Influence of Verbal Instructions on Effect-Based Action Control

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Abstract

According to ideomotor theory, people use bidirectional associations between movements and their effects for action selection and initiation. Our experiments examined how verbal instructions of action effects influence response selection without prior experience of action effects in a separate acquisition phase. Instructions for different groups of participants specified whether they should ignore, attend, learn, or intentionally produce acoustic effects produced by button presses. Results showed that explicit instructions of action-effect relations trigger effect-congruent action tendencies in the first trials following the instruction; in contrast, no evidence for effect-based action control was observed in these trials when instructions were to ignore or to attend to the action effects. These findings show that action-effect knowledge acquired through verbal instruction and direct experience is similarly effective for effect-based action control as long as the relation between the movement and the effect is clearly spelled out in the instruction.

Key words: verbal instruction; congruency; effect-based action control; action-effect learning; ideomotor theory; action control style;

Introduction

Humans are adept in transforming verbal instructions into new behaviors. Behavioral and neuropsychology have recently started to study in depth the underlying processes of this capacity (e.g., Brass, Wenke, Spengler, & Waszak, 2009; Hartstra, Kühn, Verguts, & Brass, 2011; Meiran, Pereg, Kessler, Cole, & Braver, 2015a; Liefooghe, Wenke, & De Houwer, 2012). In these studies participants are typically instructed to use arbitrary stimulus-response (SR) mappings (e.g., “press the left button when you see a blue item and the right button when you see a yellow item”). Behavioral effects of SR instructions are probed with presentations of the instructed stimuli in an upcoming task or in an intermixed task for which the SR instruction is irrelevant (e.g., responses to the shape of objects presented in blue and yellow colors). Using such procedures, studies showed that the stimuli elicit instruction-congruent response tendencies even when there was no or hardly any training of the SR mappings (e.g., Cohen-Kdoshay & Meiran, 2007, 2009; De Houwer, Beckers, Vandorpe, & Custers, 2005; Eder, 2011; Theeuwes, Liefooghe, & De Houwer, 2014; Wenke, De Houwer, Winne, & Liefooghe, 2014). These instruction-induced effects were explained with temporary associations that are established by SR instructions and that evoke the associated response without conscious intention once the release condition for the instructed response is met (Meiran, Cole, & Braver, 2012; Wenke, Gaschler, & Nattkemper, 2007; see also Gollwitzer, 1999; Hommel, 2000). In support of a response-priming explanation, EEG studies observed an early activation of the instructed response in motor-related cortices upon the presentation of matching stimuli that belonged to an SR mapping for an unrelated task (Everaert, Theeuwes, Liefooghe, & De Houwer, 2014; Meiran, Pereg, Kessler, Cole, & Braver, 2015b). Research also found that instruction-based response activations are eliminated by a concurrent working memory load (Meiran & Cohen-Kdoshay, 2012) and by insufficient task preparation (Liefooghe, De Houwer, & Wenke, 2013), suggesting that the representation of SR instructions must be active in working memory to enable automatic response activations. Thus, there is strong evidence that instructed, arbitrary SR mappings trigger associated responses automatically and without extensive training, provided that the procedural representation is held active in working memory.

Instructions of Action-Effect Contingencies

The reviewed research used SR instructions to study how people transform verbal knowledge about SR relations into corresponding actions. For action planning, however, people must also know relations between possible actions and their corresponding effects on the environment. Modern ideomotor theory even claims that knowledge of action effects provides the very basis for action control in that the anticipated sensory effect is used to select, initiate, and execute an action (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kunde, Elsner, & Kiesel, 2007). Supportive of this claim, numerous studies showed (i) that perceptions of action consequences become associated with the producing movements in memory, (ii) that knowledge of the sensory effect is automatically retrieved from memory during action selection, and (iii) that anticipated sensory effects are causally involved in the production and control of a motor response (for reviews see Hommel, 2013; Nattkemper, Ziessler, & Frensch, 2010; Shin, Proctor, & Capaldi, 2010). Thus, knowledge of relations between actions and their effects on the environment is of particular relevance for intentional action.

Research has shown that bidirectional relations between actions and their effects are established not only by direct experiences but also indirectly via observation of other people's actions (Paulus, van Dam, Hunnius, Lindemann, & Bekkering, 2011). Furthermore, two studies investigated directly whether verbal instructions of response-effect (RE) contingencies trigger effect-congruent action tendencies. Participants in one study imagined that they deliver short and long acoustic effects to another person (or dummy) with short and long presses of a response key. Responses were initiated faster when the duration of the instructed effect corresponded with the duration of the button press, showing that the imagined effect was active during action initiation (Pfister, Pfeuffer, & Kunde, 2014). Another study used instructions for a so-called “inducer task” to specify relations between particular responses and subsequent visual effects (e.g., “press the left button to remove the letter *E* from a grid filled with letters”) (Theeuwes, De Houwer, Eder, & Liefooghe, 2015). The letters described for the RE contingencies were then presented as stimuli (among others) in an unrelated “diagnostic task” in which participants responded to a feature other than the letter identity using the same response buttons. Combinations of stimuli and responses for the diagnostic task were hence congruent and incongruent with the RE contingencies instructed for the inducer task. Results showed faster responses with congruent relative to incongruent combinations, confirming that instruction-congruent response tendencies are elicited following the instruction of RE relations and without direct experience of the response effects.

Instructions may also have a capacity to induce different action control styles. Research on intentional action control has shown that it makes a difference whether the intention is to produce certain effects in the environment (effect-based action control style) or whether the intention is to respond to stimuli in line with SR instructions (stimulus-based action control style). More specifically, experiments observed that perceptions of response effects prime associated actions after a free-choice learning phase but not after a forced-choice learning phase (Herwig, Prinz, & Waszak, 2007; Herwig & Waszak, 2012). Subsequent research ruled out differences in attention to the action effects as explanation (Herwig & Waszak, 2009). Other research showed that action-control styles affect more the usage, and less the acquisition, of action-effect relations for action control (Pfister, Kiesel, & Melcher, 2010; Pfister, Kiesel, & Hofmann, 2011). Instructions to produce specific action effects may hence be capable of inducing an effect-based action style, which in turn promotes usage of action-effect relations for action control. In line with this hypothesis, it was observed that spatially congruent and incongruent response effects influenced action selection only after explicit instructions to produce certain response effects, while no influence was observed when instructions emphasized reactions to stimuli (Zwosta, Ruge, & Wolfensteller, 2013; see also Ansorge &

Wühr, 2004; Hommel, 1993). This research shows that an effect-based action control style is adopted after corresponding instructions even if actions must be selected according to predefined SR rules.

The Present Research

Although previous research provided clear evidence that instructions of action effects enable effect-based action control, it is less well understood *what* components of instructions are effective and *how* they affect action control. The present research was therefore conducted to examine what types of RE instructions trigger effect-based action tendencies. For this aim, we compared effect-based action control after different types of action-effect instructions. We also compared effect-based action control after instructions of RE relations with action control after an actual training of RE relations, using an RE learning task developed by Elsner and Hommel (2001).

In the paradigm of Elsner and Hommel (2001), participants repeatedly carry out two actions in an initial learning phase such as presses of left and right response keys. Each response produces a distinct sensory effect (e.g., a high or low tone). In a subsequent test phase, the former action effects (i.e., tones) are presented as imperative stimuli, and participants respond to them by pressing the key that had produced either the same tone (congruent response-effect mapping) or a different tone (incongruent response-effect mapping) in the learning phase. Responses are typically selected faster when the associated response effect is congruent with the imperative stimulus, although instructions are to ignore the acoustic effects during the test. This congruency effect suggests that a behavioral response is triggered automatically by activating its associated effect in memory, indexing effect-based action control (for a review see Shin et al., 2010).

For a comparison of instruction-based and training-based congruency effects we realized test conditions with and without prior learning phase using different groups of participants. In a *standard (baseline) condition*, participants experienced response-tone contingencies in a learning phase as described above. In the other conditions, participants received instructions only for the test phase in the absence of a prior leaning phase. Importantly, four conditions with different instructions were realized that examined what type of instruction is most effective to promote congruency effects based on RE instructions (see Table 1 for an overview and the Appendix for the instructions):

(1) Instructions in the *unspecified-ignore condition* were the same as those given for the standard condition: Participants should respond to the first tone by pressing the assigned key and they should ignore the tone produced by the key press.

(2) Instructions in the *unspecified-attention condition* asked participants to attend to the tone produced by a keypress. Thus, attention was directed to the response effects in this condition but without specification the RE relations.

(3) In the *specified-contingency condition*, instructions explicitly stated the specific RE contingencies. However, it was also stated that the acoustic effects are irrelevant for the response task.

(4) The *specified-intention conditi*on instructed participants to produce the acoustic response-effect intentionally with corresponding button presses in a specific subset of trials. Thus, participants were prepared in this condition to use the instructed RE knowledge for the upcoming task.

It should be noted that participants in the instruction conditions received no separate training of the RE relations in a learning phase and that they experienced the RE contingencies during the test phase. While this procedure cannot rule out rapid learning of action effects during the test phase, the experiential basis for action-effect learning is identical for all instruction conditions. Accordingly, differences in congruency effects between the conditions can be attributed to differences in the instruction and their implementation during the task. Performance in the first 10 trials after the instruction was analyzed for congruency effects after few experience of RE contingencies (for a similar approach see Cohen-Kdoshay & Meiran, 2007). Furthermore, the acoustic effects followed responses with a jitter (50-850 ms) to impede action-effect learning during the test phase. In the following we refer to congruency effects observed in the first trials as *instruction-based congruency effects* to distinguish them from effects that are based on an extensive training of RE relations.

Research Hypotheses

It was hypothesized that explicit instructions of specific RE contingencies induce an effect-based action control style that promotes usage of response effects for response selection and/or prepares for rapid acquisition of action effects. Based on previous research (Pfister et al., 2014; Theeuwes et al., 2015), we hypothesized that instructions of specific RE instructions in the contingency/intention conditions enable effect-based action tendencies in the very first trials after the instruction. According to the intentional-weighting hypothesis (Memelink & Hommel, 2013), preparation for an upcoming task increases the weight of task-relevant stimulus and response features and hence their influence on action selection. From this approach it follows that instruction-based congruency effects should be strongest in the intention condition. However, instructions of RE contingencies should be sufficient to induce congruency effects even in the absence of an explicit weighting process (Zwosta et al., 2013). Thus, an instruction-based congruency effect of smaller magnitude was also expected for the contingency condition.

Instructions for the ignore/attention conditions did not specify the RE contingencies. Hence, participants must first learn these contingencies from experience before they can be used for action selection. Elsner and Hommel (2001) argued that response-contingent events are acquired automatically even when participants are instructed to ignore these events. According to their automatic-integration hypothesis, effect-based action tendencies should develop with task practice even after instructions to ignore action effects. Zwosta and colleagues (2013), however, observed action-effect learning in a stimulus-based response task only with instructions that specified RE contingencies. Latter research suggests that the experience of RE contingencies alone is not sufficient for effect-based action control in a speeded SR task. Furthermore, it is not clear how attention to the response effects affects action-effect acquisition. On the one hand, explicit instructions to attend to the response effects may facilitate the acquisition of response effects by drawing the participants' attention to the response effects (Flach, Osman, Dickinson, & Heyes, 2006). On the other hand, Herwig and Waszak (2009) obtained no evidence that an effect-based control mode directs more attention to the response effects. In short, hypotheses are unclear whether instructions of unspecified action-effects can induce an effect-based action control mode in a speeded SR task, and if yes, whether instructions to attend to the response effects would facilitate the acquisition and/or usage of response effects for action control.

Method

Participants

One-hundred and eighty-one students at the University of Würzburg (18 left-handed, 80 women, 18–32 years, M = 21.9 years) were paid for participation. Participants were assigned to one of five conditions (see Table 1). Informed consent was obtained from all participants before participation.

Apparatus and Stimuli

Participants responded with the index fingers of their left and right hands by pressing the 'd' and 'l' keys that were marked with green color patches. Sinusoidal tones of 60 dB with a frequency of 400 Hz (low pitch) and 800 Hz (high pitch) were presented via headphones as response cues and response effects. The key–tone assignment was counterbalanced across participants.

Procedure

Acquisition phase (only Baseline Condition). Participants were instructed to respond as quickly as possible to the onset of a white asterisk (1 s) with a press of a response key. They had a free choice between button presses in a trial but instructions also stated that both keys should be pressed about equally often in a block. Upon a key press, a high or low tone was presented for 200 ms immediately after a response (counterbalanced assignment). Responses faster than 100 ms were considered as anticipations and responses slower than 1 s as omissions. In these cases, a warning signal appeared for 1s on the screen and the trial was repeated. There was an interval of 1,500 ms between trials. Participants worked through 4 blocks with 50 trials each. After each block, a summary informed about the relative frequencies of right- and left-hand responses.

Test phase (all conditions). The same high and low tones were presented as response cues and as response-contingent effects. Half of the participants in each group received a tone-key mapping that was congruent with the produced tones (i.e., high-high, low-low tones); for the other half, the SR mapping instructed responses with incongruent acoustic effects (i.e., high-low, low-high tones). Instruction was to respond to the first tone as quickly and as correctly as possible. Participants were assigned randomly to one of the two congruency groups in each experimental condition. Instructions for the intention condition additionally announced randomly intermixed trials in which the words HIGH and LOW will appear instead of a first tone. Participants were instructed to respond to these words as quickly as possible with a button press producing a corresponding tone. Importantly, these trials were only announced but not actually presented (i.e., the test phase was identical for all instruction conditions). A secondary response task with identical RE-relations was instructed to strengthen intentions to produce acoustic effects and to prevent a recoding of the responses in terms of the SR mapping (for a similar task procedure see De Houwer, Beckers, Vandorpe, & Custers, 2005).

Trial procedure was identical in all conditions. First, a white asterisk appeared and a high or low tone for 200 ms as response cues. After registration of a correct response, the high or low tone was played again in the congruent condition, while a different tone was played in the incongruent condition. Response effects were presented after a correct response with a jitter of 50 ms to 850 ms. The jitter was introduced to slow down action-effect learning through experience while still allowing for a registration as response effects (Dignath, Pfister, Eder, Kiesel, & Kunde, 2014; Elsner & Hommel, 2004). The next trial started after 1,500 ms. A warning message appeared for 1.5s (instead of an acoustic effect) when the key press was too fast (RT < 100 ms), too slow (RT > 1000 ms) or incorrect. Invalid trials were repeated in random order after the last trial block.

Participants performed 4 practice trials (2 high/2 low tones) and 5 blocks with 20 test trials. High and low tones appeared equally often as response cues in a trial block and they were presented in random order. After each block, a message on the screen informed participants about their mean RT and error rate.

RE contingency knowledge check. A knowledge check was performed after the test phase that asked participants to press the buttons that produced high and low tones, respectively. We also realized contingency and intention conditions in which participants performed a knowledge check immediately after the instruction of the RE contingencies, which served as a check that the instructions were really understood (instructions and knowledge test were repeated in these conditions until answers were correct). Results of these conditions are reported in the supplement and they were in line with those conditions with a knowledge check after the test phase (i.e., the conditions that are reported below).

Results

Reaction times and error rates in the test phase were analyzed for an influence of congruency and task instructions. Tukey (1977) outlier thresholds were used for each condition to identify outliers in the number of erroneous trials. These thresholds removed 4 participants from the *baseline condition*; 1 participant from the *ignore condition*; 3 participants from the *attention condition*; 2 participants from the *contingency condition*. One additional participant from the *baseline condition* was excluded because of insufficient training during the acquisition phase (see the supplement for analyses).

Trials with anticipated responses (0.1%) and omitted responses (1.6%) were removed from the analyses. In addition, trials with incorrect responses (7.5%) were discarded from the RT analyses. Overall analyses included all test trials including those that were repeated after the last block. In addition, a block analysis was performed by subdividing the 100 test trials into 10 subblocks. Trend analyses were planned for each condition to examine whether a performance difference between congruent and incongruent groups is proportional to the number of performed trial blocks. We also analyzed the performance in the four practice trials; however, response performance in these trials was too poor for a meaningful analysis (see the supplement). Congruency effects (CE) were computed by subtracting performance (RTs, accuracy) in the congruent condition from performance in the incongruent condition. CEs for each instruction condition are reported in Table 2 and block analyses are displayed in Figure 1 (RT) and Figure 2 (errors). Standardized effect sizes (Cohen's *d*, partial eta-square) are reported when appropriate. Complementary analyses of the acquisition phase (baseline condition), practice trials, and the contingency knowledge check are reported in a supplement to this article.

Reaction times

Analyses of the first trial block. Table 2 shows the performance in the first 10 trials. An analysis of variance (ANOVA) with the between-subject factors *condition* (baseline, ignore, attention, contingency, intention) and *congruency* (congruent, incongruent) yielded a significant main effect of congruency, $F(1, 161) = 23.99$, $p < .001$, $\eta_p^2 = .130$, that was qualified by a significant interaction with condition, $F(4, 161) = 3.12$, $p < .05$, $\eta_p^2 = .072$. The main effect of condition was not significant ($F = 1.67$, $p = .17$).

Planned comparisons of congruent and incongruent groups in each condition with Bonferroni-adjusted t-tests ($\alpha = .01$) revealed significant CEs for the *baseline condition* (*CE* = 89 ms, *d* = 1.07), $t(24) = 2.61$, $p < .01$ (one-tailed); the *contingency condition* (*CE* = 97 ms, *d* = 1.17), $t(38) = 3.60$, $p < .001$; the *intention* condition (*CE* = 141 ms, *d* = 1.57), $t(40) = 4.95$, $p <$

.001. In contrast, no significant RT difference was observed in the *ignore* and *attention conditions* (with |*t*s| < 1).

Trend analyses. In a mixed ANOVA with the between-subject factors *condition* (baseline, ignore, attention, contingency, intention) and *congruency* (congruent, incongruent) and the within-factor *block* (1-10), the main effect of *block*, $F(9, 1449) = 9.05$, $p < .001$, $\eta_p^2 = .053$, the main effect of *congruency*, $F(1, 161) = 34.89$, $p < .001$, $\eta_p^2 = .178$, the main effect of *condition*, $F(4, 161) = 8.39$, $p < .001$, $\eta_p^2 = .175$, and the interaction between *congruency* and *condition* were significant, $F(4, 162) = 6.35$, $p < .001$, $\eta_p^2 = .136$. The three-way interaction ($F < 1$) and all other effects did not reach significance according to a conventional criterion (largest $F = 1.48$). Trend analyses revealed significant linear and quadratic trends for the block factor, $F(1, 161) = 16.14$, $p < .001$, $\eta_p^2 = .091$, and $F(1, 161) = 15.44$, $p < .001$, $\eta_p^2 = .087$, respectively. The linear trend of the block x condition interaction missed significance with $F(4, 161) = 2.28$, $p = .063$, $\eta_p^2 = .054$. The linear trend of the block x congruency interaction was significant, $F(1, 161) = 4.34$, $p < .05$, $\eta_p^2 = .026$, indicating decreasing CEs in later trial blocks. Trends for the block x congruency x condition interaction effect were however not significant (with *F*s < 1).

Trend analyses of CEs in each condition revealed no significant linear or quadratic trends for the congruency x block interaction (largest $F = 1.62$, all *p*s > .20). For the *ignore condition*, a quadratic trend for the interaction effect approached significance, $F(1, 24) = 3.76$, $p = .064$, $\eta_p^2 = .136$. In sum, trend analyses show that RT differences between congruent and incongruent groups, if existent, were relatively stable across trial blocks and conditions (see Figure 1 for visual inspection).

Overall analyses. An ANOVA of the overall performance (100 trials plus repeated incorrect trials) produced a significant main effect of *congruency*, $F(1, 161) = 35.17$, $p < .001$, $\eta_p^2 = .179$. The main effect of *condition*, $F(1, 161) = 8.71$, $p < .001$, $\eta_p^2 = .178$, and more important, the interaction between *condition* and *congruency* was significant, $F(4, 161) = 6.26$, $p < .001$, $\eta_p^2 = .135$.

Bonferroni-adjusted t-tests revealed significant CEs for the *baseline condition* (M = 90 ms, d = 1.76), $t(24) = -4.30$, $p < .001$; the *contingency condition* (M = 84 ms, d = 1.16), $t(38) = -3.58$, $p < .001$; the *intention condition* (M = 126 ms, d = 1.65), $t(40) = -5.23$, $p < .001$. However, no significant CEs were observed for the *ignore condition* (M = 1 ms, $t < 1$) and for the *attention condition* (M = 4 ms, $t < 1$).

Error rates

Analogous analyses were performed with the error data. Table 2 shows the means and standard deviation of the error proportion in each condition.

Analyses of the first trial block. No effect reached significance in the ANOVA (largest F = 1.04, all ps > .30). The CE in the baseline condition (M = 10.7%, d = 0.86) missed significance after Bonferroni-adjustment (α-level = .01), $t(24) = -2.10$, $p = .02$ (one-tailed). CEs in the other conditions were far from significance with $|ts| < 1$.

Trend analyses. In a mixed ANOVA with the factors *condition*, *congruency,* and *block*, the main effects of *block*, $F(9, 1449) = 4.25$, $p < .001$, $\eta_p^2 = .026$, and *congruency* were significant, $F(1, 161) = 7.05$, $p < .01$, $\eta_p^2 = .042$. All other effects were not significant (largest F = 1.11, all ps > .30). Trend analyses showed a significant linear trend for the block factor, $F(1, 161) = 11.06$, $p < .01$, $\eta_p^2 = .064$, indicating fewer errors with task practice. Linear and quadratic trends for the block x congruency interaction effect (largest F = 1.25, ps > .20) and for the three-way interaction effect between block x congruency x condition (largest F = 1.79, ps > .10) were not significant.

Separate trend analyses for each condition showed that the magnitude of CEs increased monotonically with block in the *ignore condition*, $F(1, 24) = 5.46$, $p < .05$, $\eta_p^2 = .185$, and in the *attention condition*, $F(1, 24) = 4.49$, $p < .05$, $\eta_p^2 = .114$; however, no linear trends were observed for the block x congruency interaction effect in the remaining conditions (with Fs < 1) (see Figure 2 for visual inspection).

Overall analyses. Participants made less errors with a congruent response mapping (*M* = 7.6%) relative to the incongruent condition (*M* = 9.4%), but this difference was not statistically reliable, $F(1, 161) = 3.84$, $p = .052$. The main effect of *condition* ($F < 1$) and the interaction between both factors, $F(4, 161) = 2.03$, $p = .09$, were not significant. Comparisons with Bonferroni-adjusted t-tests ($\alpha = .01$) revealed a significant CE only for the *baseline condition* (*M* = 3.5%, $d = 0.82$), $t(24) = -2.04$, $p < .01$. CEs were not significant for the *ignore condition*, $t(24) = -1.81$, $p = .04$ (one-tailed); the *attention condition*, $t(35) = -2.24$, $p = .02$ (one-tailed); the *contingency condition*, $t(38) = 1.16$, $p = .25$); and the *intention condition* ($t < 1$).

Discussion

The present research examined how verbal instructions of action effects influence action selection and acquisition of action-effects in an upcoming reaction time task. Instructions specified for different conditions whether participants should ignore, attend, learn, or intentionally produce acoustic effects that were produced by button presses. It was hypothesized that explicit instructions of specific RE contingencies induce an effect-based action control style that makes use of response effects during response selection. Results showed that instructions that informed participants about specific RE contingencies produced a congruency effect in the first ten trials of the reaction task; in contrast, no congruency effect was observed when participants were asked to ignore or to attend to the response effects. Thus, instructions must be explicit about RE relations to produce effect-based response tendencies. Furthermore, the size of instruction-based congruency effects was comparable to the magnitude of congruency effects that were obtained after extensive training of RE contingencies in a separate learning phase. This finding shows that contingency knowledge acquired through verbal instruction and experience is similarly effective for effect-based action control. Interestingly, congruency effects in the intention and contingency conditions were maximal from the beginning and did not further increase with direct experience of the RE contingencies during the reaction task. This result may indicate that knowledge of RE contingencies, once established by verbal instructions, does not benefit from direct experience of the instructed contingencies; however, it could also reflect a ceiling-effect or impaired learning of action effects that are presented after a random time interval. As a matter of fact, Elsner and Hommel (2004; see also Dignath et al., 2015) obtained action-effect learning only with presentations of temporally contingent action effects. Thus, the temporal jitter for the RE interval may have impaired action-effect learning by experience. Experience of RE contingencies, however, fostered some RE learning as indexed by the error measure in the ignore/attention conditions that did not specify the RE relations. The reasons for this discrepancy are unclear. Future research may want use more sophisticated analyses for a comparison of learning curves after different instructions.

Although the instruction-based congruency effects in the intention and contingency condition were not enhanced by task practice (as suggested by our trend analyses), it is still plausible that the implementation of the instruction during the task was necessary for effect-based action control. In fact, research on instructed SR mappings showed that instruction-based response activations are generated only when participants must apply the instructed mapping to an upcoming task; in contrast, instructions produced no effect when the instruction was merely maintained in memory for future recall (Liefooghe et al., 2012) or when task preparation was unnecessary because the instruction was repeated at a later point in time (Liefooghe et al., 2013). Furthermore, Pfister and colleagues (2014) observed an instruction effect only in conditions in which participants actively imagined the instructed action effects. In the contingency condition of present research, participants were presumably also prepared to put the instructed RE contingencies to a test, although this was not necessary for the completion of the task. An implicit task preparation in this condition may also explain why there was no significant difference to the intention condition with an explicit intentional weighting of the response effects. Future research may examine more closely whether task preparation is necessary for an instruction-based RE compatibility effect.

Participants in our conditions did not only receive instructions of RE contingencies but also experienced these contingencies. Accordingly, our research is not conclusive in respect to whether our instructions enabled an extremely rapid RE learning through experience (see Wolfensteller & Ruge, 2011) or whether RE knowledge was immediately available for effect-based action control after the instruction (see Theeuwes et al., 2015). In respect to the possibility of rapid RE learning, it is clear that learning from experience alone cannot explain congruency effects in the first trials after the instruction, given that the same exposure did not produce analogous congruency effect in the attention and ignore conditions. Thus, instructions must have influenced the effectiveness of RE learning processes for an explanation with rapid RE learning. Responding to stimuli according to pre-defined SR rules alone does not prevent learning of response effects (Pfister et al., 2011). Explicit information about the relations between the responses and their effects may hence have facilitated action-effect learning in the contingency/intention conditions, while the variable time interval between the action and their effects impeded action-effect acquisition in the ignore/attention conditions. According to this account, instructions of response-contingent effects induce an effect-based action control style that prepare for rapid acquisition of response-contingent effects.

An alternative, and more parsimonious explanation, is that knowledge of the RE contingencies, once established by the verbal instruction, was immediately available for effect-based action control. This explanation is in line with research by Theeuwes and colleagues (2015) who observed instructed-based congruency effects in a diagnostic task without presentations of response effects (and hence without the possibility of rapid RE learning). According to this explanation, verbal instructions are another way to establish bidirectional relations between movements and external effects. These relations could be stored in an associative format, as proposed by modern ideomotor accounts (Hommel et al., 2001), or they could have a propositional format (Mitchell, De Houwer, & Lovibond, 2009). Future research should clarify whether knowledge of RE relations established through verbal instructions is stored in a different representational format than knowledge acquired through direct experience.

Action instructions are used in everyday life to improve behavioral skills and action performance. As we have argued in this paper, instructions of specific RE contingencies are of particular importance in this respect. They can be used to direct attention to external effects of movements (Wulf & Prinz, 2001); they can be used to specify relevant action effects among multiple possible outcomes (Flach et al., 2006); and they can be used to define feedback signals for effective motor control and performance monitoring (Todorov & Jordan, 2002). In short, instructions of action effects bear a great potential for behavior optimization that psychologists should exploit for practical use. As the present research shows, alerting people to the production of particular action effects may be an effective intervention in this respect as long as the relationship between movement and their effects is clearly spelled out in the action instruction.

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Table 1

Manipulated factors in the instruction conditions

	Instruction condition				
	Baseline	**Ignore**	**Attention**	**Contingency**	**Intention**
Prior action-effect learning (acquisition phase)	***yes***	***no***	***no***	***no***	***no***
Attention to action effects	**no**	**no**	***yes***	***yes***	***yes***
Knowledge of action-effect contingency	**no**	**no**	**no**	***yes***	***yes***
Intentional weighting of action effects	**no**	**no**	**no**	**no**	***yes***
N (participants)	31	27	40	42	42

Table 2

Means (standard deviations in parentheses) of reaction times in ms and error rates in percent in the test trials (total) and in the first trial block (initial).

Condition	**Response mapping**	**RT (total)**	**Error (total)**	**RT (initial)**	**Error (initial)**
	congruent	345 (33)	5.9 (2.5)	381 (70)	5.0 (6.7)
Baseline	*incongruent*	434 (65)	9.4 (3.5)	469 (99)	15.7 (16.5)
	Difference (CE)	90*	3.5*	89*	10.7
	congruent	389 (50)	7.0 (2.9)	407 (101)	10.8 (17.3)
Ignore	*incongruent*	391 (59)	9.9 (4.9)	447 (120)	11.4 (11.7)
	Difference (CE)	1	2.9	40	0.6
	congruent	384 (59)	6.5 (4.4)	417 (107)	12.9 (13.8)
Attention	*incongruent*	388 (44)	10.4 (6.2)	415 (95)	12.5 (13.4)
	Difference (CE)	4	3.9	-1	-0.4
	congruent	392 (51)	10.7 (6.7)	391 (71)	12.8 (17.1)
Contingency	*incongruent*	475 (88)	8.0 (8.0)	488 (95)	14.6 (16.0)
	Difference (CE)	84*	-2.7	97*	1.8
	congruent	393 (60)	7.9 (5.6)	396 (82)	11.8 (13.0)
Intention	*incongruent*	520 (94)	9.2 (7.1)	538 (103)	10.5 (12.8)
	Difference (CE)	126*	1.3	141*	-1.3

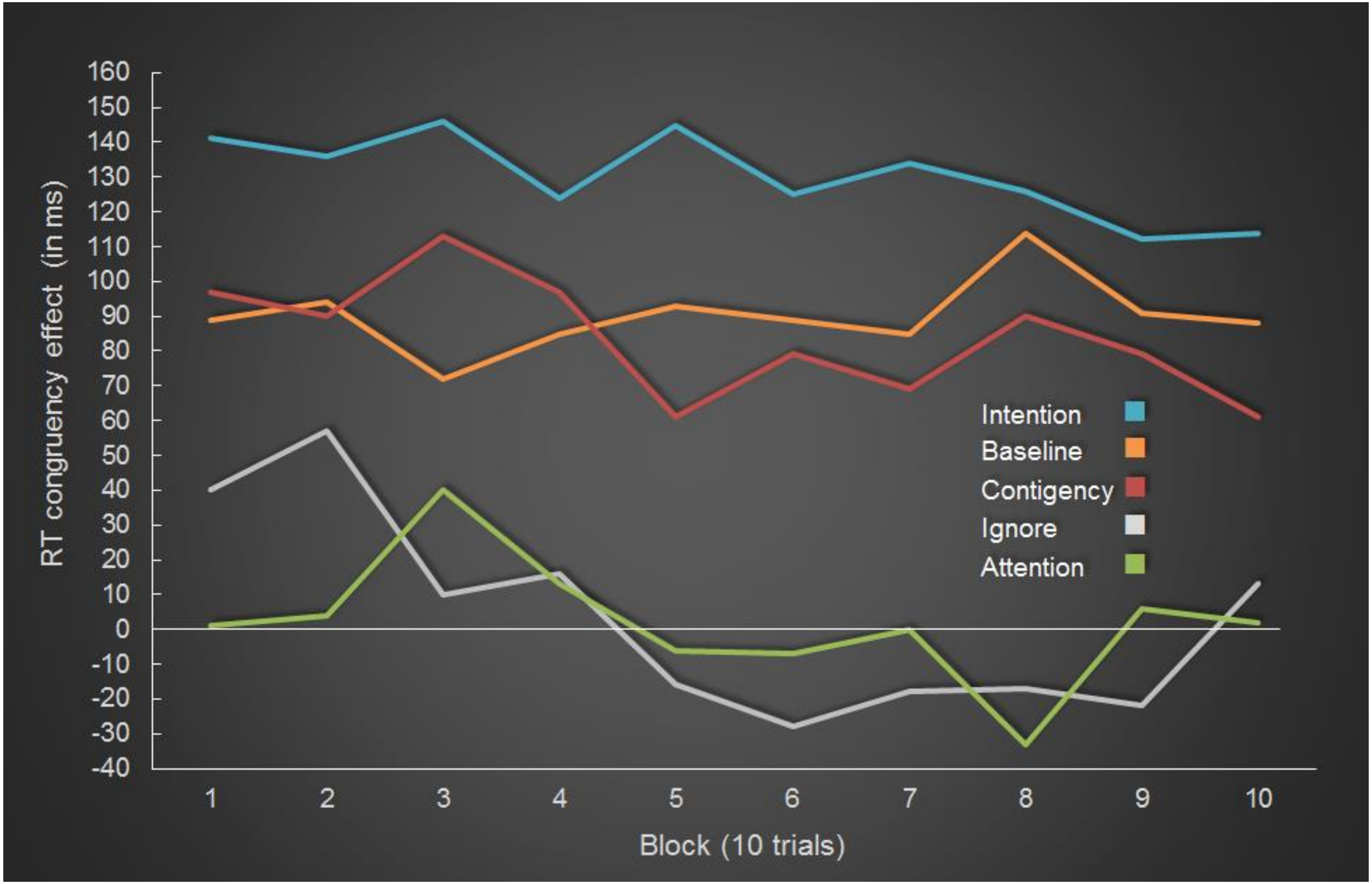
Note. Small differences in numbers are due to rounding. CE = congruency effect.

* significant with $p < .01$ after Bonferroni-correction

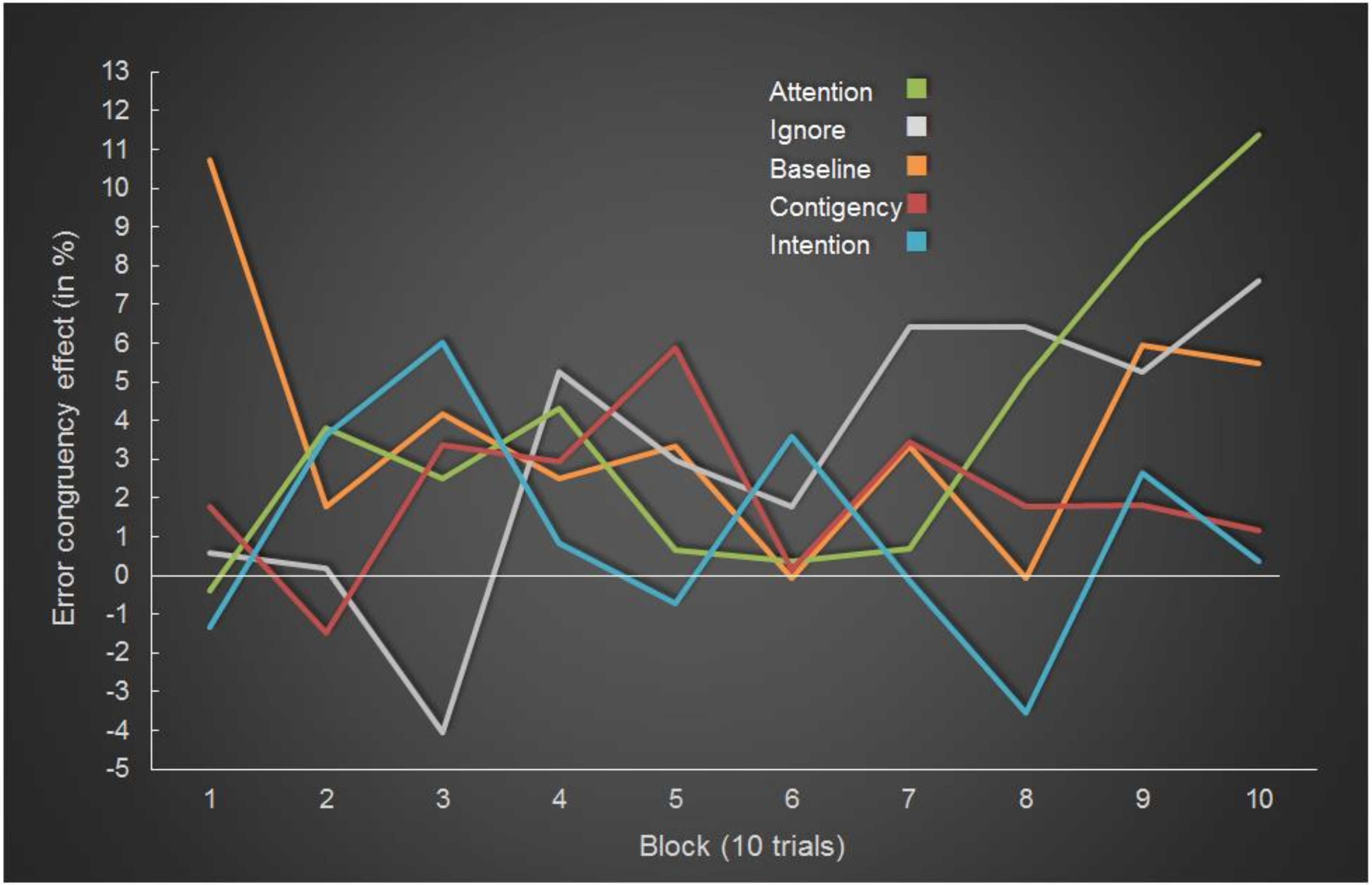
Figure Captions

Figure 1. Congruency effects (RTs in incongruent trials minus RTs in congruent trials) as a function of trial block and experimental condition.

Figure 2. Congruency effects (errors in incongruent trials minus errors in congruent trials) as a function of trial block and experimental condition.



RT congruency effect (in ms)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
1
2
3
4
5
6
7
8
9
10
Block (10 trials)
Intention
Baseline
Contigency
Ignore
Attention



Attention
Ignore
Baseline
Contigency
Intention
Error congruency effect (in %)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
1
2
3
4
5
6
7
8
9
10
Block (10 trials)

Appendix

Instructions

Baseline condition (after acquisition phase)

Your task is to respond to a high (low) tone as fast as possible with a press of the left button and to a low (high) tone as fast as possible with a press of the right button.

Each key press produces a tone. This tone is irrelevant for your task and should be ignored.

Unspecified-ignore condition (no acquisition phase)

Same as in the baseline condition.

Unspecified-attention condition (no acquisition phase)

Your task is to respond to a high (low) tone as fast as possible with a press of the left button and to a low (high) tone as fast as possible with a press of the right button.

Each key press produces a particular tone. Find out which response key produces which tone. We will ask you at the end of the experiment about this relationship.

Specified-contingency condition (no acquisition phase)

Your task is to respond to a high (low) tone as fast as possible with a press of the left button and to a low (high) tone as fast as possible with a press of the right button.

Each button press produces a tone. This tone is irrelevant for the task at hand and can be ignored. A press of the left button produces a high (low) tone. A press of the right button produces a low (high) tone. Please memorize these relations. We will ask you at the end of the experiment about them.

Specified-intention condition (no acquisition phase)

Each button press produces a tone. The left button produces a high (low) tone, the right button produces a low (high) tone. Please memorize these relations. You will need them for the upcoming task.

Your task is to respond to tones: Create a high (low) tone as quickly as possible when you hear a high tone and create a low (high) tone as quickly as possible when you hear a low tone.

Attention: In some trials the words HIGH and LOW will appear instead of a tone. You must quickly produce a corresponding tone in these trials (i.e., HIGH-high tone, LOW-low tone).

Supplement

Analyses of the response rates in the acquisition phase (baseline condition)

Relative frequencies of left and right key presses were computed for each participant. To check whether participants have pressed both response keys about equally often, a ratio of 44.5% to 55.5% or more extreme was considered as a deviation from equal distribution. This ratio corresponds to the application of a two-category chi-square goodness-of-fit test performed at a significance level of $\alpha = .15$ for each participant to avoid Type II errors (cf. Hoffmann, Lenhard, Sebald, & Pfister, 2009). One participant was excluded because his response ratio deviated from equal distribution. The rest of the sample pressed both keys about equally often (*Ms* [*SDs*] = 99.5 [3.7] vs. 100.5 [3.7]) in line with the task instructions for this phase.

Analyses of the practice trials

Each participant performed 4 practice trials with 2 high and 2 low response cues. 62 out of 181 participants (after removal of one subject with insufficient training in the baseline condition) produced 2 or more errors during the practice phase ($M = 1.3$, $SD = 1.16$). Given the low number of correct trials, only error rates were analyzed. In an ANOVA with the between-subject factors *condition* and *congruency*, only the main effect of *congruency* reached significance, $F(1, 171) = 7.17$, $p < .01$, $\eta_p^2 = .040$. Errors were more frequent with an incongruent response mapping ($M = 1.5$, $SD = 1.24$) relative to a congruent mapping ($M = 1.0$, $SD = 1.02$). The main effect of *condition*, $F(4, 171) = 1.16$, $p = .33$, and the interaction between both factors ($F < 1$) were not significant. Follow-up comparisons in each condition revealed no significant CEs (largest $t = 1.6$, *p*s > .10).

Knowledge of RE contingencies

Answers were analyzed for explicit knowledge of the contingencies between key presses and auditory effects. Answers were scored “correct” if both RE contingencies were correct and “incorrect” if one or both contingencies were incorrect. Distributions of correct and incorrect answers in the *conditions* did not differ from one another, $\chi^2(4, N = 182) = 2.38$, $p =$

.67. A chi-square analysis on the responses collapsed across conditions showed a significant difference between *congruency* groups, $\chi^2(1, N = 182) = 39.67$, $p < .001$, $\varphi = -.47$. Knowledge of the response-effect contingencies was near perfection with a congruent response mapping; in contrast, only slightly more than half of the sample could report the key-tone relations correctly when the response mapping was incongruent (see Table 3). Follow-up tests confirmed significant knowledge differences between congruency groups for the *baseline condition* (two-tailed Fisher's exact test, $p = .04$, $\varphi = -.43$); the *ignore condition* (two-tailed Fisher's exact test, $p = .008$, $\varphi = -.53$); the *attention condition* (two-tailed Fisher's exact test, $p = .001$, $\varphi = -.61$); the *contingency condition* (two-tailed Fisher's exact test, $p = .002$, $\varphi = -.48$); the *intention condition* (two-tailed Fisher's exact test, $p = .087$, $\varphi = -.29$). In short, an incongruent SRE mapping impaired knowledge of the response-effect relations, irrespective of the instructions.

Table 3

Proportion of participants who indicated the correct relationship between a key press and the produced tones. Total number of participants in each condition in parentheses.

Condition	**Congruent**	**Incongruent**	***Total***
Baseline	100% (*n* = 15)	68.8% (*n* = 16)	83.9% (*n* = 31)
Ignore	100% (*n* = 12)	53.3% (*n* = 15)	74.1% (*n* = 27)
Attention	100% (*n* = 21)	47.4% (*n* = 19)	75.0% (*n* = 40)
Contingency	100% (*n* = 19)	60.9% (*n* = 23)	78.6% (*n* = 42)
Intention	95.5% (*n* = 22)	75.0% (*n* = 20)	85.7% (*n* = 42)
Total	98.9% (*n* = 89)	61.3% (*n* = 93)	

For a test whether explicit knowledge of RE contingencies affects the results, ANOVAs were conducted only with participants who reported the RE contingencies correctly in the contingency awareness test (*n* = 137). In an ANOVA of the reaction times (all trials) with the between-subject factors *condition* (baseline, ignore, attention, contingency, intention) and *congruency* (congruent, incongruent), the main effect of condition, $F(4, 127) = 11.06$, $p < .001$, $\eta_p^2 = .258$, the main effect of congruency, $F(1, 127) = 29.79$, $p < .001$, $\eta_p^2 = .190$, and the interaction between both factors were significant, $F(4, 127) = 7.17$, $p < .001$, $\eta_p^2 = .222$. In an analogous ANOVA of the error rates, only the main effect of congruency reached significance, $F(1, 127) = 5.87$, $p < .05$, $\eta_p^2 = .044$. In short, the effects of the instruction conditions on CEs were reproduced with perfect knowledge of the RE relations.

Analyses of conditions with R-E knowledge checks before the test phase

We also realized contingency and intention conditions (with *n* = 26 each) in which knowledge of the R-E contingencies was probed before the test phase. Instructions and knowledge test were repeated in these conditions until the answers were correct. Table 4 shows the response speed and error rates observed in these conditions.

Analyses of the reaction times in the first trial block revealed significant CEs for the *contingency condition* in the RT measure (*CE* = 148 ms, *d* = 1.77), $t(24) = 4.33$, $p < .001$, and in the error measure, (*CE* = 12.3%, *d* = 1.05), $t(24) = -2.56$, $p < .05$; for the *intention condition* in the RT measure (*CE* = 133 ms, *d* = 1.64), $t(24) = 4.02$, $p < .001$, and in the error measure (*CE* = 9.2%, *d* = 0.71), $t(24) = -1.74$, $p < .05$ (one-tailed). Analysis of the overall performance yielded similar effects. Reaction times were faster in the congruent relative to the incongruent condition in the *contingency condition* (*M* = 93 ms, *d* = 1.82), $t(24) = -4.46$, $p < .001$; and in the *intention condition* (*M* = 112 ms, *d* = 1.96), $t(24) = -4.81$, $p < .001$. Planned comparisons of the error rates revealed a significant CE in the *contingency condition* (*M* = 5.0%, *d* = 1.01), $t(24) = -2.47$, $p < .05$; and in the *intention condition* (*M* = 7.3%, *d* = 1.05), $t(24) = -2.58$, $p < .05$.

Table 4

Means (standard deviations in parentheses) of reaction times in ms and error rates in percent in all test trials (total) and in the first trial block (initial) in conditions in which a knowledge test was performed before the test phase.

Condition	**Response mapping**	**RT (total)**	**Error (total)**	**RT (initial)**	**Error (initial)**
	congruent	353 (44)	6.9 (4.4)	372 (74)	13.1 (10.3)
Contingency	*incongruent*	447 (62)	11.9 (5.8)	519 (99)	25.4 (13.9)
	Difference (CE)	93*	5.0*	148*	12.3*
	congruent	359 (50)	6.9 (7.2)	392 (91)	8.5 (10.7)
Intention	*incongruent*	470 (67)	14.3 (7.3)	525 (77)	17.7 (15.9)
	Difference (CE)	112*	7.3*	133*	9.2*

Note. Small differences in numbers are due to rounding. CE = congruency effect.

* significant with $p < .05$ (one-tailed)