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Response-Effect Compatibility in Manual Choice Reaction Tasks

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This study investigated whether compatibility between responses and their consistent sensorial effects influences performance in manual choice reaction tasks. In Experiment 1 responses to the nonspatial stimulus attribute of color were affected by the correspondence between the location of responses and the location of their visual effects. In Experiment 2, a comparable influence was found with nonspatial responses of varying force and nonspatial response effects of varying auditory intensity. Experiment 3 ruled out the hypothesis that acquired stimulus-effect associations may account for this influence of response-effect compatibility. In sum, the results show that forthcoming response effects influence response selection as if these effects were already sensorially present, suggesting that in line with the classical ideomotor theory, anticipated response effects play a substantial role in response selection.

Human behavior virtually always is goal-oriented, that is, it serves to produce certain desired effects in the environment. For example, we press a light switch to light a room, we turn on the radio to hear some music, and so on. How do actors determine the appropriate behavioral acts that reliably produce the desired effects? Quite a simple and suggestive answer to this fundamental question has been proposed more than 100 years ago by James (1981/1890) in his ideomotor hypothesis. He stated that actors first acquire associations between movements of their body and the perceivable movement effects. These associations are then assumed to become activated in the opposite direction, when a certain effect is subsequently desired, so that an anticipatory effect image automatically activates the motor pattern that reliably produced this effect in the past. Indeed, James proposed that movements are represented exhaustively by their reafferences and thus that there is no way to access a movement other than by recollecting the sensorial experiences (proprioceptive, visual, auditory, etc.) that represent it (cf. Harleß, 1861; Lotze, 1852, for similar suggestions).

Although it is widely accepted that some cognitive representation of a voluntary movement must precede its execution (cf. Rosenbaum & Krist, 1996), the specific assumption of ideomotor theory that these representations inevitably include the perceivable movement effects has rarely been examined experimentally (cf. Hoffmann, 1993; Hommel, 1998, for the fate of the ideomotor hypothesis in the history of psychology). The few studies that intended to support the ideomotor hypothesis pursued a logic by Greenwald (1970c): If actions are actually selected by representations of their effects, then the perception of these effects should induce the actions from which they result. For example, Greenwald (1970a) observed in line with this logic that vocally naming an aurally presented letter is easier than writing it, which he attributed to the fact that an aurally presented letter is sensorially more similar to the auditory effects of naming than to the visual effects of writing (see also Greenwald, 1970b). Likewise, Hommel (1996; Elsner & Hommel, in press) more recently showed that presenting an effect in a choice reaction task (CRT) increases the probability and speed of selecting the particular response that produced this effect in a preceding training phase.

Although these studies suggest that action effects in general have an impact on action selection, their underlying rationale contradicts the functional motivation of ideomotor hypothesis. Ideomotor hypothesis explicitly claims that voluntary movements are selected by *future* (anticipated) but not by *present* (perceived) effects, and thus it attributes "a facilitatory function to the *image* of feedback from an action rather than to the feedback itself" (Greenwald, 1970c, p. 86, italics in the original publication). For example, one does not press a light switch when the light goes on but because one wants a room to become light. In fact, priming of actions by perceiving their effects would even be dysfunctional because the perceived effects of an executed action would induce the same motor pattern again, resulting in behavioral perseveration (cf. Greenwald, 1970c, for this circular-reflex problem).

Thus, to obtain convincing support for the ideomotor hypothesis, it is not sufficient to show that effects may be helpful (or detrimental) when perceived before response execution, but it is essential to show that these effects necessarily become anticipated when a voluntary response is generated, even when they are not already perceived in advance of response execution. In the present study, I am going to present such evidence by showing that response selection is affected by effects that consistently follow (but do not precede) response execution. Observing such an impact of forthcoming response effects necessarily implies that anticipatory effect representations are indeed endogenously activated before response execution, as stated by ideomotor hypothesis.

Following this rationale, the present experiments show that response selection is affected by the compatibility between responses and their forthcoming effects. So far, compatibility influ-

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ences have been primarily examined between stimuli and responses. It is well established that stimulus–response (S-R) compatibility effects result from stimuli automatically priming corresponding responses with which they share a common feature on an overlapping dimension (cf. Kornblum, Hasbroucq, & Osman, 1990). This priming is helpful when stimuli actually require the responses they evoke automatically (e.g., when responding to a left stimulus with a left response and to a right stimulus with a right response) but detrimental when the primed responses must not be carried out (e.g., when required to respond to a left stimulus with a right response and to a right stimulus with a left response; Fitts & Seeger, 1953).

Although response effects are not perceivable until a response is actually carried out, ideomotor hypothesis claims that they must be anticipated in a percept-like way to voluntarily generate a response. If (and only if) this anticipation actually takes place, these anticipated effects can be expected to also automatically prime corresponding responses (and thus to yield compatibility influences) much as if they had been presented as stimuli in advance of response execution. Hence, ideomotor hypothesis predicts that the well-known compatibility influences between stimuli and responses may manifest themselves also between responses and their consistent effects.

Influences of response–effect (R-E) compatibility have not been systematically investigated so far, nor have they been considered as support for the ideomotor hypothesis. There are, however, studies that can be taken as tentative hints for the existence of the proposed R-E compatibility influences. In a study by Riggio, Gawryszewski, and Umiltà (1986), participants responded to a left- or right-sided stimulus either with a spatially corresponding or a noncorresponding response key. The keys were manipulated with sticks that were either held parallel or crossed. With crossed sticks, response times (RTs) were overall higher than with parallel sticks. This RT increase may be interpreted as an influence of the noncorrespondence between the location of the response (made at the one side of the stick) and the resulting response effect (namely, depressing the response key resulting at the other end of the stick). Unfortunately, the dissociation of responses and effects was not very thorough in these experiments. For example, the sticks could be seen as functional extensions of the hands, so it becomes less clear which location should be interpreted as the response location and the effect location. Additionally, biomechanical factors may at least partly contribute to the results because the crossed sticks were presumably held in a less-than-optimal position (but cf. Nicoletti, Umiltà, & Ladavas, 1984, on this issue).

A second relevant study was reported by Hommel (1993). He had participants respond with a left or right response key to the pitch of a laterally presented tone. By pressing the keys, two different groups of participants lit an effect lamp on either the same or on the opposite side of the response key (left response → left lamp, right response → right lamp vs. left response → right lamp, right response → left lamp). The study also included a control condition in which participants responded to the pitch of a bilaterally presented tone with a left or right response key that lit a lamp on either the same or on the opposite side of the key. This condition would have allowed the author to examine the impact of pure R-E compatibility effects because there was no feature overlap between stimuli and responses nor between stimuli and effects. An inspection of the data of this condition indeed reveals that responses were faster when the location of the responses matched the location of their light effects. However, because the study focused on compatibility between stimulus location and response effect location (as did the study by Riggio et al., 1986), these differences were not systematically examined (although unreported analysis revealed some of these differences significant; B. Hommel, personal communication, October 1999).

To summarize, although observing R-E compatibility effects would be of considerable theoretical relevance for the understanding of voluntary action, and although preliminary empirical hints for them can be identified, R-E compatibility has not been considered as an independent phenomenon that deserves further examination. The purpose of the present study was to provide a first systematic investigation of R-E compatibility effects.

Experiment 1

The purpose of Experiment 1 was to implement the basic R-E compatibility phenomenon. Location was selected as the overlapping dimension for responses and response effects, which is certainly the most extensively used dimension in the domain of S-R compatibility. Participants performed a four-choice reaction task in which they responded to a nonspatial stimulus attribute (color) with four horizontally aligned responses (keypresses).

Each response led to a certain visual effect (the lighting up of one of four horizontally aligned boxes on a computer screen). The critical variation of the experiment concerned the mapping of responses and their effects: In separate blocks, the responses either switched on a spatially corresponding or a spatially noncorresponding lamp (see Figure 1). Thus, the effect of lighting a lamp either corresponded or did not correspond with the respective response. It was expected that a noncorresponding mapping would substantially increase response latencies because in this condition the anticipated effect of a requested response would also activate a spatially corresponding but not requested response.

Method

Participants. Ten undergraduates (6 men, 4 women) at the University of Würzburg, aged 19 to 29 years, participated in fulfillment of a course

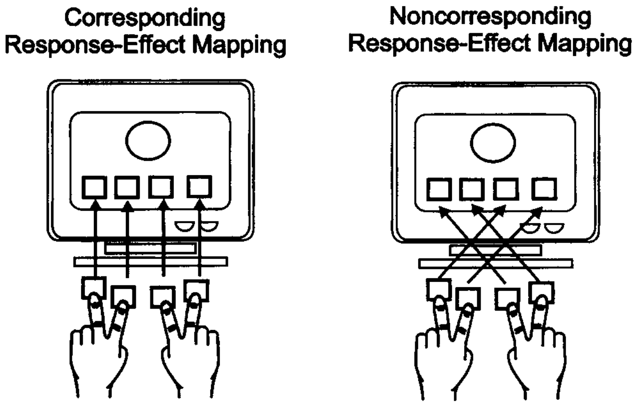

Figure 1. Corresponding and noncorresponding response–effect mapping in Experiment 1.

requirement. The participants were naive about the purposes of the experiment.

Apparatus and stimuli. The presentation of the stimuli, the recording of responses and RTs, and the presentation of the response effects were provided by an IBM-compatible PC (International Business Machines Corporation, Armonk, NY) with a Sony VGA graphics display (Sony Electronics, Inc., New York). The viewing distance was approximately 60 cm. Responses were executed with the index and middle fingers of both hands on an external four-key pad connected to the parallel port of the computer. The key midpoints were separated by approximately 30 mm. The imperative stimulus was a circular colored dot (45 mm in diameter) presented in the middle of the black screen. The colors red, green, blue, and yellow (from the standard VGA color palette) were mapped onto the response keys from left to right for all participants. Throughout the experiment, four white square boxes (25 mm × 25 mm, with an intercenter distance of 40 mm) were displayed at the bottom of the monitor. When a response was given, the inside of one of the boxes became white for 300 ms. In the case of a corresponding mapping, the box above the pressed response key was filled, whereas with a noncorresponding mapping, a box two positions adjacent to the response key was filled (see Figure 1).

Procedure. Each trial started with an auditory warning click (100 Hz, 20 ms). After a blank interval of 500 ms, the color stimulus was presented and remained visible until a response was executed. The response immediately lit up one of the boxes on the screen, according to the current R-E mapping. In the case of an error, a brief visual error feedback (the word *Fehler,* the German word for *mistake*) was displayed for 500 ms, and 1,000 ms after the response, the warning tone for the next response started.

The participants worked through 240 trials with a corresponding R-E mapping and 240 trials with a noncorresponding mapping. Each mapping condition consisted of 15 miniblocks of 16 trials, respectively, in which each stimulus was presented four times. The order of stimuli was random with the exception that stimulus repetitions were not allowed. Half of the participants received the corresponding mapping first, and then, after a brief rest of about 5 min, they received noncorresponding mapping; for the other participants, the order of mappings was reversed.

The participants were instructed to respond to the stimuli as quickly and as accurately as possible. They were informed that each response would light a feedback lamp, indicating the registration of their responses, which in separate blocks would either correspond or not correspond with the pressed key. It was emphasized that the response for the presented stimulus should be executed as quickly as possible, irrespective of the correspondence or noncorrespondence of the lamp.

Results

Responses with RTs below 200 ms and above 1,500 ms were considered as outliers and were discarded (0.02% of all responses). RTs were entered into an analysis of variance (ANOVA) with R-E mapping (corresponding vs. noncorresponding) as repeated measure and order of mapping (corresponding → noncorresponding vs. noncorresponding → corresponding) as between-subjects variable. The mean RTs (and percentages of error, PEs) for the corresponding versus noncorresponding mapping were 482 ms (5.7%) versus 504 ms (5.2%) for participants with corresponding mapping first and 497 ms (4.2%) versus 518 ms (5.3%) for participants with the corresponding mapping last. The ANOVA of RTs revealed that with corresponding R-E mapping, responses were significantly faster than with noncorresponding R-E mapping—490 ms versus 511 ms, $F(1, 8) = 9.28$, $p < .02$. The effect of order of mapping and its interaction with R-E mapping was far from significant (both Fs < 1).[1] The analysis of error rates yielded no significant effects (all ps > .10).

To explore whether the compatibility influence remains stable with practice, we computed an additional analysis with the data from only the last 2 miniblocks (i.e., the last 32 trials) within each R-E mapping (i.e., after participants were highly familiar with the respective mapping). This analysis left the data pattern virtually unchanged (corresponding mapping RT: 485 ms, PE: 4.1%; noncorresponding mapping RT: 522 ms, PE: 5.3%).

To gain insight into the temporal dynamics of the compatibility effect, we performed distribution analysis on the RT data. For each participant, the RT distributions for the corresponding and noncorresponding R-E mapping were computed separately. Then, each distribution was divided into five proportional bins, and the mean RTs within these bins were subjected to an ANOVA with bin and R-E mapping as repeated measures. Aside from main effects of bin, $F(4, 36) = 681.95$, $p < .01$, and mapping, $F(1, 9) = 9.88$, $p < .02$, the analysis revealed a reliable interaction of these factors, $F(4, 36) = 5.31$, $p < .01$, indicating an increasing influence of mapping with increasing RTs (see Figure 2). Single comparisons revealed significant influences of compatibility from the second bin on ($p < .05$, one-tailed).

Discussion

The purpose of Experiment 1 was to investigate whether the spatial correspondence between responses and their sensorial effects has an impact on the ease of initiating these responses. This was indeed the case: When the location of the responses corresponded to the location of their visual effect, responses were faster (and slightly more accurate) than when the locations did not correspond.

Note that the response effects were presented exclusively after the response had been carried out. Thus, they seemingly influenced response initiation backward in time. This apparently paradoxical influence can be explained satisfactorily by assuming that in an effort to initiate an action, its sensorial effects become anticipated, as it is assumed by the ideomotor hypothesis. When responses and effects are mapped noncorrespondingly, a problem is created: Because of the reliance on a common feature (horizontal location), the anticipation of a certain effect will also activate a spatially corresponding but not required response.

Distribution analysis revealed an effect of R-E compatibility from the second bin on. The extent of this effect increased with increasing RT. This increase is in contrast to the temporal dynamics of standard S-R compatibility effects (e.g., the Simon effect;

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[1] The lack of influences of mapping order (subsequently replicated in Experiments 2 and 3) is of some interest in the context of R-E learning because it suggests that there was no influence of acquiring a certain R-E mapping (in the first half of the experiment) on the acquisition of a new R-E mapping (in the second half). This finding accords with recent evidence for a lack of proactive interference in animal R-E learning (Rescorla, 1991, 1995). Note that this does not necessarily mean that acquired R-E associations are easily overwritten. In fact, Rescorla (1991) observed that initially acquired R-E associations remain retrievable when certain situational cues indicate that these original R-E relations are valid again. However, because the present experiments were not designed to allow firm conclusions on the acquisition of R-E associations, this issue is not discussed in more detail (cf. Elsner & Hommel, 2001, for the acquisition and maintenance of R-E associations in humans).

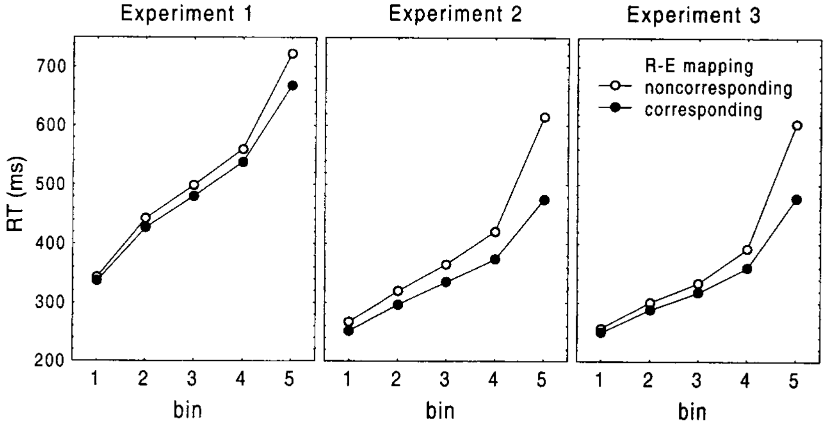

Figure 2. Reaction time (RT) as a function of RT quintile and response–effect mapping in Experiment 1 (4 choice reaction task with spatially varying responses and effects), Experiment 2 (2 choice reaction task with intensity-varying responses and effects), and Experiment 3 (free-choice procedure with intensity varying responses and effects). R-E = response-effect.

Simon, 1969), which tend to decrease with longer RTs (De Jong, Liang, & Lauber, 1994; Hommel, 1994; Rubichi, Nicoletti, Iani, & Umiltà, 1997). The decrease of the standard Simon effect is attributed to the decay of the location code of the stimulus over time so that this code will affect responses with lower likelihood the later the response is executed. In contrast, the increase of the influence of R-E compatibility in the present study presumably results from the fact that the effect code that is assumed to affect the response is not an inherent component of the stimulus (that shows no similarity with the response) but is anticipated—that is, endogenously activated—by the actor. This endogenous activation is likely to be time consuming so that anticipated effects will affect responses more strongly the more time these effect codes have to evolve.

An apparently similar pattern of results was observed by Hommel (1996, Experiment 4) for the impact of perceived effects on response selection. He found that RTs in a CRT were lower when the imperative stimulus was presented simultaneously with the sensorial effect (e.g., a tone of certain pitch) of the required response rather than when presented with the effect of a not-required response. This priming effect also increased with RT. Hommel attributed this increase to a temporal lead of the perceptual encoding of the imperative stimulus over the perceptual encoding of the irrelevant response effect, so with low RTs, responses were presumably selected before the presented effects were coded. Obviously, this explanation does not hold for the increase of R-E compatibility in the present experiment because the response effects were presented after response execution. Thus, the increase of R-E compatibility with RT in the present experiment cannot have resulted from the perceptual encoding of effects but must be related to their anticipation. This issue is further considered in the General Discussion.

Aside from the ideomotor concept, there are alternative accounts of the influence of R-E compatibility. One may suggest that in everyday life the location of responses and visual response effects match quite often. For example, switching on the computer or television set often lights a power LED that usually is located next to the switch. Having experienced such relations, participants may have been surprised when these preexperimentally established relations were violated, which may have withdrawn some resources from processing the task. Following the "surprise" hypothesis, the influence of R-E compatibility should primarily result from the initial trials with a noncorresponding R-E mapping and decrease with practice. Yet, the influence of R-E compatibility remained stable even after participants had an opportunity to experience the R-E relations more than 200 times. It is hard to see that something could have astonished participants after such a considerable period of practice.[2]

A second alternative explanation concerns the specific type of effects that were used. Filling in a box represents an abrupt visual onset, which automatically captures visual attention (Jonides, 1981). Additionally, there is evidence that visual attention is oriented toward the location at which a certain action is intended to be carried out (Deubel, Schneider, & Paprotta, 1998). Thus, it seems plausible that the conditions of Experiment 1 caused some kind of attentional split between response location and visual-effect location. This split would be necessary with a noncorresponding as well as with a corresponding mapping. However, with a noncorresponding mapping, attention had to be split over a broader area (cf. Figure 1), which may have withdrawn attention more strongly from processing the next imperative stimulus. A way to rule out this account is to demonstrate an impact of R-E compatibility by using other, nonspatial response and effects features. We explored this possibility in Experiment 2.

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[2] However, the surprise hypothesis may account for initial differences between corresponding and noncorresponding mapping. A closer inspection of the data shows that a difference between corresponding and noncorresponding mapping was numerically (19 ms) present even within the individual first blocks of each mapping. Comparable differences were also observed in the first blocks of Experiment 2 (42 ms) and Experiment 3 (41 ms). It seems plausible that these initial differences at least partly reflect some kind of participants' distraction from violation of preexperimental experience by a noncorresponding R-E mapping.

Experiment 2

Research in S-R compatibility revealed that responding forcefully to an intensive stimulus and softly to a weak stimulus is easier than responding forcefully to a weak stimulus and softly to an intensive stimulus (Romaiguere, Hasbroucq, Possamai, & Seal, 1993; Stevens, Mack, & Stevens, 1960). This influence has also been observed in the case that participants responded to the stimulus form so that stimulus intensity was task irrelevant (Mattes, Ulrich, & Leuthold, 1999). Thus, it is justified to assume that intensive stimuli automatically prime forceful responses and weak stimuli automatically prime soft responses.

If the influence of R-E compatibility observed in Experiment 1 points to a general principle in the initiation of motor actions, it should certainly not be restricted to the attribute of location. To test this, we asked participants in Experiment 2 to respond to two color stimuli with a forceful or soft press on a single pressure-sensitive response key. A two-choice task was selected because pilot studies showed that four different pressure levels were very hard to discriminate. Responses led to either a loud or quiet auditory effect. It was expected that pairing the forceful response with a loud auditory effect and the soft response with a quiet auditory effect would result in superior performance than pairing the forceful response with the quiet auditory effect and the soft response with a loud effect.

Observing this kind of effect would additionally rule out the visual-attention account of Experiment 1. Because no visual effects were presented and responses were made in a single location, there was no way that spreading attention between response location and effect location could account for such an effect.

Method

Participants. Ten new students from the University of Würzburg (3 men, 7 women) aged from 20 to 32 years participated in fulfillment of a course requirement.

Apparatus and stimuli. A single pressure-sensitive response key (20 mm × 20 mm) was positioned in front of the participants. The key measured the response force in a range from 0 cN up to 3,000 cN. A maximum force of 3,000 cN depressed the plate by about 0.5 mm. The response force was sampled by the computer with a rate of 500 Hz. Participants were instructed to comfortably rest the index finger of the right hand on the key so that a pressure above 20 cN and below 200 cN was measured. The response device should have been pressed softly ($\leq$800 cN) when a green response signal was presented and forcefully ($>$800 cN) when a red stimulus appeared. Participants were instructed to press the response device briefly with the requested force and then to turn back to the rest pressure. RT was the interval between stimulus presentation and the point in time when a response force of more than 200 cN was measured. The peak force within each trial was assumed to be reached when the response force was equal to or lower than the force measured 8 ms before.

Immediately after a correct response had been recorded, either a quiet (65 dB) or loud (78 dB) tone (300 Hz, 500-ms duration) was presented by two loudspeakers positioned on the left and right sides of the monitor, according to the current R-E mapping. With a corresponding mapping, a loud tone was presented after detecting a forceful response, and a quiet tone was presented after detecting a soft response. With a noncorresponding mapping, this R-E relation was reversed. A visual error feedback was provided when the peak force was identified as the wrong response alternative (i.e., when a soft response was given but a forceful response was required or vice versa).

Procedure. Each trial started with a (100 Hz) warning click of 20 ms. Following an interval of 500 ms, a red or green color stimulus was presented and remained visible until the peak force of the response or a force of more than 800 cN was reached. Then, the appropriate sound under the current R-E mapping was emitted immediately. After an intertrial interval of 1,000 ms, the next trial started.

After 24 trials of practice without sound feedback, the participants worked through 8 miniblocks of 16 trials with a corresponding R-E mapping and then 8 miniblocks with a noncorresponding mapping. The order of stimuli was random. Half of the participants received the corresponding mapping first, and then, after a brief rest of about 5 min, the noncorresponding mapping. For the other participants, the order of mappings was reversed.

Participants were instructed to respond to the stimuli as quickly and as accurately as possible. They were informed that each response would lead to a certain sound. They were also informed about the respective R-E mapping. It was emphasized that the response for the presented stimulus should be given as quickly as possible, irrespective of the sound that resulted from the required response.

Results

Responses with RTs below 200 ms and above 1,500 ms were discarded (0.8% of the data). RTs were entered into an ANOVA with R-E mapping (corresponding vs. noncorresponding) as the repeated measure and order of mapping (corresponding → noncorresponding vs. noncorresponding → corresponding) as the between-subjects variable. The mean RTs (PEs) for the corresponding versus noncorresponding mapping were 346 ms (4%) versus 398 ms (5.6%) for participants with the corresponding mapping first and 351 ms (4.8%) versus 400 ms (4.4%) for participants with the corresponding mapping last. The ANOVA revealed that responses were significantly faster with a corresponding than with a noncorresponding mapping, 349 ms versus 399 ms, $F(1, 8) = 51.77$, $p < .01$. No other effect approached significance (all Fs < 1). The analysis of error data led to no significant effects (all Fs < 1).

To test for a practice-related decrease of the influence of R-E compatibility, we again restricted the analysis to only the last two miniblocks within each mapping. As in Experiment 1, this left the data pattern unchanged (corresponding mapping RT: 341 ms, PE: 4.5%; noncorresponding mapping RT: 387 ms, PE: 5.7%).

Distribution analysis of the RT data indicated a significant increase of R-E compatibility with increasing bin, $F(4, 36) = 11.92$, $p < .01$, for the interaction of R-E mapping and bin. Single comparisons revealed the influence of R-E compatibility to be significant in all bins (all ps $< .05$, one-tailed).

Discussion

In Experiment 2, we attempted to broaden the empirical basis of R-E compatibility by applying it to the nonspatial dimension of response and effect intensity. This attempt was successful: The correspondence of response intensity and the intensity of an auditory response effect markedly affected performance. Additionally, the impact of R-E compatibility remained stable with practice and increased with increasing RT as in Experiment 1. Thus, Experiment 2 replicated the main results of Experiment 1. Because there was only one response location and no visual effect, Experiment 2 also ruled out the possibility that in Experiment 1 R-E compatibility was merely the result of a split of visual attention between response and effect location.

Experiment 3

The ideomotor account put forward above stresses the role of R-E relations for the observed results. However, in Experiments 1 and 2, each effect followed not only a response but also a certain stimulus, namely, the response signal for that response. Therefore, it seems possible that aside from R-E associations, stimulus–effect (S-E) associations may have also evolved and may have contributed substantially to the pattern of results.

For an illustration of this complication, consider the condition with the noncorresponding R-E mapping in Experiment 2: A stimulus S_1 (calling for a forceful response) was followed by a soft tone, and a stimulus S_2 (calling for a soft response) was followed by a loud tone. Thus, S_1 contingently preceded a soft tone and S_2 contingently preceded a loud tone. This contingency may let the stimuli acquire properties of the subsequent response effects. In particular, S_1 may acquire the property of being *soft* and S_2 may acquire the property of being *intensive.* In this situation, a *soft* stimulus would require a forceful response, and an *intensive* stimulus would require a soft response. Thus, with a noncorresponding R-E mapping, there may arise a conflict between the acquired meaning of the stimulus and the required response (see Hasbroucq & Guiard, 1991, for a comparable account of the Simon effect). This potential conflict is not present with a corresponding R-E mapping, where the stimuli could only be associated with effects that were compatible with the required response.

A method to prevent the acquisition of S-E associations while concurrently allowing the acquisition of R-E associations has been applied by Elsner and Hommel (2001). They had participants perform different responses (consistently followed by response-specific effects) to only a single stimulus. We applied a similar procedure in Experiment 3. Participants were required to respond as quickly as possible to a go signal with either a soft or forceful response that in different blocks again led to either a corresponding or a noncorresponding tone effect. The key difference to Experiment 2 was that participants were to choose freely whether to respond to the go signal softly or forcefully in each individual trial. The only constraints were that both responses should be executed about equally frequently and in a random order (cf. Berlyne, 1957, for the use of such free-choice procedures). Thus, there was no contingency between the go signal and any of the two effects. If the pattern of results observed in Experiments 1 and 2 is a result of response signals becoming associated with the features of contingent effects, it should be no more observable under these conditions. If, in contrast, it reflects the compatibility between responses and upcoming (and thus anticipated) effects, it should remain relatively unchanged.

Method

Participants. Ten new undergraduates (1 man, 9 women) at the University of Würzburg, aged 19 to 33 years, participated in fulfillment of a course requirement.

Apparatus, stimuli, and procedure. The apparatus and stimuli were the same as in Experiment 2. The participants were instructed to respond as quickly as possible to a green go signal by pressing the response key either softly or forcefully, whereas they were asked to withhold every response with a red no-go signal. The go signal was presented in 75% of the trials, and the no-go signal occurred in 25% of the cases with the order of trials being random. Participants were to choose spontaneously on stimulus presentation which response to execute to the go signal, but they were to make both responses about equally often and in a random order. The number of soft versus forceful responses already performed was displayed on the screen for 3,000 ms after every 32 trials.

Each trial started with a (100 Hz) warning click of 20 ms. Following an interval of 500 ms, either the green go or the red no-go stimulus was presented and remained visible until either 1,500 ms had elapsed or a soft or forceful response was detected. If a response was given, the appropriate sound under the current R-E mapping was emitted immediately. After an intertrial interval of 1,000 ms, the next trial started.

After 24 trials of practice without auditory feedback, participants worked through 8 miniblocks of 16 trials with a corresponding R-E mapping and then 8 miniblocks with a noncorresponding mapping. Half of the participants received the corresponding R-E mapping first, and then, after a brief rest of about 5 min, the noncorresponding mapping; for the other participants, the order of mappings was reversed. Participants were informed about the respective R-E mapping. It was emphasized that with a go signal, one of the two responses should be executed as quickly as possible, irrespective of which tone would result.

Results

Distribution of response types. Participants almost perfectly followed the response ratio instruction. The average proportion of soft versus forceful responses of all correct responses was 50.8% versus 49.2%, respectively, with the corresponding R-E mapping, and it was 50.8% versus 49.2%, respectively, with the noncorresponding mapping. The maximum observed frequency imbalance for a single participant was 44.3% soft responses and 55.7% forceful responses. No consistent pattern concerning the preferred order of responses was apparent.

Response times and errors. Responses with RTs below 100 ms and above 1,500 ms were considered outliers and discarded (0.8% of all responses). RTs were entered into an ANOVA with R-E mapping (corresponding vs. noncorresponding) as the repeated measure and order of mapping (corresponding → noncorresponding vs. noncorresponding → corresponding) as the between-subjects variable. The mean RTs (PEs) for the corresponding versus noncorresponding mapping were 349 ms (0.8%) versus 384 ms (1.8%) for participants with the corresponding mapping first and 329 ms (0.3%) versus 372 ms (0.6%) for participants with the corresponding mapping last. Responses were significantly faster with a corresponding rather than with a noncorresponding R-E mapping, 339 ms versus 378 ms, $F(1, 8) = 11.83$, $p < .01$. No other effect approached significance (all Fs < 1). No effects were present in the error data.

The impact of R-E compatibility again remained relatively unchanged also in the last miniblocks of each R-E mapping (corresponding mapping RT: 332 ms, PE: 0.6%, noncorresponding mapping RT: 380 ms, PE: 0.9%). As in Experiments 1 and 2, distribution analysis revealed an increase of R-E compatibility with increasing RT, $F(4, 36) = 42.96$, $p < .01$, for the interaction of compatibility and bin. Single contrasts revealed a marginally significant impact of compatibility in the third bin ($p < .10$) and a significant influence in the fourth and fifth bins ($p < .05$, one-tailed).

Discussion

Experiment 3 was designed to show that an influence of R-E compatibility can be obtained even when the type of response is not determined by a response-specific stimulus. The maintenance of this influence under such conditions would eliminate the possibility that R-E compatibility reflects a kind of S-R compatibility by the imperative stimuli acquiring properties of the sensorial effects that consistently follow them. A significant influence of the R-E mapping was observed, and it followed the same temporal dynamics as in the foregoing experiments. Therefore, Experiment 3 renders it unlikely that any factors related to processing the response signals contributed considerably to the pattern of results observed in Experiments 1 and 2.

Nevertheless, the impact of R-E compatibility was numerically smaller than in Experiment 2. Two reasons for this decrease emerge. First, with no-go trials, no response is executed, and thus no auditory response effect is presented. This procedural variation may have led to a less tight R-E coupling than in Experiment 2 in which R-E associations were reinforced in every trial. Second, at least in a certain proportion of trials, participants may have selected their response already before presentation of a go signal (presumably allowing for fast responses), which would reduce the impact of anticipated response effects that are assumed to mediate response selection.

General Discussion

The investigation of R-E compatibility phenomena in the present study was prompted by the basic assumption of ideomotor hypothesis that voluntary movements are accessed by anticipations of their perceivable effects (James, 1981/1890; Greenwald, 1970c). Because anticipated effects represent anticipated stimuli, it was hypothesized that the compatibility between responses and their forthcoming effects should affect responses in a similar way as if these effects acted as response stimuli. Three experiments provided converging evidence for these assumptions. Experiment 1 showed an influence of compatibility between the location of responses and the location of their visual effects. Experiment 2 revealed a similar compatibility effect with responses of varying force and auditory effects of varying loudness. Experiment 3 showed differences between corresponding and noncorresponding R-E mappings with only a single imperative stimulus, which verified that the compatibility between responses and their upcoming effects but not acquired S-E associations contribute to these mapping effects.

The response effects in the present experiments affected response latencies, although they were presented exclusively after response initiation. This result confirms the central assumption of ideomotor hypothesis that anticipatory effect representations ("images" in James's, 1981/1890 terms) become endogenously activated for the purpose of response selection, a conclusion not possible from previous research that solely demonstrated an impact of effects (or effect-like stimuli) perceived in advance of response initiation. Because the effects in the present experiments were completely task irrelevant, the results support a strong version of the ideomotor hypothesis claiming that (a) representations of all reliable effects automatically become associated with their producing response and that (b) these representations are automatically activated in the course of initiating this response.

The assumption of an endogenous activation of effect representations receives support by the distribution analyses. An endogenous activation of effect codes presumably is time consuming, which would render it more probable to observe an influence of anticipated effects the more time these effect codes have to evolve, that is, the later the response is executed. Thus, the impact of R-E compatibility should not decrease as typically observed for the impact of irrelevant stimulus codes in S-R compatibility (e.g., in the Simon effect) but should remain constant or even increase with RT. Indeed, an increase was observed in all experiments.

However, one aspect of the distribution analyses requires some consideration: Although the influence of the response effects was numerically present even in the fastest bin (and in Experiment 2 also significantly so), it was nevertheless comparably small in the lower part of the RT distributions. Because the ideomotor hypothesis assumes that effect representations must obligatorily be activated for response generation, the question arises of how responses in the lower RT quintiles were initiated without (or not that strongly) being influenced by effects that are assumed to mediate their access.

There are two not mutually exclusive answers to this question. First, presumably R-E compatibility reflects facilitation of a corresponding mapping as well as interference of a noncorresponding mapping. Provided that facilitation plays a considerable role, it may be that a floor effect prevented a further reduction of RTs from the corresponding mappings in the fastest bins. A second answer (implying a different interpretation of the distribution analyses) is that within the lowest bins (those in Experiments 2 and 3 were within the range of simple RTs with pressure responses; cf. Ulrich & Mattes, 1996), there may be a higher proportion of responses that were selected in advance of the response signal. Because anticipated response effects are assumed to play a role in response selection it is not surprising that we obtained a reduced impact of response effects for such more or less selected responses. This interpretation is also in line with Experiment 3 in which responses could be selected before stimulus presentation, and the influence of R-E compatibility was reduced especially in the lower RT bins, the most likely place for these preselected responses to be located.

The present study raises some questions open to further experimental investigation. First, the conditions necessary to observe R-E compatibility effects need to be further specified. One basic condition is quite apparent: R-E compatibility will only emerge with corresponding and noncorresponding R-E mappings blocked because only in this case the effects follow the responses consistently and can thus serve as a reliable mental cue to address a certain motor pattern. However, a condition with corresponding and noncorresponding trials randomly mixed may serve as an appropriate neutral condition to assess the contribution of facilitation and interference to R-E compatibility. Second, researchers need to clarify the phases of response generation (selection and/or initiation) on which anticipated effects have their main impact. A way to dissociate their impact on these phases would be to eliminate the necessity of response selection (by informing participants before stimulus presentation which response will be required) and to see if an influence of R-E compatibility remains observable or not. Finally, from an ideomotor point of view responses are exhaustively represented by their sensorial effects. Thus, there is no response in the sense of a pure motor pattern in the cognitive system. This view suggests that what was actually manipulated in the present experiments is not R-E compatibility but effect–effect compatibility, that is, compatibility between the various anticipated effects (e.g., proprioceptive, visual, auditory ones) of a certain motor pattern. Future experiments must show if this kind of compatibility actually exists. Clearly, observing this type of influence will strengthen rather than weaken the main conclusion of the present experiments, namely, that anticipated response effects mediate the control of voluntary action. However, in the absence of any evidence for this kind of influence, it still seems appropriate to describe the observed results as R-E compatibility.

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