Instruction-based task-rule congruency effects

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Abstract

The present study investigated the functional characteristics of task-sets that were never applied before and were formed only on the basis of instructions. We tested if such task-sets could elicit a task-rule congruency effect, which implies the automatic activation of responses in the context of another task. To this end, a novel procedure was developed that revealed instruction-based task-rule congruency effects in two experiments. Although the effect seems quite general (Experiment 1) it still necessitates the formation of a task-set as it cannot be induced by the mere maintenance of instructions in declarative working memory (Experiment 2). We conclude that a task-set representing only key features of an upcoming task can be formed on the basis of instructions alone to such a degree that it can automatically trigger a response tendency in another task. Implications of our results for the impact of instructions on performance in general, and for the occurrence of task-rule congruency effects in particular, are discussed.

Keywords: task-set, task switching, task-rule congruency, instructions

Instruction-based task-rule congruency effects

Goal-directed behavior is assumed to be based on task-sets that specify and group the control settings of different task-related processes, such as stimulus identification, response selection, and response execution (e.g., Vandierendonck, Liefooghe, & Verbruggen, 2010). While the functional properties of task-sets have been studied extensively in the task-switching paradigm (see, Kiesel et al., 2010; Monsell, 2003; Vandierendonck et al., 2010 for reviews), only little is known on how task-sets are formed when the instructions of a particular task are presented. This is surprising because it seems obvious that instructions play an important role, for instance, by indicating which task to perform or how a task must be performed. Accordingly, the present study further investigated the functional characteristics of task-sets formed only on the basis of instructions. We tested if a task-set that is formed on the basis of instructions meant for a particular task that has not yet been executed, can elicit automatic response tendencies despite being irrelevant in the context of another task. This was done by using the task-rule congruency effect.

Task-Rule Congruency

The task-rule congruency effect is a robust finding in task-switching studies that require participants to switch between two tasks (e.g., shape or color judgment) that share stimuli (e.g., colored shapes) and responses (e.g., a left or right response key; see, Kiesel et al., 2010; Monsell, 2003; Vandierendonck et al., 2010 for reviews). Each response thus has two “meanings” (e.g., circle and red for the left response and square and green for the right response) and stimuli trigger these two meanings, with one related to the relevant task and the other related to the irrelevant task. The task-rule congruency effect refers to the finding that RTs are shorter when both response meanings point toward the same physical response (e.g., press the left response key for a red circle) than when both response meanings point toward different responses (e.g., press the left response key for a green circle). The task-rule congruency thus is a response-compatibility effect that results from the activation of a task-irrelevant response.

The task-rule congruency effect was initially interpreted as a marker for the interference of task-sets in working memory (e.g. Meiran, 1996, 2000; Rogers & Monsell, 1995). When frequent task switching is imposed, two task-sets are concurrently represented in the capacity-limited portion of working memory that involves the most accessible subset of representations, to which we refer as the direct-access region (see also, Oberauer, 2009, 2010). Because both task-sets are simultaneously active to a certain degree and both tasks overlap, task-irrelevant responses are triggered. Research, however, challenged this interpretation in two ways. First, the task-rule congruency effect does not seem to be dependent on the capacity-limitations of the direct-access region, because adding a concurrent load during task switching does not modify the task-rule congruency effect (Kessler & Meiran, 2010; Kiesel, Wendt, & Peters, 2007). Second, changing the difference in activation between both task-sets, for instance by preparing one task more in advance, does not modify the task-rule congruency effect (see, Yamagushi & Proctor, 2011 for an extensive test).

These findings suggest that the task-rule congruency effect does not reflect interference between task-sets in the direct-access region. Additional findings suggest that the task-rule congruency effect might instead originate from the retrieval of S-R associations that are represented in the part of working memory that has a virtually unlimited capacity, namely active long-term memory (e.g., Oberauer, 2009, 2010). More precisely, it has been observed that the amount of practice stimuli receive in task, significantly influences the task-rule congruency effect. For example, Kiesel et al. (2007) demonstrated that the task-rule congruency effect was much stronger for stimuli that were frequently encountered in the context of the now-irrelevant task compared to stimuli that were not previously encountered in the context of the now-irrelevant task. Furthermore, Meiran and Kessler (2008) demonstrated that for novel and arbitrary S-R mappings, practice is needed in order to obtain the task-rule congruency effect. However, for S-R mappings referring to accessible and preexisting response codes such as ‘up’ or ‘down’, the task-rule congruency effect immediately shows up. These results suggest that the task-rule congruency effect is triggered by specific S-R associations (e.g., ‘8-left’) that are represented in long-term memory either because they are preexisting or because they are formed on the basis of practice. These S-R associations then subsequently trigger responses in the context of another task.

Taken together, it seems that a task-set formed on the basis of task-instructions alone cannot elicit a task-rule congruency effect. Findings by Waszak, Wenke, and Brass (2008) are in line with this view. These authors compared the task-rule congruency effect for irrelevant S-R mappings that were previously executed with the task-rule congruency effect for irrelevant S-R mappings that were instructed but never executed. A task-rule congruency effect was observed only for irrelevant S-R mappings that had been executed previously.

Instruction-based response activation

Although research on task switching does not offer strong support for the hypothesis that a task-set solely formed on the basis of instructions may lead to automatic response activations in the context of another task, other research does offer some indications that merely instructed S-R mappings can activate responses automatically. Cohen-Kdoshay and Meiran (2007, 2009) adapted a flanker task (Eriksen & Schultz, 1979) in order to investigate the automatic activation of responses on the basis of instructions. At the beginning of each experimental block, participants were presented with a new stimulus-set and with a new pair of category-to-response mappings (e.g., if a number is even, then press left; if a number is odd, then press right). The authors observed a flanker-compatibility effect for targets and flankers that were encountered for the first time. This effect was present early on after the onset of the instructions (Cohen-Kdoshay & Meiran, 2007) and even on the very first trial following the instructions (Cohen-Kdoshay & Meiran, 2009). Cohen-Kdoshay and Meiran (2007, 2009), however, used single-task situations which implies that the task-set formed on the basis of the instructed category-response mappings was relevant for the task at hand. The question thus remains if responses are activated on the basis of instructions that are irrelevant for the task at hand, as it is the case for the task-rule congruency effect.

There exists some evidence in favor of such hypothesis. De Houwer, Beckers, Vandorpe, and Custers (2005, Experiment 2) instructed participants with the S-R mappings of three tasks with each task requiring the verbal responses ‘bee’ and ‘boo’. The first two tasks were location-relevant tasks in which these responses were to be made to the words left and right or to left- and right-pointing arrows. The third task was location-irrelevant and required participants to respond to the color of a dot that randomly appeared on the left or the right-side of the screen. Participants first performed the location-irrelevant task and were asked to keep the S-R mappings of the location-relevant tasks active because they may have to perform these tasks at any time. In reality, the stimuli for the location-relevant tasks never appeared. For the location-irrelevant task, De Houwer et al. (2005) observed a small but significant influence of the congruency between the dot location (left vs. right) and the location with which the responses ‘bee’ and ‘boo’ were linked via the instructions of the location-relevant tasks (left vs. right). This finding indicates that left and right stimuli activated responses on the basis of instructions.

Wenke and colleagues (Wenke, Gaschler, & Nattkemper, 2007; Wenke, Gaschler, Nattkemper, & Frensch, 2009) used a procedure in which participants first received arbitrary S-R mappings of a letter task (e.g., if P press left key; if L press right key). These mappings were to be applied in a delayed letter task, in which one of the letters was presented and participants had to respond on the basis of the instructed S-R mappings. Before the onset of this letter, participants performed an embedded size task. The size task involved two adjacent letters with different font sizes. Participants judged if the bigger letter appeared on the left or on the right by pressing a central response key once or twice. Responses in the size task were slower when the letter position on the screen was incompatible with the response locations assigned to these letters in the instructed S-R mapping than when the left-right positions were compatible with the response locations of the instructed S-R mappings. Wenke et al. (2007, 2009) also observed similar but smaller effects when the stimulus position in the size task was irrelevant and participants had to decide if the bigger letter was presented in a particular color.

The findings of De Houwer et al. (2005) and Wenke et al. (2007, 2009) suggest that a task-set that is based solely on instructed S-R mappings can influence performance even when the instructed mappings are irrelevant for the current task. However, it is not entirely clear to which extent the effects in these studies are indeed due to the automatic activation of a task-irrelevant response. In the studies of Wenke et al. (2007, 2009), responses during the size task (press 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. While the study of De Houwer et al. (2005) may provide more direct evidence, their results in part rely upon the over-learned 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 location-relevant tasks. As such, their results are based on the Simon effect (see, Simon, 1990 for a review), and it is unclear if an instruction-based response activation could equally be observed without the presence this latter effect.

The Present Study

Taken together, it remains unclear whether a task-set formed on the basis of instructions alone can also lead to a task-rule congruency effect. While evidence from Meiran and Kessler (2008), Kiesel et al. (2007), and Waszak et al. (2008) indicated that prior execution is an important prerequisite, the studies used by De Houwer et al. (2005) and Wenke et al. (2007, 2009) provided evidence in favor of this hypothesis. However, the latter studies do only offer indirect evidence for the hypothesis that a task-set formed on the basis of instructions can automatically trigger responses in another task. In order to shed new light on this issue, we devised a procedure for investigating automatic response activation on the basis of task-irrelevant instructions, which was closely modeled after the procedures used by De Houwer et al. (2005) and Wenke et al. (2007, 2009), on the one hand, but permitted the measurement of a task-rule congruency effect as defined in task-switching research, on the other hand.

Our procedure (see Figure 1 for an outline) involved two types of tasks, an inducer task and a diagnostic task. Each run of trials started with the presentation of a pair of S-R mappings for the inducer task. These mappings indicated how to respond to the identity of a probe stimulus (letters, digits, or symbols) presented later on (e.g., if N press left; if P press right). Between the onset of the S-R mappings and the onset of the probe, several trials of the diagnostic task were presented. The stimuli and responses in the diagnostic task were the same as in the inducer task. However, the identity of the stimuli was irrelevant for the diagnostic task and participants had to respond to the orientation of the stimuli (upright or *italic* font). Participants performed several of these runs, each with a new pair of stimuli for the inducer and the diagnostic task. The number of trials the diagnostic task had to be performed varied across runs such that the probe onset was unpredictable and participants were encouraged to be constantly ready to respond to the probe of the inducer task.

Participants were thus submitted to a dual-task situation, consisting of an S-R task (the inducer task) and a categorization task (the diagnostic task) and the question was how the instructions of the S-R task influenced responding in the categorization task. Based on previous findings (e.g., De Houwer et al., 2005; Wenke et al., 2007, 2009), we hypothesized that in order to respond adequately in the inducer task, which involves the correct application of one of the two instructed S-R mappings, participants will prepare for that task by forming a task-set, in which the instructed S-R mappings are represented as functional S-R associations. The question was if a task-rule congruency effect would emerge in the diagnostic task on the basis of that task-set.

The present study not only tested for the presence of an instruction-based task-rule congruency effect. In order to better understand its representational underpinnings we also investigated the boundary conditions to obtain this effect. More precisely, in Experiment 1 we manipulated the degree of overlap in responses between the inducer and the diagnostic task. The results showed that even for physically different but conceptually overlapping responses an instruction-based task-rule congruency effect was present. This finding indicates that the instruction-based task-rule congruency effect is robust and is based on task-sets for the inducer task that code only minimal conceptual information. The presence of the effect for conceptually overlapping responses however may suggest that the effect is very general and can even be obtained when participants merely have to maintain the two instructed S-R mappings, without having to prepare for applying them. This was ruled out in Experiment 2, in which, an instruction-based task-rule congruency effect was only observed under conditions of intended enactment (Freeman & Ellis, 2003).

Experiment 1

In Experiment 1, we tested for the presence of an instruction-based task-rule congruency effect by using the aforementioned procedure. Besides using a condition in which the responses of the inducer and the diagnostic task fully overlapped, we also employed variants in which the overlap in responses between both tasks was manipulated. This was done because we were interested in the nature of the codes and associations represented in task-sets that are formed on the basis of instructions. We assumed that these task-sets represent S-R associations that are described by the instructions of the inducer task (e.g., if Q, then press left). When forming a task-set on the basis of these instructions, an S-R association is implemented but it remains unclear what information is represented in this association. Three possibilities arise. First, the S-R association may include a representation of a specific response key (e.g., if Q, then press that specific left response-key). Second, the S-R association might only contain physical information pertaining to the side of the response, without specifying the response key that has to be pressed (e.g., if Q, then press left). Third, the S-R association might simply link a specific stimulus with a particular response concept such as left and right, without any further specification (e.g., if Q, then left).

In order to discriminate between these three alternatives, the degree of overlap between the responses of the inducer and the diagnostic task was manipulated across three conditions. In the first condition, the same left and right response-keys were used in the inducer and diagnostic task (Same Response-Keys condition). In the second condition, the Different Response-Keys condition, both tasks still required responses with the left and the right hand, but both tasks used different response-keys. Finally, in the third condition, both tasks still required ‘left’ and ‘right’ responses, but now the diagnostic task was performed verbally (Verbal Diagnostic Task condition). If response codes represented in a task-set that is solely formed on the basis of instructions are highly specific, then the instruction-based task-rule congruency effect should be restricted to the Same Response-Keys condition. If only response modality is represented, then the effect should be present both in the Same Response-Keys and in the Different Response-Keys condition, but not in the Verbal

Diagnostic Task condition. Finally, if response modality is not included, then the effect should be present also in the Verbal Diagnostic Task condition.

Method

Participants

Fifty-two participants students at Ghent University participated for course requirement or credit. All participants had normal or corrected-to-normal vision and all were naïve to the purpose of the experiment.

Design

Experiment 1 consisted of three between-subjects conditions to which participants were randomly assigned: the Same Response-Keys condition (n= 17), the Different Response-Keys condition (n=18), and the Verbal Diagnostic Task condition (n=17). In each of these conditions the overlap in responses between the inducer and the diagnostic task was different. The within-subjects factor in each of these condition was Task-rule Congruency. Task-rule congruency was defined based on the relation between the instructed S-R mappings of the inducer task (e.g., press left for N; press right for P) and the response required by the diagnostic task (e.g., press left for upright; press right for italic). If the same response was required in both tasks (e.g., press left for N printed upright) a trial was congruent. If a different response was required in both tasks (e.g., press right for *N* printed in italic) a trial was incongruent. In the diagnostic task RTs and error rates were measured. In the inducer task, the encoding time (time between the onset of the S-R mappings and participants' press on the spacebar), decision time (time needed for responding to the probe), and decision-error rates were measured.

Materials

A list of fifty-six stimuli consisted of letters, numbers and single character symbols (e.g., #, @). For each participant, a set of 28 pairs of stimuli was randomly constructed on the basis of this list. These pairs were randomly assigned to four blocks. The 7 pairs of each block were randomly assigned to the 7 runs within each block (4 runs with 4 trials of the diagnostic task, 2 runs with 8 trials, and 1 run with 16 trials). Each pair of stimuli was used for only one run.

In the diagnostic task, participants had to decide whether a stimulus was printed normally or in italic by pressing a left or a right key. Response assignment of the diagnostic task was determined randomly across participants. In the inducer task, one of the stimuli presented in the instructed S-R mappings was presented in green as a probe and participants had to respond to its identity according to the instructed S-R mappings, again by pressing a left or a right key.

In the Same Response-Keys condition, the inducer task and the diagnostic task used the same pair of stimuli and the same pair of left-right keys, namely the ‘A’- and the ‘P’-key on an AZERTY keyboard. In the Different Response-Keys condition, both tasks used the same response hands, but different response keys. The inducer task could be assigned to the middle fingers (‘A’ and ‘P’ on an AZERTY keyboard) of both hands and the diagnostic task to the index fingers (‘E’ and ‘I’), or vice versa. Participants in the Different Response-Keys condition were randomly assigned to different combinations of these response mappings. For the diagnostic task of the Verbal Diagnostic Task condition, participants had to respond to the stimulus orientation by saying aloud the words ‘links’ (Dutch for left) or ‘rechts’ (Dutch for right), whereas the inducer task required the same left and right key-press responses as the Same Response-Keys condition. In the Verbal Diagnostic Task condition, RTs were registered by a Reacsys R-51 voice-key attached to the computer. Error rates were registered by the experimenter.

Stimuli for both tasks were presented at the centre of a white screen in Arial font, size 36. S-R mappings were presented in Arial font, size 16. The S-R mappings were presented randomly one above the other in the screen centre, 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 by means of a personal computer with a 17-inch color monitor running Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Instructions were presented on screen and paraphrased subsequently. Four blocks of 7 randomly ordered runs (or 48 trials of the diagnostic task) 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. The S-R mappings remained on screen until participants pressed the spacebar or a maximum time of 20 seconds elapsed. The first stimulus of the diagnostic task was presented 750 ms after the S-R mappings were removed from the screen. Each stimulus in the diagnostic task remained on screen until participants responded or a maximum response time of 2000ms elapsed. Depending on the length of the run, participants performed 4, 8, or 16 trials of the diagnostic task with an inter-trial interval of 750ms. Finally, 750ms after the last response of the diagnostic task, the green probe stimulus appeared, which remained on screen for 2000ms or until participants responded. A new run started 1500 ms after performing the inducer task. After each incorrect response, the screen turned red for 200ms. The experiment lasted for approximately 30 minutes.

Results

Diagnostic Task

The first block was considered practice and not analyzed. Furthermore, only RTs of correct trials were analyzed. In addition, only runs on which the inducer task was performed correctly were considered (data loss: 15%). RTs and accuracies were each subjected to a 3 (condition: Same Response-Keys, Different Response-Keys or Verbal Diagnostic Task) by 2 (congruency: congruent or incongruent) mixed ANOVA with repeated measures on the last factor[1]. For all analyses reported in the present study, the alpha-level was .05. Means and standard deviations of these variables are presented in Table 1.

For the RTs, the main effect of condition was significant, $F(2,49)= 3.60$, $MSE= 15783$, $\eta_p^2= .13$. RTs were longer in the Verbal Diagnostic Task condition (M=784) compared to the Same Response-Keys condition (M=707), $t(32)= 2.33$, $r^2=.15$, and compared to the Different Response-Keys condition (M=723), $t(33)= 2.26$, $r^2=.13$. RTs on both latter conditions did not differ significantly, $t<1$. The main effect of congruency was also significant, $F(1,49)= 17.33$, $MSE= 839$, $\eta_p^2= .26$. RTs on incongruent trials (M=750) were longer than RTs on congruent trials (M=726). Both main effects did not interact, $F<1$. In all three conditions (see Table 1), an instruction-based task-rule congruency was present (Same Response-Keys condition: $t(16)= 2.26$, $r^2=.24$; Different Response-Keys condition: $t(17)= 2.73$, $r^2=.30$; Verbal Diagnostic Task condition: $t(16)= 2.22$, $r^2=.23$).

For the error rates, the main effect of condition was not significant, $F<1$, but the main effect of congruency was, $F(1,49)= 17.54$, $MSE= .000749$, $\eta_p^2= .26$. Error rates were smaller on congruent trials (M=.04) than on incongruent trials (M=.07). The two-way interaction was also significant (see Table 1), $F(2,49)= 8.62$, $MSE= .000749$, $\eta_p^2= .26$. While an instruction-based task-rule congruency effect was present in the Same Response-Keys condition, $t(16)=3.53$, $r^2=.43$, and the Different Response-Keys condition, $t(17)=4.52$, $r^2=.54$, no such effect was present in the Verbal Diagnostic Task condition, $t(16)= 1.12$, $p>.13$, $r^2=.08$. In other words, the error rates were thus only partly in line the RT-data, which might suggest that with respect to the task-rule congruency effect, RT and error-rates are elicited by different processes (e.g., Meiran & Kessler, 2008). Yet, in view of the absence of an effect in this one contrast, it would be premature to draw conclusions at this stage

Inducer Task

Three separate ANOVAs, each with condition as a between-subjects factor, were conducted on the encoding time, decision time, and decision-error rates. The means and corresponding standard deviations of these variables are also presented in Table 1. Encoding times and decision times did not vary as a function of condition, F<1 and F(2,49)= 1.80, p>.15, MSE= 53790, η_p^2= .07, respectively. In contrast, decision error rates did vary significantly with condition, F(2,49)= 10.99, MSE= 0.003568, η_p^2= .31. Decision error rates were smaller in the Same Response-Keys condition, compared to the Different Response-Keys condition, t(33)=3.50, r^2=.27, and the Verbal Diagnostic Task condition, t(32)=4.41, r^2=.37. Decision error rates did not differ significantly between the latter two conditions, t(33)=1.66, p>.1, r^2=.08.

Discussion

RTs in the diagnostic task were longer for incongruent trials than for congruent trials, indicating the presence of an instruction-based task-rule congruency effect. Furthermore, the size of the effect did not depend on the degree of response overlap between the diagnostic and the inducer task. In all three conditions, the instruction-based task-rule congruency effect was present on the RTs of the diagnostic task. Our results are important for a number of reasons. First, they indicate that a reliable instruction-based task-rule congruency effect can be observed. This is important because this demonstrates that merely instructed task-sets can lead to automatic response activations, which suggest that there can be interference between tasks sets in working memory. Second, the effect appears to be robust and general given that it occurred even for tasks that do not share the same physical responses and even when these responses are produced in different modalities. This suggests that the S-R associations represented in the instruction-based task-set primarily involve abstract codes such as the concepts “left” and “right”. Response features such as the specific finger of a hand required for responding in the Different Response-Keys condition, or even the response modality do not seem to be represented at all, or the weight these features receive in the task-set is negligibly small (e.g., Hommel, Müsseler, Aschersleben, & Prinz, 2001). This conclusion is consistent with previous research in the task-switching paradigm, which also observed the task-rule congruency effects with responses that only overlap conceptually (e.g., Gade & Koch, 2007; Hübner & Druey, 2006; Schuch & Koch, 2004). It is also in line with research on different types of congruency and compatibility effects that indicate a preference for rather abstract distal coding (for an overview, see Hommel et al., 2001).

Experiment 2

The results of Experiment 1 indicate that the instruction-based task-rule congruency effect is quite general. In view of this finding, the question arises whether it depends on forming an intention to actually perform the instructed task later, or whether the mere maintenance of the instructed S-R mappings is sufficient for obtaining the effect. Several studies demonstrated that declarative information maintained in working memory can bias performance even when this information is irrelevant for the task at hand and does not entail activating or performing a response (e.g., Huang & Pashler, 2007; Olivers, Meijer, & Theeuwes, 2006; Stoet & Hommel, 2002; Weaver & Arrington, 2010). For instance, Hester and Garavan (2005) demonstrated such content effects in tasks involving inhibition and task switching. They proposed that information that is actively rehearsed becomes more salient. As a result of this increased saliency, maintained information that is presented in the context of another task can bias performance on that latter task. Similarly, Weaver and Arrington (2010) argued that information in declarative working memory is rehearsed by means of attention. As a consequence, attention can become biased by the information that is being rehearsed. In view of the idea that attention is a limited resource that must be shared between the maintenance and processing of information (e.g., Barrouillet, Bernardin, & Camos, 2004), attention biased by memory contents can in turn bias the processing of information (see also Downing, 2000; Moores & Maxwell, 2009; Soto & Humphreys, 2007).

According to this view, the instruction-based task-rule congruency effect might simply be due to maintaining the instructed S-R mappings. In fact, Cohen-Kdoshay and Meiran (2007, 2009) argued that both the results of Wenke et al. (2007, 2009) and De Houwer et al. (2005) may be based simply on the mere maintenance of instructions. In the present context, it could also be argued that the instruction-based task-rule congruency effect observed in Experiment 1 issues from a mismatch between maintaining the S-R mappings of the inducer task, such as "if Q, then left" on the one hand, and having to give a different response to the same item in the diagnostic task on the other hand, in this case a right response to the letter Q. The instruction-based task-rule congruency effect may thus not result from the activation of a task-irrelevant response, but from a (semantic) mismatch between to-be-maintained information and to-be-performed actions.

However, there is also evidence suggesting that forming an intention to act and accordingly prepare for that act is special in that such intentions might be represented in a more action-based format, such as a task-set (e.g., Eschen, Freeman, Dietrich, Martin, Ellis, Martin, & Kliegel, 2007; Freeman & Ellis, 2003; Koriat, Benz-Zur, & Nussbaum, 1990). For instance, Freeman and Ellis (2003) argued that the so-called intention superiority effect – the finding that to-be-enacted material is more accessible in tests of recognition and lexical decision than information not intended for later action (e.g., Goschke & Kuhl, 1993) – should be considered as an action-superiority effect. This research thus indicates that preparing for an upcoming task on the basis of instructions entails different processes and representations than the mere maintenance of instructions. A distinction that was equally observed in research on instructions conducted with frontal lobe patient (e.g., Luria, Teuber, & Haigh, 1980).

Experiment 2 directly addressed the question whether the instruction-based task-rule congruency effect depends on preparing to perform the inducer task later on, or whether the maintenance of the instructed S-R mappings is sufficient. To this end, a Same Response-Keys conditions (see Experiment 1) was compared with three maintenance conditions. We hypothesized that the Same Response-Keys condition requires both maintenance of the declarative rules and implementation of the S-R mappings for later application, whereas the maintenance conditions only required maintenance of the mappings. In the first maintenance condition, to which we refer as the Visual-Recognition condition, the probe of the inducer task was a new pair of S-R mappings. This new pair contained the same stimuli, but the response assignment was reversed on half of the runs. Participants were asked to indicate whether these new S-R mappings matched the instructed S-R mappings presented at the beginning of the run. One could argue, however, that Visual-Recognition may not require maintenance of the *content* of the S-R mappings in that the task can be performed by maintaining a mere visual image of the S-R mapping instruction screen. In our opinion, it is unlikely that participants would adopt such a strategy because the position of the S-R mappings on the instruction and probe screen often differed (i.e., first mapping in top position on the instruction screen but on the bottom position on the probe screen). Nevertheless, an additional condition was administered: the Verbal-Recognition condition. The Verbal-Recognition condition was similar to the Visual-Recognition condition except that the probe of the inducer task (i.e., the new pair of S-R mappings) was now presented aurally by the experimenter. Although, the role of visual priming was ruled out in this condition, recognition may still be facilitated by the familiarity (see, Yonelinas, 2002 for a review) between both pairs of instructed S-R mappings. Therefore, an even more stringent condition was added, the Verbal-Recall condition. In this condition, participants had to say the instructed S-R mappings aloud immediately after the end of the diagnostic task. This condition required recall rather than recognition, which requires a more extensive reinstatement of the learned information that cannot be based merely on visual priming or familiarity (e.g., Anderson & Bower, 1972).

If the instruction-based task-rule congruency effect issues from a task-set that is formed when preparing for the application of one of the mappings to a probe, maintenance in itself is not sufficient to obtain this effect. Accordingly, an instruction-based task-rule congruency effect should occur only in the Same Response-Keys condition. In contrast, if simply maintaining the instructed S-R mappings of the inducer task is sufficient to obtain an instruction-based task-rule congruency effect, then this effect should be present in the Same Response-Keys condition but also in one or more of the three other conditions.

Method

Participants

Seventy-two participants were drawn from the same pool of participants, but none of them participated to Experiment 1.

Design

Experiment 2 consisted of four between-subject conditions to which participants were randomly assigned: the Same Response-Keys condition (n=18), the Visual-Recognition condition (n=18), the Verbal-Recognition condition (n=18), and the Verbal-Recall condition (n=18). Task-rule congruency was defined as in Experiment 1. The same dependent variables were measured as in Experiment 1. For the exception of the decision times, which were not available for the Verbal-Recognition and Verbal-Recall condition.

Procedure

The Visual-Recognition condition was similar to the Same Response-Keys condition (see Experiment 1), for the exception that the probe was now a new pair of S-R mappings. This new pair contained the same stimuli, but the response assignment was reversed on half of the runs. Participants decided if these new S-R mappings matched the instructed S-R mappings presented at the beginning of the run, again by pressing the left (‘yes’) or the right key (‘no’). In order to avoid interference of this additional mapping, the words ‘yes’ and ‘no’ accompanied the new S-R mappings on the corresponding response locations. In line with Experiment 1, the relative top-down alignment of the initial and the new pair of S-R mappings was determined randomly and could thus differ between both presentations of the S-R mappings in the same run. As we noted earlier, this should discourage participants from adopting a visual-matching strategy. The Verbal-Recognition condition was similar to the Visual-Recognition condition with the exception that the new pair of S-R mappings were presented verbally by the experimenter and participants had to say aloud ‘yes’ or ‘no’. Instead of visually presenting a new pair of S-R mappings, 750ms after the last response of the last trial of the diagnostic task, a 750Hz was presented and the screen turned green. This cued the experimenter to say aloud the new pair of S-R mappings. The sequence in which both S-R mappings was presented (i.e., first the mapping referring to the left response or first the mapping referring to the right response), was also determined randomly. Immediately after the presentation of both mappings, participants had to respond aloud by saying ‘yes’ or ‘no’. This whole sequence of events was constrained to 4000ms after which a new run began. In the Verbal-Recall condition participants were required to say the instructed S-R mappings aloud immediately after the last trial of the diagnostic task. The verbal-repetition of the instructed S-R mappings was again cued by a tone and a green screen and participants had 4000ms to do so after which a new run was presented.

Results

Diagnostic task

Exclusion criteria of Experiment 1 were used (data loss: 11%). RTs and accuracies were each subjected to a 4 (Condition: Same Response-Keys, Visual-Recognition, Verbal-

Recognition, and Verbal Recall) by 2 (Congruency: congruent or incongruent) mixed ANOVA with repeated measures on the last factor[2]. Means and standard deviations of these variables are presented in Table 2.

For the RTs, the main effect of congruency was not significant, $F<1$, while the main effect of condition was, $F(3,68)= 4.97$, $MSE= 12693$, $\eta_p^2= .18$. RTs in the Same Response-Keys condition were significantly longer (M=747) compared to the RTs in the Visual-Recognition (M=675), $t(34)= 2.63$, $r^2= .17$, Verbal-Recognition (M=647), $t(34)= 4.43$, $r^2= .37$, and Verbal-Recall condition (M=691), $t(34)= 2.01$, $r^2= 11$. RTs in the latter three conditions did not vary significantly, largest t-value: $t(34)= 1.68$, $r^2= .08$. Both main effects did interact, $F(3,68)= 2.77$, $MSE= 912$, $\eta_p^2= .11$ (see Table 2). In the Same Response-Keys condition, RTs on incongruent trials were longer than RTs on congruent trials, $t(17)= 2.49$, $r^2=.26$. This was not the case in the Visual-Recognition condition, $t(17)<1$, in the Verbal-Recognition condition, $t(17)= 1.88$, $p<.10$, $r^2=.17$, and in the Verbal-Recall condition, $t(17)<1$. The effect in Verbal-Recognition condition tended to be reversed but given that it did not reach standard levels of significance, it will not be discussed further.

Concerned with power issues, data of the three maintenance conditions were furthermore aggregated. Such analysis did not offer an indication of an instruction-based task-rule congruency effect for mere maintenance, $F(1,53)= 2.11$, $MSE= 936$, $\eta_p^2= .04$. Furthermore, the interaction between condition and congruency may have been biased by the fact that RTs were longer in the Same Response-Keys condition compared to the other three conditions. As a control, RTs were log-transformed. Yet, a similar interaction was observed, $F(3,68)= 2.93$, $MSE= .00181$, $\eta_p^2= .11$, and an instruction-based task-rule congruency effect was again only observed in the Same Response-Key condition: $t(17)= 2.41$, $r^2=.25$.

Error rates differed slightly between the four conditions, $F(3,68)= 2.44$, $p<.10$, $MSE= .0017560$, $\eta_p^2= .10$. They were significantly lower in the Same Response-Keys condition

(*M*=.04) compared to the Visual-Recognition (*M*=.06), *t*(34)= 2.14, r^2=.12, Verbal-Recognition (*M*=.06), *t*(34)= 3.03, r^2=.21, and Verbal-Recall condition (*M*=.06), *t*(34)= 2.64, r^2=.17. Error rates did not differ significantly in the latter three conditions: *t*(34)<1 for all three comparisons. Although the interaction between condition and congruency was not significant, *F*(3,68)= 1.58, *MSE*= .0065672, η_p^2= .07, additional analyses indicated that a significant congruency effect was present only in the same-response key condition, *t*(17)= 2.95, r^2=.34, and not in the three other conditions: *t*(17)<1 in each condition. The pattern of error rates thus matches the pattern of RTs.

Inducer task

Means and standard deviations of the inducer task are also presented in Table 2. The effect of condition was significant for the encoding times, *F*(3,68)= 12.33, *MSE*= 5964111, η_p^2= .35. Encoding times were significantly longer in the Verbal-Recall condition than in the Same Response-Key, *t*(34)= 4.01, r^2= .32, the Visual-Recognition, *t*(34)= 4.29, r^2= .35, and the Verbal-Recognition condition, *t*(34)= 3.82, r^2= .30. Encoding times in the latter three conditions did not differ significantly: *t*(34)<1 for each comparison. Decision times were only available for the Same Response-Keys condition and the Visual-Recognition condition. They were longer in the Visual-Recognition condition than in the Same Response-Keys condition, *F*(1,34)= 63.65, *MSE*= 152174, η_p^2= .65. The effect of condition was also significant for the decision-error rates, *F*(3,68)= 4.37, *MSE*= .0036441, η_p^2= .16, with higher error rates in the Verbal-Recall condition than in the Visual-Recognition, *t*(34)= 2.77, r^2= .18, and the Verbal-Recognition conditions, *t*(34)= 2.93, r^2= .20, but not compared to the Same Response-Key condition, *t*(34)= 1.45, r^2= .06. Decision-error rates did not differ significantly between the Same Response-Keys, Visual-Recognition, and Verbal-Recognition conditions, largest difference: *t*(34)= 1.73, r^2= .08.

Discussion

An instruction-based task-rule congruency effect was observed only in the Same Response-Keys condition, both in the RTs and the error rates of the diagnostic task. In contrast, we did not observe instruction-based task-rule congruency effects in the diagnostic task of the Visual-Recognition, Verbal-Recognition, and Verbal Recall conditions. Taken together, although the three maintenance conditions required participants to maintain the S-R mappings, none of these conditions revealed a significant instruction-based task-rule congruency effect. We propose that maintaining S-R mappings for future recall or recognition calls upon rehearsal-processes in *declarative working memory* (see also for instance, Haist, Shimamura, & Squire, 1992), which, as Experiment 2 demonstrates, do not lead to a task-rule congruency effect in another task.

In contrast, the instruction-based task-rule congruency effect in the Same Response-Keys condition suggests that a task-set is formed when future application of the instructed rules is expected (also see Wenke et al., 2009). We propose that such task-sets consist of functional S-R associations that are represented in *procedural working memory*. Once formed, such task-sets elicit automatic response activations in the context of another task. We elaborate this view in the General Discussion.

General Discussion

The present study investigated the functional characteristics and representational underpinnings of task-sets that were never applied before and that were formed on the basis of instructions. We were especially interested if such task-sets could trigger responses when being irrelevant in the context of another task. Because previous research (Cohen-Kdoshay & Meiran, 2007; 2009; De Houwer et al., 2005; Meiran & Kessler, 2008; Waszak et al., 2008; Wenke et al., 2007; 2009) offered mixed and at best indirect evidence in favor of such hypothesis, we devised a new procedure that allowed investigating instruction-based task-rule congruency effects. Using this procedure, we demonstrated in Experiment 1 that task-sets formed on the basis of instructions can trigger responses in the context of another task even when response modality differed across both tasks. These findings not only demonstrate the existence and robustness of instruction-based task-rule congruency effects. They also indicate that responses in instruction-based task-sets are represented in terms of conceptual codes (e.g., “left” or “right”) without further specification. Experiment 2 showed that task-sets eliciting such effects are formed only when participants intend to enact the instructed task. No instruction-based task-rule congruency effects were observed when the instructed S-R mappings had to be maintained for recognition or recall, suggesting that no task-sets were formed under these conditions.

Formation of task-sets on the basis of instructions

Working memory is often assumed to consist of active long-term memory on the one hand and a capacity-limited part such as the direct-access region on the other hand (e.g., Oberauer, 2009, 2010). Yet, as was already suggested in the Discussion of Experiment 2, our results may be better framed in a more elaborate working-memory architecture. Oberauer (2009, 2010, see also Anderson & Lebiere, 1998; Logan & Gordon, 2001) proposes that a distinction should be made between declarative and procedural working memory, with the latter containing representations guiding actions, such as condition-action rules. While active long-term memory may be common to both types of working memory, procedural working memory is characterized by a separate counterpart of the direct-access region, called “the bridge”, which supposedly contains task-sets. We assume that the formation of a task-set on the basis of instructions is a preparatory activity by which declarative information is translated into a functional representation (i.e., a task-set) in the bridge (see also, Brass, Wenke, Spengler, & Waszak, 2009). As a consequence, instructed S-R mappings may be represented in both a declarative and a procedural format (also see, Hartstra, Kuhn, Verguts, & Brass, 2011, for a similar account), with only the latter format eliciting an instruction-based task-rule congruency effect. This view seems consistent with the action-superiority account of the retention advantage of to-be enacted verbal information relative to verbal items encoded for verbal report (i.e., the intention superiority effect; Eschen et al., 2007; Freeman & Ellis, 2003; Koriat et al., 1990). This account claims that when a verbal instruction is encoded for future enactment, this information is translated into an action-based format, possibly by sensorimotor coding (Koriat et al., 1990).

Wenke et al. (2007, 2009) suggested that the transformation of a declarative into a procedural representation involves processes such as feature activation and feature binding (Hommel, 2004) that integrate representations of the task-relevant stimuli and responses. Experiment 1 indicates that the represented features and codes are quite abstract and possibly of a conceptual nature, and may commonly code stimulus and response features. One possible explanation for this "reductionist" coding of instructions is that the amount of information that can be represented in a task-set is limited by capacity restrictions, so that only basic information is included, which comprise only the most relevant features of the instructions (e.g., Q-left). In addition, participants generally prefer distal coding in a modality unspecific way to proximal coding involving specific motor codes (e.g., Hommel et al., 2001).

Two causes of task-rule congruency

The rationale of the present study is that the instruction-based task-rule congruency effect indicates the presence of a task-set that is formed solely on the basis of instructions. We thus endorse the assumption that encoding S-R mappings in view of their prospective application leads to the formation of a task-set, which is maintained in procedural working memory. This explanation is at odds with accounts of the task rule congruency effect observed when participants frequently switch between tasks. As outlined in the introduction, there is evidence that such task-rule congruency effect is triggered by S-R associations that are represented in active long-term memory and is not related to the interference between task-sets (Meiran & Kessler, 2008; Kessler & Meiran, 2010; Kiesel et al., 2007; Wendt & Kiesel, 2008; Yamagushi & Proctor, 2011). In view of these accounts, an alternative explanation for our results could be that the instruction-based task-rule congruency effect is also based on S-R associations in active long-term memory. This hypothesis could in part be inspired by the account of Meiran and Kessler (2008) who argued that for preexisting response codes (e.g., the codes 'left' and 'right' as used in the present study), the execution-based task-rule congruency effect shows up after minimal practice because these codes are highly accessible in active long-term memory. Hence, encoding S-R mappings – for instance accompanied by covert mental practice – may have the same outcome than the actual execution of S-R mappings, namely the formation of S-R associations in active long-term memory.

However, we think that this explanation for the instruction-based task-rule congruency effect is rather unlikely. Most importantly, unlike the execution-based task-rule congruency effect, instruction-based response activations seem to depend on a capacity-limited system. For example, Cohen-Kdoshay and Meiran (2007) showed that their instructed flanker-compatibility effect disappeared with a concurrent load (see also Meiran & Cohen-Kdoshay, 2012). In a similar vein, Cohen, Jaudas, and Gollwitzer (2008) only observed automatic response activation of merely instructed S-R mappings with a restricted number of instructed mappings. This was confirmed by the results of an unpublished experiment that was conducted at our lab. In this study, we did not observe an instruction-based task-rule congruency effect when the inducer task involved four instead of two instructed S-R mappings. This might also be the reason of why Waszak et al. (2008) failed to observe an instruction-based task-rule congruency effect as these authors instructed eight different mappings.

Taken together, we argue that task-rule congruency effect in general has two sources, S-R associations in active long-term memory on the one hand, and between task-set interference on the other hand. The relative contribution of both sources probably depends on the specific conditions cognitive control is submitted to. In situations requiring frequent switching, working-memory capacity is impeded (Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008) and the level of task-set inhibition frequently varies (for a review, see Koch, Gade, Schuch, & Philipp, 2010). As a consequence of these two factors, only one task-set can be maintained at the same time (see also, Mayr & Kliegl, 2001, 2003; Rubinstein et al., 2001). As such, the task-rule congruency effect observed in these situations is unlikely to reflect between task-set interference and is more likely to reflect S-R associations in active long-term memory that were established through practice. However, when frequent switching is not required and the irrelevant task has been merely instructed, the observed (instruction-based) task-rule congruency effect is more likely to reflect the presence of an irrelevant task-set that was formed on the basis of instructions. Such a conclusion would imply that, under certain experimental conditions, participants are able to maintain two task-sets active at the same time. Moreover, in our experiments the diagnostic task was heavily practiced. This may have reduced the need to actively maintain the task-set of the diagnostic task, thereby saving capacity for the maintenance of the task-sets of the inducer task.

Conclusion

In conclusion, our research aim was to further investigate the formation of task-sets on the basis of instructions, as this is an important but often neglected aspect of goal-directed behavior. We observed that merely instructed mappings can lead to the automatic activation of responses, when being irrelevant. We argue that this effect is based not on the maintenance of declarative information in working memory but on the formation and maintenance of a task-set in procedural working memory. Because working-memory is in part capacity-limited, the instruction-based task-rule congruency effect might be present only for simple task-sets that represent a small number of S-R associations of which only the key features are included.

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Tables

Table 1. Mean results and corresponding standard deviations (between brackets) of Experiment 1. The size of the instruction-based task-rule congruency effect (IB-TRCE) is equally reported.

Diagnostic Task	Trial Type	Condition		
		Same Response Keys	Different Response Keys	Verbal Diagnostic Task
RTs	Incongruent	715 (112)	739 (82)	794 (90)
	Congruent	697 (97)	707 (63)	774 (95)
	IB-TRCE	*18*	*32*	*20*
Error Rates	Incongruent	.07 (.05)	.07 (.03)	.06 (.05)
	Congruent	.03 (.02)	.04 (.02)	.07 (.04)
	IB-TRCE	*.04*	*.03*	*-.01*
Inducer Task				
Encoding Times		4742 (1812)	5739 (2468)	5088 (2133)
Decision Times		986 (207)	935 (216)	1082 (268)
Decision Error Rates		.05 (.04)	.11 (.05)	.14 (.08)

Table 2. Mean results and corresponding standard deviations (between brackets) of Experiment 2. The size of the instruction-based task-rule congruency effect (IB-TRCE) is equally reported.

Diagnostic Task	Trial Type	Condition			
		Same Response Keys	Visual Recognition	Verbal Recognition	Verbal Recall
RTs	Incongruent	760 (73)	670 (89)	640 (65)	691 (94)
	Congruent	737 (80)	681 (97)	654 (60)	692 (96)
	IB-TRCE	*23*	*-11*	*-14*	*-1*
Error Rates	Incongruent	.05 (.02)	.06 (.05)	.06 (.04)	.05 (.03)
	Congruent	.02 (.02)	.06 (.04)	.06 (.03)	.05 (.03)
	IB-TRCE	*.03*	*.00*	*.00*	*.00*
Inducer Task					
Encoding Times		3969 (1869)	3797 (1580)	4218 (1721)	8022 (3860)
Decision Times		1051 (162)	2088 (527)		
Decision-Error Rates		.07 (.05)	.04 (.06)	.04 (.05)	.10 (.08)

Figure Captions

Figure 1. Outline of a run of the inducer task and the diagnostic task. S-R mappings of the inducer task were presented for a maximum of 20s. 4, 8 or 16 trials of the diagnostic task could be presented. The instructed S-R mappings and the stimuli of the diagnostic task were printed in black. The probe of the inducer task was printed in green. Maximum response time in both tasks was 2000ms. The inter-trial interval within a run was 750ms. The interval between two runs was 1500ms.

Figures

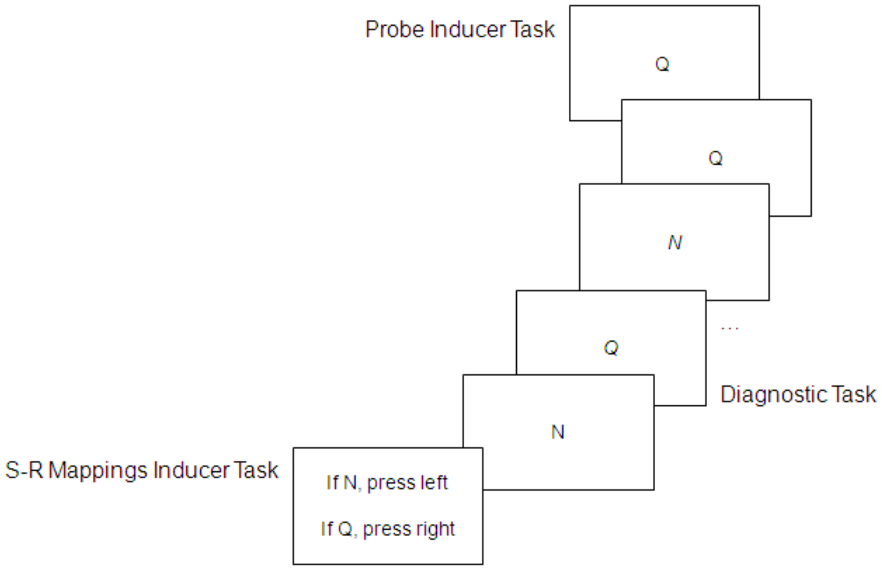

Figure 1

Footnotes

Footnote 1. Note that following our design, it was equally possible to include the number of trials the diagnostic task had to be performed, to which we refer to as the Run-Length (4, 8, or 16 trials), in our analysis. As mentioned above, Run-Length was only varied in order to make the onset of the probe of the inducer task unpredictable, such that participants would be constantly prepared to respond to the probe of the inducer task. For reasons of parsimony, we first tested whether Run-Length had a significant influence. Neither for the RTs, nor for the error rates Run-length did interact significantly with the other factors of our design. The largest F-value, $F(4,98)=1.17$, $MSE= 3335$, $\eta_p^2= .05$, was obtained on the RTs for the interaction between all four factors. Accordingly, we did not include the factor Run-Length furthermore.

Footnote 2. We again first tested whether Run-Length raised significant interactions with the other factors. This was not the case. The largest F-value, $F(2,136)=1.81$, $MSE= 1970$, $\eta_p^2= .03$, was obtained for the interaction between Run-Length and Congruency for the RTs.