test phases are identical. In Experiment 2 these phases employed different response effectors and still some transfer of practice occurred between training and testing. The finding that practice effects of novel S-R mappings can be based on different types of practice. This was also recently demonstrated by Theeuwes, Liefooghe, De Schryver, and De Houwer (submitted) who observed practice effects for novel S-R mappings, which were only practiced 'mentally' without explicit response execution. As it is the case for the present study, these results suggest that practice effects are essentially based on the formation of associations only containing abstract codes. Accordingly, practice effects can be induced by different types of training phases, which do not necessarily share all features with the actual test phase.

To conclude, the present study demonstrated that changing the validity of merely instructed S-R mappings taxes performance in a general way, but also impedes processes involved in the decision whether newly instructed or previously valid mappings should be applied. For overtly practiced S-R mappings, additional interference effects were observed, which are probably based on the retrieval of S-R associations that only include abstract stimulus and response codes. It is clear that the present study is only a first step and that many more questions need to be addressed. However, the basic idea that the validity of instructions can vary and that these changes tax performance even for unpracticed instructions, opens a whole new perspective for research on instruction implementation.

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CHAPTER 7

GENERAL DISCUSSION

INTRODUCTION

The aim of the present thesis was to contribute to extend the growing body of research focusing on the processes underlying the unique human ability to learn on the basis of verbal instructions without overt practice. At the center of this thesis was the execution of novel S-R mappings in the absence of actual practice. Within this context, we pursued two lines of research. The first line of research elaborated on previous research focusing on the automatic effects of merely instructed S-R mappings. The second line of research aimed to understand how practice modulates the implementation of novel S-R mappings. In this concluding chapter, we first provide a critical overview of the different chapters that were presented. Next, we consider the implications of our findings for the theoretical interpretations of research on instructions and discuss some avenues we believe research on instructions should address in the future.

CRITICAL OVERVIEW

Instruction-based Congruency effects

Chapter 2: Eliminating the Simon effect by instruction

In Chapter 2, the interaction between instruction-based response congruency (IBRC) and the Simon effect was investigated. To this end, the procedure developed by Liefooghe, Wenke and De Houwer (2012; see also Liefooghe, De Houwer & Wenke, 2013) was adapted in such a way that the impact of instructed spatial S-R mappings on the Simon task could be tested. More specifically, we measured the impact of spatially compatible and incompatible S-R mappings on performance in a Simon task. The results obtained in Chapter 2 indicate that merely instructed spatially incompatible S-R mappings are sufficient to eliminate the Simon effect. In contrast, spatially instructed compatible S-R mappings do not increase the Simon effect. The effect of merely instructed incompatible S-R mappings and moderately practiced incompatible S-R mappings was comparable.

In Chapter 2, we concluded that the elimination of the Simon effect was based on response competition between responses activated on the basis of LTM associations and responses activated on the basis of short-term associations that were formed on the basis of instructions. Yet, as argued in the discussion of Chapter 2, alternative explanations are possible. First, presenting participants with spatially incompatible S-R mappings may have induced conflict, which might have resulted in an increase of cognitive control. In line with accounts of conflict adaptation (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001), implementing a spatially incompatible S-R mapping may have led participants to assign more weight to the relevant task features of the Simon task and ignore its irrelevant features, thus, resulting in the elimination of the Simon effect. Second, maintaining an additional S-R mapping may have increased the load on working memory to such an extent that no Simon effect was observed. Indeed, previous research on the Simon effect (e.g., Proctor, Miles, & Baroni, 2011), repeatedly demonstrated that when working memory is taxed during a Simon task, the irrelevant task features are not represented in working memory, which again results into the absence of a Simon effect. Finally, presenting spatially incompatible S-R mappings may have led to a shift in strategy. Participants might have been encouraged to endorse an opposite-response strategy, in which they start to respond in opposition to intuitively compelling response tendencies. Vu (2007) argued that such strategy can also result in the absence of a Simon effect, albeit for spatially incompatible S-R mappings that have been extensively practiced. Although we argued against these alternative explanations in the discussion of Chapter 2, we also acknowledged that the findings of Chapter 2 call for further research, which can offer us more certainty about the processes underlying the elimination of the Simon effect on the basis of task-irrelevant instructions. A possible solution is to further extend the procedure that was used in Chapter 2 by including a condition in which the inducer task uses vertically compatible or vertically incompatible spatial S-R mappings (e.g., if the stimulus is on the upper side, press the lower key). Such vertical S-R mappings have similar functional properties in terms of conflict, load, and opposite-responding as do horizontal S-R mappings, but we do not expect them to lead to response competition with a horizontal Simon Task. The question thus becomes whether the results of Chapter 2 can be replicated when using vertical S-R mappings or whether eliminating the Simon effect is only possible for horizontal S-R mappings. Observing a dissociation between vertical and horizontal S-R mappings, would offer additional evidence that the elimination of the Simon effect on the basis of horizontally incompatible S-R mappings, is most likely the result of a competition between automatic instruction-based response activation (AIBRA) and response activations based on LTM associations.

Chapter 3: Automatic motor activation by mere instruction

Chapter 3 was quintessential for the hypothesis that IBRC (Liefooghe et al., 2012) is actually based on AIBRA. Indeed, behavioral research on IBRC can be open to alternative explanations (see Meiran, Cole, & Braver, 2012 for examples). In contrast, Chapter 3 offered more direct evidence that instructed S-R mappings, that were not practiced overtly before, can lead to AIBRA by using electrophysiological measures, namely lateralized readiness potentials (LRPs), which markers reflecting activity in the motor cortex. The LRP was found to deflect in the direction of the response tendency that corresponded with the instructed S–R mapping. Early activation of the instructed response was observed but this occurred predominantly on slow trials. These results strongly suggest that, like experienced S–R mappings, instructed S–R mappings can lead to AIBRA. Meanwhile, the conclusions presented in Chapter 3 have received additional support by a recent study of Meiran, Pereg, Kessler, Cole, and Braver (in press a), which replicated the results of Chapter 3 by using a slightly different procedure.

The analyses performed in Chapter 3 revealed an interesting feature of IBRC that received only little attention, namely the observation that the size of the IBRC effect is modulated by the IBRC on the previous trial. More specifically, a larger IBRC effect is observed for trials following upon IBRC congruent trials compared to trials following upon IBRC incongruent trials. The sequential modulation of response compatibility effects, which is commonly referred to as the Gratton effect (Gratton, Coles & Donchin, 1992), has been extensively studied for compatibility effects that are based on practiced S-R mappings (see Egner, 2007; Schmidt, 2013; Verguts & Notebaert, 2009 for reviews). Nevertheless, in the context of merely instructed S-R mappings, this modulation was only recently investigated by Wenke, De Houwer, De Winne and Liefooghe (in press). Wenke et al. (in press) observed that a Gratton effect for instructed S-R mappings that did not differ from the Gratton effect of practiced S-R mappings. This finding is at odds with what could be predicted based on the conflict adaptation account (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). According to this account is the amount of control that is exerted on a given trial is depended on how much response conflict was experienced on the previous trial. Wenke et al. (in press) argued that the response conflict based on practiced S-R mappings should be larger because response conflicts are larger when an S-R mapping is practiced. Yet, the lack in differences does not support this conflict adaptation account. Both the results in Chapter 3 and the study of Wenke et al. (in press) suggest that the Gratton effect (Gratton et al., 1992) can also be observed for IBRC. The question, of course, is what are the processes behind this modulation? A considerable amount of research has been devoted to understanding the processes underlying the Gratton effect for compatibility effects that are based on practiced S-R mappings (for a review see Egner, 2007; Schmidt, 2013). Similarly, future research will have to systematically assess which processes underlie the sequential modulation of IBRC effects.

Chapter 4: Congruency effects on the basis of instructed response-effect contingencies

In Chapter 4, we investigated whether IBRC effects are limited to S-R mappings or if other types of instructions can lead to similar effects. To this end, we focused on Response-Effect (R-E) contingencies, which specify the relation between a particular response and the effect this response has in the environment. Previous research demonstrated that R-E contingencies that are learned incidentally during an acquisition phase, can lead to response compatibility effects in a test phase (for a review see Shin, Proctor & Capaldi, 2010). In Chapter 4, we tested whether such compatibility effects can also be obtained on the basis of R-E contingencies that were only instructed. In a series of three experiments, we adapted the procedure of Liefooghe et al. (2012, 2013) such that the inducer task now used instructed R-E contingencies instead of instructed S-R mappings. The results of Chapter 4, indicated that response compatibility effects can be obtained on the basis of instructed R-E contingencies.

On the one hand, the results of Chapter 4 indicate that IBRC effects are not restricted to S-R mappings. As we will discuss later on, these results question to which extent relational information is represented when implementing instructions. On the other hand, the results of Chapter 4 can also be considered in light of the concern that Meiran and colleagues (Meiran et al. 2012; in press a; Meiran, Pereg, Kessler, Cole & Braver, in press b) formulated about the type of procedures that were used in the present thesis. Meiran et al. (2012) pointed out that the effects observed in procedures similar to the one used by Liefooghe et al. (2012, 2013), such as by De Houwer, Beckers, Vandorpe and Custers (2005), may be a consequence of task misapplication, with participants performing the inducer task instead of the diagnostic task. On the basis of theories of automaticity (e.g., Logan, 1988), it could be hypothesized that even a single misapplication of the instructions of the inducer task during the diagnostic task is sufficient to form S-R associations, which might subsequently bias performance in the diagnostic task. As a result, IBRC effects in the diagnostic task may not reflect a bias based on S-R associations formed on the basis of instructions, but the automatic retrieval of S-R associations formed on the basis of actual practice. Within the procedure of Liefooghe et al. (2012, 2013), such misapplication of instructions could arise from the fact that the goals of both tasks are highly comparable, namely judging stimulus identity by pressing a left or right key in the inducer task and judging stimulus orientation of the same stimuli by pressing the same left or right key in the diagnostic task. However, in the procedure used in Chapter 4, it is unlikely that the effects of R-E contingency instructions were due to a misapplication of the instructions of the inducer task during the diagnostic task, because the goals of both tasks were very distinct. This distinction should have minimized the chance of misapplication. Although the first two experiments of Chapter 4, could still be prone to task misapplication through the recoding of R-E contingencies in terms of S-R mappings, we argue that in the third experiment of Chapter 4, task misapplication seems very unlikely.

As was already mentioned in Chapter 1, Meiran and colleagues (in press a, in press b) introduced an alternative procedure, which also may minimize the risk of task misapplication. The nature of the diagnostic task was crucially different between the procedure of Meiran et al. (in press a, in press b) and the procedure of Liefooghe et al. (2012). In the procedure of Meiran et al. (in press b), participants were presented with two S-R mapping instructions of the inducer task. When stimuli were presented in a green square, participants were instructed to perform the inducer task. In between the presentation of the instructions and the execution of the inducer task, a diagnostic phase was inserted in which on each trial one of the two stimuli of the inducer task was presented in a red square. In the diagnostic task, participants were asked to simply press a single response key, the “next” response in order to move on to the next trial. The crucial manipulation is that this next response was part of one of the two S-R mappings used in the inducer task. In other words, it could be the left or the right response-key of the inducer task. Based on this response overlap and the presence of “irrelevant” stimuli in the diagnostic phase, Meiran et al. (in press b) calculated an instruction-based compatibility effect on the basis of the “next” response. Meiran et al. (in press b) argued that task misapplication was very unlikely in their procedure, because participants were not required to perform an actual task in the diagnostic phase. On the basis of this procedure, Meiran et al. (in press a) even demonstrated that IBRC can be obtained if participants do not react at all in the diagnostic phase. In their study, the trials of the diagnostic task were no-go trials and no next response was required. At the same time, LRPs were measured and a similar pattern of results was obtained as in Chapter 3. The procedure of Meiran and colleagues (in press a; in press b) thus seem to provide a powerful tool to investigate instruction-based effects. However, the absence of an actual task induces a certain degree of freedom during the diagnostic phase. On the one hand, the possibility exists that participants actively rehearsed the mappings of the inducer task during the diagnostic phase. On the other hand, participants may engage in some form of covert mental practice, which may be sufficient to elicit IBRC effects. Taken together, while the procedure of Meiran and colleagues (in press a; in press b) seems promising in avoiding task misapplication, future research is needed to test how watertight their procedure actually is. At the same time, the R-E variant of Liefooghe's et al. (2012, 2013) procedure does impose a task in the diagnostic phase and also minimizes the risk of task misapplication. More generally, the issue of task misapplication will have to be addressed in future research to assess the degree by which task misapplication can induce or inflate effects that are supposedly based on instructions. One possibility to measure the contribution of task misapplication is by investigating IBRC effects in procedures, which systematically vary the degree in overlap between the inducer and the diagnostic task. Alternatively, we could directly instruct participants to apply the inducer task on some trials of the diagnostic task.

The effect of practicing novel instructions

Chapter 5: Mentally and physically practicing novel instructions: How does it help?

Chapter 5 investigated the added value of physical and mental practice to the implementation of on novel instructions. To this end, a "virtual typing" procedure was developed which permitted us to investigate performance improvement in central processes, such as response selection, and more peripheral processes involved in response execution. The results suggest that while physical practice leads to the improvement of both central and peripheral processes, the effect of mental practice is mainly restricted to an improvement of central processes.

The findings of Chapter 5 were interpreted in view of the proposals of Ruge and Wolfensteller (2010). These authors proposed that whereas the implementation of instructions leads to the formation of an initial task representation, additional physical practice leads to the formation of a more fine-grained task representation, which includes low-level features that are needed to attain nearly automatic performance (see also Ramamoothy & Verguts, 2012). We proposed that mental practice also leads to such additional task representation, albeit a less detailed one. However, the results concerning mental practice are open to alternative explanations. First, it could be argued that mental practice did not lead to the formation of an additional task representation, but only improves the processes involved in the maintenance and application of the initial representation that is formed on the basis of instructions. This alternative explanation calls for additional research. One possible avenue is “enriching” the mental representations participants make when engaging into mental practice. Such approach was also used by Rieger, Martinez and Wenke (2011, Experiment 2), who instructed participants to imagine errors in a virtual typing procedure. These authors showed that the difference between mentally and physically executing a task can be reduced by adding such ‘error’-instructions but when participants were asked to correct their mistakes still a large difference between the mental and physical conditions was observed. Rieger et al. (2011) concluded that in general participants do not imagine making mistakes and even when participants are explicitly instructed to incorporate errors into the virtual typing the level of imagined errors is still smaller than the mistakes made in reality. In a similar vein, novel procedures could be developed that encourage participants to make more detailed representations during mental practice. For example, participants could first be asked to perform a series of button presses at the beginning of the experiment and to pay close attention to the senso-motoric feedback these button presses evoke. In a subsequent mental training phase participants are instructed to incorporate these senso-motoric experiences when mentally practicing S-R mappings. The question is whether under such conditions, participants would form a representation that more closely resembles to the fine-grained representation that is formed after physical practice. This would be evidenced by modulations of peripheral-process markers.

A related question about Chapter 5, is whether the performance improvement obtained by means of mental practice, directly results from mental practice or whether participants additionally engaged in some form of (verbal) rehearsal, which could also improve performance. Possibly, while engaging into mental practice, participants were in fact encouraged to rehearse the S-R mappings in working memory. In order to investigate this alternative hypothesis, future research could adopt a dual-task approach (e.g., Baddeley, & Hitch, 1974) in which participants are hampered in the (verbal) rehearsal of the S-R mappings, by performing a concurrent articulatory suppression task (Baddeley, Lewis, & Vallar, 1984; Murray, 1968). The question is whether mental practice would still improve performance under such dual-task conditions. More generally, such manipulations would be helpful to disentangle the effects of rehearsal and mental practice.

Finally, in Chapter 5, participants could have used micro movements during the mental practice phase. Before and after each mentally executed response, the spacebar had to be pressed. Therefore, the finger that participants had to use to respond was not totally fixed during the mental-practice training phase. Participants could have included some response-relevant movements in the interval between two spacebar responses, such as small pointing movements in the direction of the correct response. Future experiments, could require participants to keep their response hand flat on the table during mental practice. Spacebar responses would then be simply replaced by verbal responses. Excluding micro movements, will further enable us to assess the impact of mental practice, while keeping the contribution of physical practice as minimal as possible.

Chapter 6: The cost of changing merely instructed and practiced

In Chapter 6, instructed and practiced S-R mappings were investigated in relation to mental flexibility. Previous research in the task-switching literature (see Kiesel et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010 for reviews), indicated that changing S-R mappings leads to a cost in performance. These studies, however, mainly focused on S-R mappings that are frequently applied. In Chapter 6, we investigated whether changing merely instructed S-R mappings also leads to a cost in performance. In addition, we compared this cost in performance with the performance cost that is induced when practiced S-R mappings are changed. The results indicated that changing merely instructed S-R mappings mainly induces a general cost in processing, whereas changing overtly practiced S-R mappings results into additional performance costs. These additional costs are possibly based on the automatic retrieval of S-R associations that were formed through overt practice. Our results, furthermore, suggest that these S-R associations only include abstract stimulus and response codes. As such, the additional performance costs associated with changing overtly practiced S-R mappings can transfer across different response effectors.

As mentioned before, even though learning through instructions and learning through overt practice are often discussed in relation with each other, at the present time there is a lack of studies doing systematic comparisons between both types of learning. To our knowledge, the study of Wenke et al. (in press) is one of the few examples of such comparison. The results of Chapter 6 are of importance in this context, because they again demonstrate that merely instructed S-R mappings and overtly practiced S-R mappings do lead to different effects. Nevertheless, whereas Chapter 6 dissociates between merely instructed and overtly practiced S-R mappings, the procedure introduced in that chapter may also be useful to address additional questions about these different types of mappings. First, research on the implementation of instructions assumes that instructions are translated into a functional representation, such as a task-set (Liefooghe et al., 2012, 2013), an event-file (Wenke, Gaschler, & Nattkemper, 2007; Wenke, Gaschler, Nattkemper, & Frensch, 2009) or a plan (Meiran et al., 2012). Research on task switching leads to the prediction that changing or reconfiguring such representation should lead to a cost in performance (see Kiesel et al., 2010; Monsell, 2003; Vandierendonck et al., 2010 for reviews). In Chapter 6, it was not possible to investigate this prediction, because the participants had ample time to prepare for the imposed changes and the costs that were measured were most probably residual in nature, that is, only related to the automatic retrieval of S-R associations (see Allport & Wylie, 2000 for this particular point). A straightforward manipulation, is to reduce the time provided between the practice and the training phases, such that performance costs would be more indicative of processes related to the reconfiguration and maintenance of task-sets. The question will be whether under such restricted time window, changing unpracticed S-R mappings does not also lead to mapping switch costs and mixed set costs as it is the case for practiced S-R mappings. Such finding is of importance because it would confirm the common hypothesis that task-sets can be formed on the basis of instructions and this without overt practice (e.g., Liefooghe et al., 2012; Meiran et al., 2012; Wenke et al., 2007, 2009). At the same time, such findings would also be of importance for the study of task switching. Indeed, as far as we know, it has not been tested whether the local switch cost in task switching can be observed under conditions that exclude the contribution of overt practice. Some accounts of the local switch cost (e.g., Rogers & Monsell, 1995) do interpret this cost as the result of proactive control mechanisms operating on task-sets in working memory. From this perspective, the overt execution of a task on a previous trial thus is not an prerequisite to observe a local switch cost. Hence, the procedure introduced in Chapter 6 could be further adapted by changing the instruction sets into distinct tasks, that have to be applied to different stimulus features and comprise distinct goals. Taken together, combining the literature on task switching and the literature on learning through instructions may considerably advance our knowledge of both these important mental abilities.

THEORETICAL IMPLICATIONS AND FUTURE AVENUES

Now that we have provided a brief overview and discussion of the different findings of the current thesis, in this section we consider the various implications of our findings for future theorization and research on instructions. As mentioned in Chapter 1, there is a consensus that instructions are represented in working memory (e.g., Liefooghe et al., 2012; Meiran et al., 2012). Liefooghe et al. (2012) argued that when an instruction is prepared for, the information that is represented in declarative working memory is translated into a functional representation in procedural working memory (see also, Brass, et al., 2009; Meiran et al., 2012). Meiran et al. (2012) argued that instructed S-R associations are assumed to be represented in the Bridge (i.e., the capacity-limited portion of procedural working memory, see Chapter 1) in the form of a temporal binding (see also Wenke et al., 2007, 2009) between preexisting representations in activated long-term memory (ALTM; see Chapter 1), such as stimulus and response codes. Once such representation has been formed, stimuli can unintentionally activate a specified action in a reflex-like manner (i.e., Exner, 1879; Hommel, 2000). Meiran et al. (2012), furthermore, assume that overt practice leads to the formation of S-R associations in LTM (see also Logan, 1988).

In Chapter 1, we briefly discussed the different findings that led to these accounts of instruction implementation. In the present section, we discuss what the current thesis has to add. At the same time, we consider some future avenues we believe research on instructions should address. We identified four main issues that future research on instructions should consider: (a) working memory and the role of preparation; (b) the representation of relational information; (c) automatic effects of merely instructed, overtly practiced and mentally practiced S-R mappings; and (d) extensions beyond verbally instructed S-R mappings and IBRC.

Working memory and the role of preparation

Liefooghe et al. (2012) only found an automatic effect of instructed S-R mappings when these had to be executed and not when they had to be remembered for future recall. They concluded that in the former case a procedural representation was created, whereas in the latter case only a declarative representation was maintained. Such conclusion fits within Oberauer's (2009) assumption that declarative and procedural working memory are two distinct systems (see also Anderson & Lebiere, 1998; Logan & Gordon, 2001). However, the results of Chapter 4 (Experiment 3) question whether both systems are actually so distinct. More precisely, in Chapter 4 (Experiment 3) the inducer task was a speeded-recognition task and an IBRC effect was observed. In other words, although participants did not have to apply the instructions, an instruction-based effect was present. This finding contrasts with the findings of Liefooghe et al. (2012), who did not observe an IBRC effect when the inducer task involved recall or recognition. The crucial difference, however, is that in Chapter 4 a very short response deadline was imposed in the inducer task, whereas this was not the case in the study of Liefooghe et al. (2012). Previous research demonstrated that that the level of preparation participants engage in, is of crucial importance for observing IBRC effects (Liefooghe et al., 2013; Wenke et al., 2009) and the results of Chapter 4 suggest that a sufficient degree of preparation can even induce IBRC effects for instructions that do not have to be applied. In other words, maintaining declarative information to a sufficiently high level of activation in working memory can also lead to IBRC. The question becomes if a distinction between declarative and procedural working memory still holds in view of this result? Of course, we should not capitalize too heavily on this single finding. However, more generally, the question can be addressed how information in the declarative system induces the formation of a representation in the procedural system. Models assuming a distinction between declarative and procedural working memory, such as the model of Oberauer (2001, 2002, 2009), but also the influential Executive Control of Visual Attention model of Logan and Gordon (2001), have no clear answer to this question. We believe that research on instruction implementation is at the center of this issue (see also, Verbruggen, Mclaren & Chambers, 2014), and one piece of the answer will rely upon our further understanding of the concept of "preparation", which seems a crucial component translating declarative information into procedural information.

One possible way to further our understanding of the processes underlying preparation on the basis of newly instructed S-R mappings is by investigating the preparation to execute a novel instruction in real time. This could be examined by adapting a procedure developed by Kessler and Meiran (2008) in which the time characteristics of updating declarative information was investigated. In the study of Kessler and Meiran (2008) a series of screens was presented, each containing one, two or three stimuli (e.g., Screen 1: 3-5-8; Screen 2: 3-5-9; screen 3: 3-0-7; etc.). Participants were asked to always remember the last screen. At the end of each sequence of screens, participants were asked to complete a memory test of all items as presented on the last screen. The time that was needed to proceed to the next screen was used as an online measurement of updating information in working memory. To clearly state what is changed for a specific screen (n) in comparison to the previous screen (n-1), the following expression is used: number of items that changed/total number of items displayed. Consider the following example :Screen 1: 3-5-8; Screen 2: 3-5-9; screen 3: 3-0-7. Screen 2 would be expressed as followed : 1/3 and Screen 3 would be expressed as :2/3. The procedure of Kessler and Meiran (2008) was developed to test two different hypothesis. The global updating hypothesis states that whenever any item is changed, all the items in working memory have to be updated together (Kessler & Meiran, 2006), whereas the local updating hypothesis states that an item can be updated in working memory independently of other working memory content (Hazy, Frank, & O'Reilly, 2006; Vockenberg, 2006). The global updating cost compared the cost of updating working memory between different number of presented items in total while the number of changed items stayed constant (i.e., 1/1, 1/2, 1/3). As such the amount of information that changed is identical but the total amount of information varied. The local updating cost compared the cost of updating working memory between different number of changed items while the number of presented items in total stayed constant (i.e., 1/3, 2/3, 3/3). Kessler and Meiran (2008) observed both a global and local updating cost which were independent to each other We propose that this procedure of Kessler and Meiran (2008) would be extended to the updating of action rules. To this end, a series of S-R mappings could be instructed (e.g., if P press left; if Q press middle; if R press right). At the end of this series , the S-R mappings presented on the last screen have to be executed in an inducer task. Equivalent to Kessler and Meiran (2008), the local and global updating cost could be identified. Interestingly, these concepts connect nicely with the notions of S-R associations and a task-set. For example, similar to the global updating hypothesis explained above, Vandierendonck, Christiaens and Liefooghe (2008) argued that any change in a task-set component (e.g., changing one individual S-R mapping) leads to a complete rebuilding of the task set. Thus, in a first step, we could investigate whether similar updating mechanisms which are found with simple items in working memory can be identified for S-R mapping instructions. In a second step, additional manipulations could enable us to further investigate preparation. To investigate instruction preparation, the task-characteristics of the inducer task could be manipulated. For instance, in a first experiment a condition in which the S-R mappings have to be merely recalled could be compared to a condition in which the S-R mappings have to be executed. Liefooghe et al. (2012) observed an IBRC effect when the instructions of the inducer task had to be executed but not when they were merely instructed. The study proposed here would investigate whether similar differences could be observed during instruction updating. If such a dissociation could be observed then this can further extend our knowledge of the distinction between declarative and procedural working memory. Similarly, the response deadline during the inducer task could be manipulated. Liefooghe et al. (2013) showed that an IBRC effect could only be observed when there was a strict response deadline. Using the procedure of Kessler and Meiran (2008) we could again see whether we can find evidence for different levels of task preparation during the implementation of instructions. In sum, such a procedure could become a basic tool to investigate the implementation of instructions.

The representation of relational information

In Chapter 4, IBRC effects were observed on the basis of instructed R-E contingencies (e.g., If left is pressed, P appears). This observation leads to the question whether relational information is represented in working memory? Indeed, instructions, such as S-R mappings or R-E contingencies, explicitly specify relations between stimulus and response codes. The observation of an IBRC effect on the basis of R-E contingencies could suggest that this relational information is not represented in the functional associations that are formed on the basis of instructions. Neither Liefooghe et al. (2012), nor Meiran et al. (2012)

considered the issue of relational information. Liefooghe et al. (2012) only proposed that instructions can lead to the formation of task-sets. Meiran et al. (2012) propose that the Bridge represents novel bindings between stimulus and response codes that are represented in ALTM. In this conceptualization, relational information is not represented in working memory, which is supported by the results of Chapter 4.

However, the presence of IBRC effects on the basis of R-E contingencies still allows for the possibility that relational information is not represented in working memory. The representations formed on the basis of instructions may include relational information but, at the same time, lead to a congruency effect in a diagnostic task even though the order of events in this diagnostic task is incompatible with this relational information. If so, the question then becomes how relational information can be represented? One possibility is that the bindings that relate stimulus and response codes are more complex than was proposed by Meiran et al. (2012). The bindings would not only include stimulus and response codes, but also qualifiers denoting the relation between these codes. An instruction, such as “If Q, then press left”, not only activates the stimulus “Q” and the response “left” in ALTM, but also codes representing the relation “ ___ then press___”. The temporary binding in the Bridge may thus not only involve stimulus and response codes (e.g., Q-left), but also the relational qualifier between these codes (Q-then press-left). The idea that procedural working memory, contains more than unqualified bindings is in line with the Adaptive Character of Thought (ACT) model of Anderson (1976, 1993, 1996). ACT assumes that procedural information is not represented by means of S-R associations, but in terms of production rules, which are more elaborated than a mere link between a stimulus and a response. In principle, relational information provided by instructions could thus be represented in working memory. However, in view of the capacity limits of working memory relational qualifiers may not always be represented, as working-memory capacity would be exceeded (see also Chapter 4 for this point).

At this stage, we do not favor one position over the other, mainly because the results of Chapter 4 are not conclusive with this respect. Investigating whether relational information can be represented in working memory calls for more refined procedures, which measure instruction-based compatibility between relational information instructed in an inducer task and relational information experienced in a diagnostic task. A new line of research could be elaborated in which the automatic effects of instructed relations is further investigated. For instance, the procedure of Liefooghe et al. (2012) could be adapted so that the instructions of the inducer task refer specifically to relational information between two stimuli. For instance, participants could e told that Non-word 1 precedes Non-word 2 and Non-word 3 precedes Non-word 4. In the inducer task, the order of these events has to be evaluated, as fast as possible. In the diagnostic task, the identity of the non-word is irrelevant and the relevant feature is the color of the non-word. The non-words are presented in pairs and participants have to judge a particular color sequence: red-red, press key 1; red-blue, press key 2; blue-blue, press key 3; and blue-red, press key 4. The question then becomes how the irrelevant relational information (i.e., the sequence of non-word identities) affects the relevant relational information (i.e., the sequence of colors). Of course, this example is restricted to sequential relations. Nevertheless, one could think of other types of relations, such as size relations or hierarchical relations. Observing “compatibility effects” in such type of procedure, would offer us additional insights on when and how relational information is represented in working memory.

Automatic effects of merely instructed, overtly practiced and mentally practiced S-R mappings

Until now, we assumed somewhat of a dichotomy between merely instructed S-R mappings, on the one hand, and overtly practiced S-R mappings, on the other hand. This was especially the case in Chapter 2, in which we contrasted IBRC effects and the Simon effect. The rationale behind Chapter 2, was that the IBRC effect is a proxy of automatic response activations on the basis of instructions and the Simon effect is a proxy of automatic response activations on the basis of S-R associations in LTM. Such associations are supposedly established through overt practice during a participant’s learning history.

Chapter 5 of the present thesis, however, indicates that automatic effects of S-R mappings may not be restricted to merely instructed and overtly practiced S-R mappings. Indeed, the results of this Chapter 5 – making abstraction of the concerns discussed previously – indicate that S-R associations may also be formed on the basis of mental practice. Taken together, research on the implementation of novel instructions may discern three types of effects: automatic effects based on overtly practiced mappings, automatic effects based on merely instructed mappings and automatic effects based on mentally practiced mappings.

Considering these three types of effects may be useful to further understand the role of (mental) practice in the formation of associations in ALTM. Automatic effects of overtly practiced S-R mappings do not seem to be confined to working-memory limitations (Kessler & Meiran, 2010; Kiesel, Wendt, & Peters, 2007), whereas automatic effects of merely instructed S-R mappings do seem to be so (Cohen-Kdoshay & Meiran, 2007; Meiran & Cohen-Kdoshay, 2012). But what about automatic effects of mentally practiced S-R mappings? Do they attenuate when taxing working memory, as it is the case for merely instructed S-R mappings, or are they relatively immune to working-memory load, as it is the case for overtly practiced S-R mappings? It becomes clear that this is an interesting avenue for research on instructions. One possible way to investigate this issue, is by combining the procedure developed in Chapter 5 with the procedure of Liefooghe et al. (2012, 2013). Instead of merely instructing the S-R mappings of the inducer task, these mappings would now be practiced mentally following the procedure developed in Chapter 5. This practice phase would then be followed by a diagnostic task in which automatic effects of the inducer task are measured. In a first step, automatic effects of merely instructed, overtly practiced and mentally practiced S-R mappings could be compared. This could be done behaviorally, for instance by comparing the signature of these effects by using distributional analyses (e.g., Balota, & Yap, 2011; Heathcote, Popiel, & Mewhort, 1991; Luce, 1986; Ratcliff, 1979; Ratcliff & Murdock, 1976), but also neuro-physiologically, by measuring the EEG markers as was done in Chapter 3. In a second step, additional load could be placed on working memory, for instance by means of concurrent articulatory suppression (Baddeley, Lewis, & Vallar, 1984; Murray, 1968) and the impact of this additional load could be investigated.

It becomes clear that considering research on instructions in terms of merely instructed, overtly practiced and mentally practiced mappings opens a whole range of novel perspectives. Overt and mental practice can be varied in intensity (i.e., number of times) and/or quality (e.g., real and imagined feedback vs. no feedback). Accordingly, parametric manipulations along these lines can help us discover when automatic effects of overt and mental practice differ and when they do not. Finally, the consideration can be made that mental practice is perhaps a key aspect of the preparation, which is needed to translate declarative representations into procedural representations (see above).

Extensions beyond verbally instructed S-R mappings and IBRC

Research presented in the present thesis and research on automatic effects of instructions in general, mainly focuses on instructions that link a specific stimulus to a response key (i.e., S-R mappings and R-E contingencies). However, in reality instructions can encompass a wide variety information, which do not necessarily refer to a particular response. In addition, automatic effects of instructions might not necessarily take the form of a response-compatibility effect. The fact that research on the automatic effect of instructions can be extended along these lines, is illustrated by a recent study of Tibboel, Liefooghe, and De Houwer (submitted). Tibboel et al. (submitted) compared S-R mappings with stimulus-stimulus (S-S) instructions. S-S instructions inform a participants about the relationship between two arbitrary stimuli or stimulus features (e.g., the letter P will be presented in blue). By using a variant of the procedure of Liefooghe et al. (2012, 2013), Tibboel et al. (submitted) investigated attentional biases toward stimuli that were part of an S-R mapping and toward stimuli that were part of an S-S mapping. As in the procedure of Liefooghe, these mappings were only instructed. Furthermore, an adapted dot-probe task (e.g., Bradley, Mogg, Falla, & Hamilton, 1998; Posner, Snyder, & Davidson, 1980) was used as a diagnostic task, in which participants were asked to identify a probe stimulus (i.e., the letter 'E' or the letter 'F'). Before the presentation or the probe stimulus, two stimuli were presented of which one of the stimuli were part of the instructions of the inducer task. This resulted in two types of trials: compatible trials in which the location of the probe corresponded with the location of the instructed stimulus and incompatible trials in which the location of both stimuli did not correspond. Tibboel et al. (submitted) observed a compatibility effect for the S-R mappings but not for the S-S mappings.

On the one hand, the study of Tibboel et al. (submitted) illustrates that different types of instructions can be compared systematically (see also Hartstra et al., 2010). On the other hand, it indicates that automatic effects of instructions can be situated at different processing levels. Future research may thus want to elaborate his approach, which intends to identify the differences and communalities between different types of instructions. The advantage of systematically testing the automatic effect of different types of instructions within the same procedure, is that this could lead to the identification of processes that are common to the implementation of different types of instructions. By doing so, research instructions within the field of cognitive control, may be related to other domains in which learning through instructions has become important such as in research on fear conditioning (e.g., Costa, Bradley, & Lang, in press; Mertens et al., in press; Raes, De Houwer, De Schryver, Brass & Kalisch, 2014) and evaluative conditioning (e.g., De Houwer, 2006; Gast & De Houwer, 2013; Van Dessel, De Houwer, Gast, & Smith, in press).

OVERALL CONCLUSION

The present thesis aimed to elaborate our knowledge on instructions. We will not reiterate what we did learn, did not learn, and what is interesting for the future. The many novel plans for research that have been proposed in the current chapter, indicate that the present PhD thesis probably raised more questions about instructions than it actually answered. Research on instructions is in its first steps. On the one hand, research on instructions is still in search of suitable procedures and tasks. On the other hand, a strong overall framework of the different mental processes involved in the representation and implementation of instructions is still missing. In comparison to other topics in cognitive psychology, research on instructions has not yet established itself as an abundantly documented line of research. However, it seems that the topic of instructions increasingly attracts researchers with different backgrounds. As such, we believe that this topic will take a central position in the future. We hope that the present thesis is a first step in this direction.

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NEDERLANDSTALIGE SAMENVATTING

Nieuwe informatie verwerken en ons gedrag onmiddellijk aanpassen aan deze informatie is een unieke menselijke eigenschap. Daarom staan instructies centraal in ons dagelijks leven: we leren vlot die nieuwe camera gebruiken door de gebruiksaanwijzing te lezen. We nemen de juiste dosis van onze medicijnen op basis van het doktersvoorschrift. Wanneer we in een nieuwe stad zijn, vinden we vlot die ene winkel door het even te vragen aan een voorbijganger. Instructies zijn een vlugge route naar een ontogenetische aanpassing die 'gissen en missen' overbodig maken.

Ook in het psychologisch onderzoek nemen instructies een belangrijke plaats in. In vele experimenten wordt er aan de proefpersonen gevraagd om een nieuwe taak met nieuwe regels uit te voeren. Deze nieuwe regels worden gewoon aan het begin van het experiment aan de proefpersoon meegedeeld. Desondanks dat proefpersonen dit nog nooit in hun leven deden, zijn ze zeer goed in staat om deze nieuwe regels correct uit te voeren. Deze instructies spelen dus een grote rol in psychologisch onderzoek, maar de onderliggende dynamieken zijn pas recent het onderwerp van onderzoek. Waarom dit onderwerp in het verleden niet veel aandacht kreeg, zou te verklaren kunnen zijn door het gegeven dat één enkele uitvoering van instructies de nieuwheid van deze instructies ongeldig maakt (Cole, Bagic, Kass & Schneider, 2010).

Recent werden er verschillende procedures ontwikkeld die in staat zijn om instructies, en meer bepaald de automatische effecten die deze instructies veroorzaken, te onderzoeken (voor een overzicht zie Chapter 1; Liefooghe, De Houwer & Wenke, 2012; Meiran, Cole & Braver, 2012). Bijvoorbeeld, Liefooghe et al. (2012) ontwikkelden een procedure om een automatische response activatie op basis van instructies te onderzoeken. In deze procedure werden verschillende reeksen aangeboden die telkens uit twee verschillende taken bestonden, de induceer taak en de diagnose taak. In de induceer taak werden steeds twee arbitraire stimulus-response (S-R) regels aangeboden. In deze S-R regels werd steeds de identiteit van een stimulus gekoppeld aan een linkse of rechtse response (e.g., Als P, druk links; Als Q, druk rechts). Tussen het aanbieden van deze S-R regels van de inducer taak en de uitvoering van de inducer taak, voerden de proefpersonen de diagnose taak uit waarin dezelfde stimuli en responses gebruikt werden. In de diagnose taak beslisten proefpersonen of een stimulus rechtop of cursief gedrukt stond, door eveneens de linkse of rechtse response te geven (e.g., rechtop, druk links; cursief, druk rechts). Liefooghe et al. (2012) observeerden dat proefpersonen sneller waren en soms ook minder fouten maakten in de diagnose taak wanneer de responses overeen kwamen met de instructies van de inducer taak (e.g., P rechtop gepresenteerd; *Q* in cursief gepresenteerd) dan wanneer de responses niet overeen kwamen met de instructies van de inducer taak (e.g., *P* in cursief gepresenteerd; Q rechtop gepresenteerd). Omdat deze diagnose taak vlak na de instructies van de inducer taak werd uitgevoerd en dus voordat deze instructies toegepast werden, kon er geconcludeerd worden dat het congruentie-effect dat geobserveerd werd in de diagnose taak gebaseerd was op deze nieuwe geïnstrueerde S-R regels.

HUIDIGE PHD THESIS

Het doel van deze thesis was meer inzicht te verkrijgen in de effecten van instructies. Enerzijds bereidden we het onderzoek naar de karakteristieken van instructie-gebaseerd congruentie effect verder uit in de eerste onderzoekslijn. Anderzijds, in de tweede onderzoeklijn, onderzochten we hoe effecten en instructies gerelateerd zijn aan elkaar.

Instructie-gebaseerde congruentie-effecten

De eerste onderzoekslijn bestaat uit drie hoofdstukken. In **Hoofdstuk 2,** onderzochten we de relatieve kracht van instructie-gebaseerde congruentie-effecten wanneer deze vergeleken werden met congruentie-effecten die gebaseerd zijn op voorheen geleerde relaties. Om dit te testen werd de interactie tussen instructie-gebaseerde response congruentie (IBRC) en het

Simon effect (Simon & Rudell, 1967) was onderzocht. Hiervoor werd een aangepaste versie van de procedure van Liefooghe et al. (2012, 2013) gebruikt. In deze procedure refereerde de induceer taak naar spatiaal compatibele S-R regels (e.g., als de stimulus gepresenteerd wordt aan de linkerkant, druk links; als de stimulus gepresenteerd wordt aan de rechterkant, druk rechts) of spatiaal incompatibele S-R regels (e.g., als de stimulus gepresenteerd wordt aan de linkerkant, druk rechts; als de stimulus gepresenteerd wordt aan de rechterkant, druk links) en de diagnostische taak was een Simon taak. In een Simon taak reageren proefpersonen op een locatie-irrelevant stimulus kenmerk, in dit geval de kleur van de stimulus met een locatie-relevante response, in dit geval een linker- en rechter responseknop (e.g., Als blauw druk links; Als groen, druk rechts). Belangrijk is dat de stimuli aan de linker- of rechterkant van het scherm worden gepresenteerd, zodat er een compatibiliteit ontstaat tussen de irrelevante stimulus-locatie en de relevante response-locatie (i.e., het Simon effect). We observeerde dat spatiaal incompatibele S-R regels die enkel geïnstrueerd worden, voldoende waren om het Simon effect the elimineren. Daarentegen vonden we dat spatiaal compatibele S-R regels het Simon effect niet vergrootten. Ten slotte konden we geen verschil observeren tussen enkel geïnstrueerde en matige geoefende incompatibele S-R regels.

Gebaseerd op deze resultaten concludeerden we dat de eliminatie van het Simon effect was gebaseerd op de competitie tussen response-activatie door lange-termijn associaties en response activatie door korte-termijn associaties die gevormd worden op de basis van instructies. Enkele alternatieve verklaringen konden niet geheel uitgesloten worden. Ten eerste, proefpersonen spatiaal incompatibele S-R regels aanbieden kon resulteren in een toename van cognitieve controle. In lijn met de theorieën van conflict-adaptatie (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). Door het implementeren van een spatiaal incompatibele S-R regel zou het kunnen dat proefpersonen meer gewicht toewezen aan het relevante taakkenmerk van de Simon taak en daardoor negeerden ze de irrelevante kenmerken wat leidde tot de eliminatie van het Simon Effect. Ten tweede, het onthouden van de additionele S-R regel kon leidden tot een zodanige hogere druk op het werkgeheugen zodat er geen

Simon effect kon geobserveerd worden. Voorgaand onderzoek naar het Simon effect (e.g., Proctor, Miles, & Baroni, 2011), vond meermaals evidentie dat wanneer het werkgeheugen onder druk gezet word tijdens de Simon taak de irrelevante taak kenmerken niet gerepresenteerd worden in werkgeheugen zodat het Simon effect verdwijnt. Ten slotte, het presenteren van spatiaal incompatibele S-R regels kon geleid hebben tot een verandering in strategie. Proefpersonen konden aangemoedigd worden om een tegengestelde-response strategie te gebruiken waarin ze tegengesteld antwoorden aan de intuïtieve responsetendensen. Vu (2007) argumenteerde dat zo een strategie eveneens kan leiden tot een afwezigheid van een Simon effect, maar enkel wanneer deze uitgebreid geoefend werden. Hoewel we in Hoofdstuk 2 konden argumenteren dat deze alternatieve verklaringen niet erg waarschijnlijk zijn, kan verder onderzoek aangewezen zijn om deze definitief uit te sluiten.

In **Hoofdstuk 3,** werd een fundamentele vraag over instructie-gebaseerde congruentie-effecten behandeld. Meer bepaald of deze over instructie-gebaseerde congruentie-effecten gebaseerd zijn op automatische response-activatie. Voor deze instructie-gebaseerde congruentie-effecten bestaan namelijk eveneens alternatieve verklaringen (zie Meiran, Cole, & Braver, 2012 voor voorbeelden). Hoofdstuk 3 bood meer direct bewijs voor automatische response-activatie op de basis van instructies door gebruik te maken van elektrofysiologische maten, namelijk lateralized readiness potentials (LRPs). Deze LRPs meten de activiteit in de motor cortex. De LRP week af in de richting van de response-tendensen die correspondeerden met de geïnstrueerde S-R regels. Er werd vroege activatie van de geïnstrueerde response geobserveerd, vooral op de trage trials. Deze resultaten bieden sterk bewijs dat, net zoals geoefende S-R regels, geïnstrueerde S-R regels kunnen leiden tot automatische response-activatie. Deze conclusie van Hoofdstuk 3 werd reeds bevestigd door een recente studie van Meiran, Pereg, Kessler, Cole, en Braver (in press a), die de resultaten van Hoofdstuk 3 repliceerden in een licht afwijkende procedure.

In **Hoofdstuk 4** onderzochten we of automatische effecten van instructies beperkt waren tot S-R regels. Daarom werd een andere type relatie bekeken, namelijk response-effect (R-E) contingenties. Een R-E contingentie specificeert de contingentie tussen een specifieke response en het effect dat deze response veroorzaakt in de omgeving. Voorgaand onderzoek toont aan dat er sterk bewijs is dat het compatibiliteitseffect kan verkregen worden op basis van incidenteel geleerde R-E contingentie fase (voor een review zie Shin, Proctor & Capaldi, 2010). In hoofdstuk 4 testten we of zo een compatibiliteitseffect eveneens verkregen kan worden voor R-E contingenties die enkel geïnstrueerd werden. In een reeks van drie experimenten pasten we de procedure van Liefooghe et al. (2012, 2013) aan zodat in de inducer taak nu bestond uit geïnstrueerde R-E contingenties in plaats van geïnstrueerde S-R regels. De resultaten van Hoofdstuk 4 toonden aan dat response compatibiliteitseffecten niet beperkt zijn tot S-R regels. Daarnaast bieden de resultaten additioneel bewijs dat deze compatibiliteitseffecten wel degelijk gebaseerd zijn op instructies. Meiran en collega's (Meiran et al. 2012; in press a; Meiran, Pereg, Kessler, Cole & Braver, in press b) argumenteerden dat met een dergelijke procedure de effecten het gevolg kunnen zijn van verkeerdelijk oefenen van de diagnose taak. Doordat proefpersonen de verkeerde taak, namelijk de inducer taak, zouden kunnen uitvoeren tijdens de diagnose taak, kunnen de regels van de inducer taak niet meer puur geïnstrueerd zijn. In hoofdstuk 4 was er maar een minimale overlap tussen deze twee taken en was het hoogst onwaarschijnlijk dat de inducer taak werd uitgevoerd, en dus geoefend, tijdens de diagnose taak. Daarom konden we concluderen de geobserveerde effecten in dit hoofdstuk hoogst waarschijnlijk enkel gebaseerd zijn op geïnstrueerde R-E contingenties.

De effecten van het inoefenen van instructies

In **Hoofstuk 5** onderzochten we de toegevoegde waarde van fysieke en mentale oefening ten opzichte van het implementeren van nieuwe instructies. Om dit te onderzoeken werd een 'virtueel typen' procedure ontwikkeld. Deze procedure liet toe om de prestaties te onderzoeken van de centrale processen, zoals response selectie, en meer perifere processen die instaan voor response executie. De resultaten van hoofdstuk 5 suggereerden dat wanneer een instructie fysiek geoefend word dit leidt tot een verbetering in zowel de centrale als perifere processen. Maar wanneer een instructie mentaal geoefend werd, leidt dit enkel tot een verbetering van de centrale processen. Deze resultaten werden geïnterpreteerd binnen het kader van Ruge en Wolfensteller (2010). Deze auteurs argumenteerden dat het implementeren van instructies leidt tot de formatie van een initiële representatie. Wanneer deze instructies geoefend worden, wordt er een meer gedetailleerde representatie gevormd. Die bevatten de lage-level kenmerken die nodig zijn voor nagenoeg automatische uitvoering (zie ook Ramamoothy & Verguts, 2012). Wij stellen voor dat mentale oefening eveneens leidt tot een additionele taak representatie zoals fysieke oefening, maar wel een minder gedetailleerde representatie. Maar andere verklaringen zijn eveneens mogelijk. Ten eerste, er zou geargumenteerd kunnen worden dat mentale oefening niet leidt tot een additionele taak representatie maar wel leidt tot een verbetering van de processen die instaan voor het onderhouden en toepassen van de initiële representatie die gevormd werden op basis van instructies. Ten tweede, het zou kunnen dat de resultaten van hoofdstuk 5 niet het direct gevolg zijn van mentale oefening maar eerder doordat proefpersonen de instructies verbaal repeteerden wat eveneens de prestatie kon verbeteren. Ten slotte kunnen we de aanwezigheid van microbewegingen tijdens het mentaal oefenen niet uitsluiten. Voor en na elke mentaal uitgevoerde response werd de spatiebalk ingedrukt. Daardoor was de response-vinger niet helemaal gefixeerd tijdens deze mentale oefenfase met als gevolg dat proefpersonen taak-relevante bewegingen verwerkt zouden kunnen hebben in het interval tussen de twee spatiebalken responses. Verder onderzoek is nodig om deze alternatieve verklaringen uit te sluiten.

Ten slotte, in **Hoofdstuk 6** onderzochten we de verschillen tussen geïnstrueerde en geoefende S-R regels in relatie tot mentale flexibiliteit. Voorgaand onderzoek in het taakafwisseling paradigma (zie Kiesel et al., 2010; Monsell, 2003; Vandierendonck, et al., 2010, voor reviews) tonen aan dat het veranderen van S-R regels leidt tot een prestatiekost. Taakafwisseling onderzoek is echter vooral gebaseerd op reeds ingeoefende S-R regels. In hoofdstuk 6 testten we of het veranderen van S-R regels die enkel geïnstrueerd zijn eveneens leidt tot een kost in prestaties. Daarenboven vergeleken we deze kost met de prestatiekost die geïnduceerd wordt wanneer S-R regels geoefend worden. De resultaten suggereren dat het veranderen van enkel geïnstrueerde S-R regels een globale kost in de verwering induceert maar dat het veranderen van geoefende S-R regels leidt tot additionele prestatiekosten. Deze additionele kosten kunnen waarschijnlijk toegeschreven worden aan de automatische activatie van S-R associaties die enkel abstracte stimulus en response codes bevatten. Deze conclusie is gebaseerd op de observatie dat de additionele prestatiekost die geassocieerd is met het veranderen van geoefende S-R regels transfereren over verschillende response effectoren. Hoofdstuk 6 is eveneens belangrijk omdat het een vergelijking bevat tussen leren op basis van instructies en leren door oefening. Tot op heden werden deze nog niet systematisch vergeleken (maar zie Wenke et al., in press). Hoofdstuk 6 suggereert dat enkel geïnstrueerde S-R regels en geoefende S-R regels leiden tot verschillende effecten. Verder onderzoek is aangewezen.

CONCLUSIE

De huidige thesis had tot doel om onze kennis over instructies uit te breiden. Hoewel we er in slaagden om in elk hoofdstuk onze kennis over instructies te vergroten, blijven vele vragen over instructies onbeantwoord. Het onderzoek naar instructies zet momenteel zijn eerste stapjes. Ten eerste zijn we nog steeds op zoek naar de beste procedures en taken om instructies optimaal te onderzoeken. Ten tweede ontbreekt er alsnog een overkoepelend kader van de verschillende processen die een rol spelen bij het representeren en implementeren van instructies. In vergelijking met andere onderwerpen binnen de cognitieve psychologie heeft het nog een brede onderzoeksbasis . Dit is volop aan het veranderen, aangezien het meer en meer aandacht trekt van verschillende onderzoekers met een verschillende achtergrond. Daarom geloven we dat dit onderwerp een centrale rol zal spelen in de toekomst en we hopen dat de huidige thesis een eerste stap in die richting kan zijn.

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