

## Blindness to Response-Compatible Stimuli

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This contribution is devoted to the question of whether action-control processes may be demonstrated to influence perception. This influence is predicted from a framework in which stimulus processing and action control are assumed to share common codes, thus possibly interfering with each other. In 5 experiments, a paradigm was used that required a motor action during the presentation of a stimulus. The participants were presented with masked right- or left-pointing arrows shortly before executing an already prepared left or right keypress response. We found that the identification probability of the arrow was reduced when the to-be-executed reaction was compatible with the presented arrow. For example, the perception of a right-pointing arrow was impaired when presented during the execution of a right response as compared with that of a left response. The theoretical implications of this finding as well as its relation to other, seemingly similar phenomena (repetition blindness, inhibition of return, psychological refractory period) are discussed.

Most experiments on issues of human information processing are concerned with the impact of perception on action. In a trivial sense, this is of course true for every behavioral experiment, that is, to produce an effect, an experimental manipulation must somehow be perceived by the participants, and to obtain a measure of this effect, they must show some observable behavior. That is, perceptual and cognitive processes can be studied only insofar as they affect the participants' actions in a systematic way.

However, perception has also been found to affect action in a less trivial sense: Since the seminal work of Fitts and colleagues (Fitts & Deininger, 1954; Fitts & Seeger, 1953), it has been known that the mapping of responses upon stimuli has a large impact on reaction time (RT) and error rates. For example, if the participants respond to left- and right-side stimuli by pressing a left- or right-hand key, ipsilateral mapping (left key to left stimulus and right key to right stimulus) allows for much faster and less error-prone responses than contralateral mapping (Broadbent & Gregory, 1965). This advantage of corresponding over noncorresponding pairings is not tied to absolute spatial coordinates but is also observed with relative stimulus-response (S-R) correspondence (Nicoletti, Anzola, Luppino, Rizzolatti, & Umiltà, 1982; Umiltà & Liotti, 1987). Of impor-

tance to the present study is the fact that even symbolic stimulus-response (S-R) correspondence produces compatibility effects, such as with left-right responses to arrows (Arend & Wandmacher, 1987) or upward-downward responses to high- and low-pitched tones (Mudd, 1963; Simon, Mewaldt, Acosta, & Hu, 1976). Thus, there is evidence that any kind of feature overlap or similarity between stimulus and response leads to improved performance.

Although this article is also concerned with correspondence or compatibility between stimuli and responses, it reverses the usual perspective, that is, we investigate the impact of action on perception, an endeavor that was motivated by some unexpected findings in our laboratory (Müsseler, 1995). In these experiments, the participants were presented with a sequence of left- or right-pointing arrows while carrying out a series of already prepared left- or right-hand keypresses. With longer intervals between an arrow and a following response (element), a standard S-R compatibility effect was observed, that is, faster responses with correspondence between arrow direction and relative response position. With short intervals, however, the compatibility effect was often inverted, so that incompatible arrows allowed for faster response than compatible ones. In view of the numerous demonstrations of a facilitative effect of S-R compatibility, such an outcome is more than surprising.

In this article, we present an account for this seemingly paradoxical inversion in terms of aftereffects of response programming or execution on perception. In particular, we propose that initiating an action goes along with a temporary "blindness" to stimulation that resembles the anticipated sensory consequences or effects of that action. Implications of this assumption were tested in five experiments. Their outcomes provide first evidence that such an action-effect blindness (or effect blindness, for short) really exists. We conclude by considering possible connections between this effect and other, seemingly similar phenomena.

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### A Common-Coding Approach to Action-Effect Blindness

Our considerations are based on an interpretation of compatibility effects in terms of a common coding of stimulus and response codes (Prinz, 1990). As already suggested by Lotze (1852) and James (1890), responses may be represented cognitively by (anticipatory) codes of their sensory consequences. By repeatedly performing a movement that produces some perceivable external effect, actors may associate the responsible motor activity pattern with a code representing the to-be-expected sensory effects. Once formed, such a link could be used to activate or select the motor pattern by activating the action-effect code, thus, movements could be initiated by anticipating their external effects.

Greenwald (1970) pointed out that such a representational system may be expected to produce S-R compatibility effects naturally. If an actor perceives a stimulus that resembles the effects of a certain action, the effect code would be activated to a certain degree (depending on the extent of stimulus-effect similarity), leading to an activation of the linked motor pattern. For instance, a left-side stimulus would tend to activate automatically the code representing the sensory left-side consequences of a left-hand action—and eventually the left-hand action itself—so that ipsilateral S-R mappings may be expected to produce faster responses than contralateral mappings. In other words, S-R compatibility effects may be viewed as effects of similarity between stimulus and response-produced effects (Hommel, 1993, 1997).

Prinz (1990, 1992; Prinz, Aschersleben, Hommel, & Vogt, 1995) indicated that this notion implies that stimuli and responses are represented within the same system. Actually, both stimulus codes (i.e., codes of perceived events) and response codes (i.e., codes of to-be-produced events) refer to and, hence, represent external events and, thus, should be of a commensurable format. Although such a common system has obvious advantages for learning, sensory-motor action planning, and S-R translation, it is likely to produce some side effects, such as compatibility phenomena. In the following section, we will focus on another likely problem: the risk of perseveration.

Consider a simple action, in which an actor presses a left-hand key in response to a stimulus, such as the letter X. The letter is encoded and, after consulting the memorized mapping rules, the left-hand action is launched. In a common-coding system, this would be achieved by activating the code of the intended and, thus, expected action effect, which must be a left-side event. Activating this LEFT code would then activate the corresponding motor pattern, triggering the correct response. Of course, performing the action would produce a left-side event that, again, is perceived by the actor. However, because perceiving a left-side stimulus tends to activate the left-hand response via the effect code, there is the risk that the actor will find him- or herself in an endless perception-action cycle.

This perseveration problem with common coding of stimuli and responses was clearly stated by MacKay (1986; 1987, chapter 8). According to him, the problem is solved

by a self-inhibition mechanism: An action is thought to be initiated only if the corresponding action-related codes reach a certain activation threshold. Thereafter, each code enters a *self-inhibition phase*, resulting in a decrease of activation below the standard resting level. This is followed by a recovery phase, including a brief hyperexcitability interval, just like with a single neuron. Therefore, perseveration of the system (i.e., a response→effect→response activation loop) might be prevented by decreasing the system's sensitivity to response-produced effects. In our view, because effect-representing codes are involved in response selection, they would enter the self-inhibition phase on completion of the response selection. Consequently, the codes would be blind to any action effects until the recovery cycle brings their activation back to the resting level. Being blind, they cannot be activated (strongly) by response-produced effects and, thus, cannot build up a reverberatory loop.

Obviously, such a self-inhibition mechanism embedded into a common-coding system may be assumed to affect perception and detection of response-produced effects as well as stimuli that resemble those effects only if they appear in close temporal proximity to the response. Assuming, for instance, that a left-hand response is carried out, the LEFT code involved in the selection and programming of this action should have already entered the self-inhibition phase. If at this time, a left-side stimulus must be perceived, activation of the currently inhibited LEFT code, hence stimulus identification, should be impaired. Therefore, the perceptibility of response-compatible stimuli should be decreased during the period directly following the central movement command.

The inverse compatibility effect observed by Müsseler (1995), namely that during sequence execution, an incompatible stimulus presentation allowed for faster response than a compatible presentation, could be a natural consequence of processing within a common-coding system, by which stimuli and responses are stored together and share certain cognitive codes. If so, investigating these kinds of effects could offer new insights into the perception-action coupling and broaden the common perspective. In fact, although the impact of perception on action is widely recognized as an important factor, the possibility of an inverse influence of action on perception is usually not considered. Our assumption is that executing a response produces a temporary blindness to its anticipated effects and to stimuli that share features with them. Consequently, the present study aims to demonstrate the proposed effect of response execution on perceiving response-compatible stimuli. In Experiment 1, the basic procedure is introduced and a first, affirmative result is reported. Experiments 2 to 5 were conducted to rule out possible artifacts and theoretical objections to our finding.

#### Experiment 1

In this experiment, the participants first had to perform a sequence of two keypresses: an obligatory double keypress

(i.e., a simultaneous press of two keys,  $R_0$ ) and a speeded left- or right-digit keypress ( $R_1$ ) that signaled ahead of time by a cue ( $S_1$ , see Figure 1). The double keypress  $R_0$  triggered the presentation of a masked left- or right-pointing arrow ( $S_2$ ), the direction of which was then to be indicated with another left- or right-digit keypress ( $R_2$ ) at leisure after completing the prepared sequence  $R_0$ - $R_1$ . As the speeded left-right response ( $R_1$ ) could be selected and prepared in advance, the identification of the masked arrow ( $S_2$ ) fell into the execution phase of  $R_1$ .

This design has the following relevant features: First, the early presentation of response cue  $S_1$  allows for the selection and preparation of  $R_1$  prior to  $S_2$  presentation. Consequently,  $R_1$  selection is unlikely to be affected by  $S_2$ , so that standard effects of S-R compatibility (here between  $S_2$ - $R_1$ ) are not to be expected. Second, the double keypress always directly precedes  $R_1$  and, thus, serves as a measurable indicator of the beginning of  $R_1$ 's execution phase. Using the overt double press as a trigger signal ensures that  $S_2$  really appears during  $R_1$  execution.<sup>1</sup> Third,  $R_1$ - $S_2$  compatibility was induced by rather indirect means, namely by manipulating the symbolic relationship between horizontal response location and arrow direction. Of course, it would seem more obvious to use a positional cue like  $S_2$  instead, thus introducing spatial  $R_1$ - $S_2$  correspondence or noncorrespondence. However, this invites several methodological problems. For instance, the participants may tend to move their eyes in the direction of the manual response, and they may give way to this tendency or not. A positive  $R_1$ - $S_2$  compatibility effect could thus be explained by trivial retinal factors and a negative compatibility effect, as predicted from our approach, by an inhibition of such eye movements, which is known to go along with a temporary blindness to the location originally targeted (Rafal, Calabresi, Brennan, & Sciolto, 1989). To circumvent these possible problems, we preferred to use the symbolic-compatibility manipulation already used by Müsseler (1995; cf. Müsseler & Prinz, 1996) instead. This choice should not be crucial. Although S-R and R-S compatibility effects may increase with the degree of similarity between stimulus and response (Greenwald, 1970; Kornblum, Hasbroucq, & Osman, 1990), even symbolic arrows are known to produce reliable effects (e.g., Eimer, 1995). Consequently, we expect blindness not only to actual sensory action effects, such as left-side feedback from a left-hand response, but also to stimuli that are perceptually or symbolically similar to these.

The critical empirical test was whether perceiving the masked arrow ( $S_2$ ) and correctly indicating its direction ( $R_2$ ) depended on the compatibility between the speeded left-right response ( $R_1$ ) and the direction of the masked arrow. If there is a blindness to action effects, we would expect more identification errors with compatible than with incompatible arrows.

## Method

**Apparatus and stimuli.** The experiments were conducted on a laboratory computer (Rhothon rho-prof 200) with black-on-white projection. Presentations were synchronized with the vertical re-

traces of a 71 Hz monitor resulting in a screen update every 14 ms. The arrows (< or >) measured  $0.6^\circ \times 1.0^\circ$  and pointed with equal probability to the left or right. An individual's head was placed on a chin and forehead rest 50 cm in front of the monitor. The mask was a rectangle of  $0.7^\circ \times 1.3^\circ$  in which every pixel was set at random in each trial.

Two microswitches that were pressed by the index finger (response to left arrows) and by the middle finger (response to right arrows) of the right hand served as response keys. The keys were mounted on a flat board in front of the individuals.

**Design.** A prepared left- or right-digit response ( $R_1$ ) was paired with the presentation of a to-be-judged left- or right-pointing arrow ( $S_2$ ), yielding four possible combinations. All participants were tested on all conditions. The identification probabilities of the masked arrows were the main dependent variable, but interresponse times were also analyzed.

**Procedure.** The experiment consisted of a pretest and a test phase. In the pretest, presentation time was determined individually for each participant. Here, the stimulus presentation was initiated by pressing both response keys simultaneously. With the next retrace of the monitor, a left- or right-pointing arrow was presented in the center of the screen for 70 ms and was then deleted by the mask. The individual's task was to identify the arrow by pressing the left- or right-digit key, as needed. The mask remained visible until the individual's reaction. Feedback was provided following incorrect responses on the arrow task by the presentation of a short beep. The pretest consisted of 8 blocks of 12 trials (4 Conditions  $\times$  3 Repetitions), during which the presentation time of the arrows was adjusted. Presentation time was decreased by 14 ms if the error rate within one block was lower than 10% and increased by 14 ms if the error rate was higher than 40%. The individual presentation time was determined by averaging across presentation times of the last three blocks. In this experiment, individual presentation times ranged from 14 ms (for 8 individuals) to 28 ms (for 2 individuals), 42 ms (for 1 individual), 56 ms (for 1 individual), and up to 70 ms (for 2 individuals). Similar, individually adjusted presentation times, set constant for the test phase, were used in the subsequent experiments.

The sequence of events in the test phase is shown in Figure 1. First, an unmasked arrow ( $S_1$ ) was presented for 504 ms, at  $1^\circ$  to the left of the screen center. The participants were instructed to prepare the obligatory double keypress—for as long as they wished—before responding to this arrow. The only restriction was to perform the response ( $R_1$ ) as quickly and accurately as possible. To speed up  $R_1$ , an additional verbal feedback was presented after one trial if the response was given later than 1 s after the double keypress.

By pressing both keys, a second arrow ( $S_2$ ) was presented  $1^\circ$  to the right of the screen center. It was replaced by the mask after the individual presentation time. The individual's task was to give a judgment of whether the masked arrow had pointed to the left or to the right by pressing the left or right key, respectively ( $R_2$ ). To separate  $R_1$  and  $R_2$  temporarily, the participants were required to delay their  $R_2$  response to the masked arrow for at least 1,008 ms after the offset of  $R_1$ . The exact point in time at which the keys were released for the second response was indicated to the partic-

<sup>1</sup> So long as the time course (and even the existence) of the hypothetical blindness effect is not known, we prefer to use the presumably most optimal condition (Müsseler, 1995). Yet, according to our assumptions, blindness effects could also be expected if, for example,  $S_2$  were to follow immediately the overt  $R_1$ . In fact, we have preliminary evidence for this to be the case (Wühr, 1995), although more systematic work on this issue needs to be done.

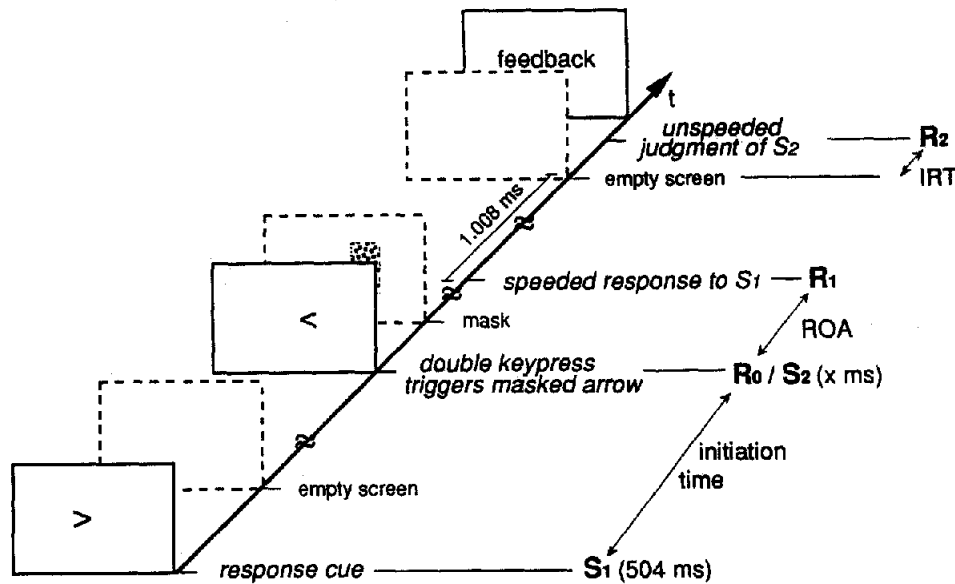


Figure 1. Series of events in Experiments 1 to 5: Participants press both keys simultaneously before performing the response  $R_1$  to the cue  $S_1$  (here, the right key). While participants are doing this, a masked arrow  $S_2$  is presented for an individually adjusted time ( $\times$  ms). The trial is completed with an unspeeded judgment of that critical arrow (here, by pressing the left key).  $S_1$  = response cue;  $S_2$  = masked arrow;  $R_0$  = double keypress;  $R_1$  = response to  $S_1$ ;  $R_2$  = judgment of  $S_2$ ; IRT = interresponse time; ROA = response onset asynchrony.

ipants by the deletion of the mask. After a short delay, the next trial started presentation of yet another unmasked arrow, and so forth.

A short auditory signal together with written feedback was presented immediately after a trial if  $R_1$  or  $R_2$  were incorrect or  $R_1$  was not completed within a 1-s interval after the double keypress. Altogether, in the main test, the participants worked through 16 blocks of 12 trials. The experiment took approximately 1 hour including warming-up trials and short breaks between the blocks.

**Participants.** Fourteen male and female students at the University of Munich with a mean age of 25.2 years were paid to participate in the experiment. All had normal or corrected-to-normal vision.

## Results

For each participant, the probabilities for identifying the masked arrows were determined. Additionally, the choice errors in the first response of the test phase were calculated. If an error was observed here, these trials were excluded from additional analysis. This was necessary in only 1% of the trials and did not depend on the compatibility between  $S_2$  and  $R_1$ , .993 vs. .989,  $t = 1.16$ ,  $p > .25$ , always two-tailed. By contrast, errors in response to the masked stimulus of the test phase were clearly affected by compatibility. The identification probability of an arrow that was compatible to the intended  $R_1$  was, as expected, lower than that of an arrow that was incompatible, .756 vs. .836,  $t = 2.30$ ,  $p = .020$ , always one-tailed; cf. Figure 2.<sup>2</sup>

The following mean response times were observed. The double keypress was initiated 1,000 ms after the onset of the first arrow. The mean response onset asynchrony (ROA) between the double keypress  $R_0$  and  $R_1$  was 333 ms (for the

compatible  $R_1$ - $S_2$  ROA = 339 ms vs. for the incompatible  $R_1$ - $S_2$  ROA = 326 ms);  $R_1$  remained pressed for an average of 188 ms, and  $R_2$  was performed 707 ms after the deletion of the mask (compatible interresponse times [IRT] of 696 ms vs. incompatible IRT of 717 ms; cf. Fig. 1). There were no compatibility effects in the response times, always  $t \leq 1.00$ ,  $p > .25$ , always two-tailed.

## Discussion

The compatibility effect in the identification probabilities seems to indicate that an intended response indeed has an influence on stimulus identification: When a left- or right-digit response is prepared, the perception of an arrow pointing in the same direction is impaired. This specific interfer-

<sup>2</sup> As  $S_1$  was presented to the left and  $S_2$  to the right of the center, this runs the risk of a Simon effect: It is shown that responses are slower and more prone to errors if their direction conflicts with the stimuli's location. However, in the present procedure, contrary to the Simon paradigm, locations may be anticipated in advance and responses may be selected without any time restrictions. Nevertheless, to control for the locations of the stimuli, additional analyses were computed that included all four conditions (i.e., the compatible  $R_1$ - $S_2$  combinations "<<<" and ">>>" and the incompatible ones "<>" and "><"). As the main difference exists only with regard to compatibility (.753 and .759 vs. .842 and .830), it can be excluded that the results are affected by the stimuli's location. Furthermore, in Experiments 4 and 5, stimuli were presented below and above the center of the screen without diminishing the effect.

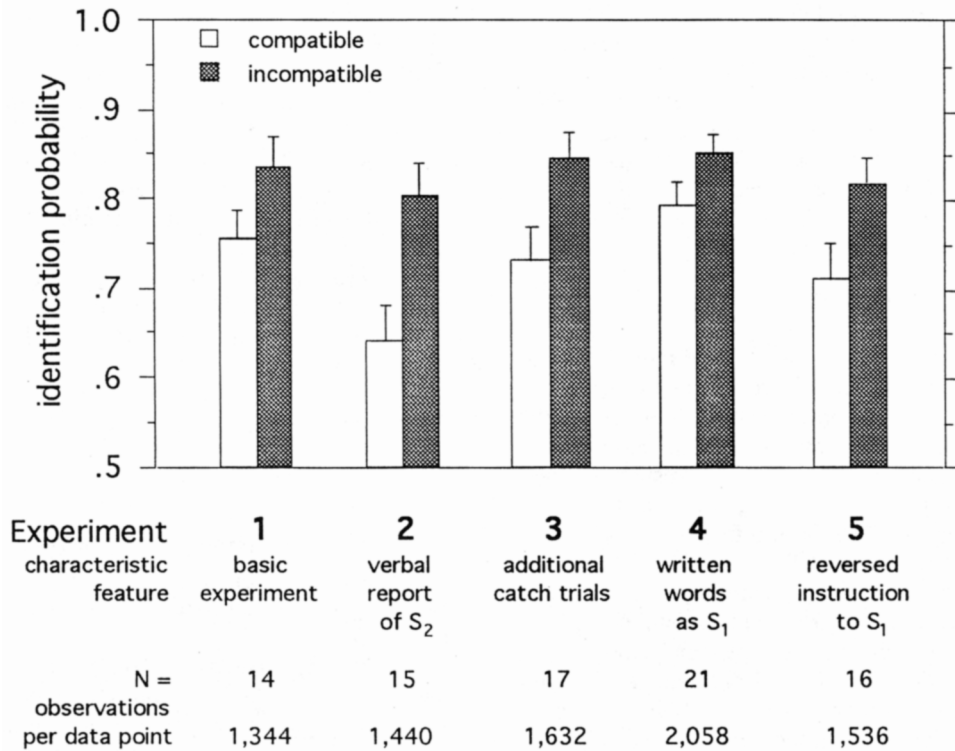


Figure 2. Mean identification probabilities and standard errors between participants of the compatible or incompatible masked arrows in Experiments 1 to 5. Chance level is 0.5.  $S_1$  = response cue;  $S_2$  = masked arrow.

ence could be due to the blindness to action effects mentioned earlier in the introduction.

The experiments that follow were designed to establish the effect and to rule out alternative interpretations. Experiments 2 and 3 will test whether the identification differences originate from two kinds of response bias, and Experiments 4 and 5 will test an interpretation in terms of a perceptual bias.

### Experiment 2

So far, a correct response in the compatible condition has always been characterized by a key repetition, that is, two identical responses  $R_1$  and  $R_2$  have to be generated in succession. The temporal separation between  $R_1$  and  $R_2$  largely prevents their common motor programming but not the possibility that the effect has something to do with their response identity. In other words, one could assume that the probability difference is not attributable to the identification mechanism but is influenced by the mere identity or non-identity of the responses.

One way to check this possibility is to introduce two response modalities, which was done in Experiment 2. As before, while  $R_1$  was pressing a left-digit or right-digit key,  $R_2$  was now the verbal report left or right. If the identification differences have something to do with response identity, they should diminish or eliminate the effect.

### Method

*Stimuli, design, and procedure.* Contrary to Experiment 1, the participants reported verbally the direction of the masked arrow in the test phase. They were instructed to do this when the mask was replaced by an empty screen (1,008 ms after  $R_1$ ). The participants' reports were registered manually by an assistant who sat in front of each individual and who had no possibility to give feedback. The reaction times for  $R_2$  and thus for IRTs were not measured. In all other regards, this experiment was identical to Experiment 1.

*Participants.* Fifteen adults with an average age of 29.5 years served as paid participants in this experiment.

### Results and Discussion

Once more, the only significant result was associated with judging the masked second arrow, which was again more frequently incorrect in the compatible than in the incompatible condition, .640 vs. .802,  $t = 3.06$ ,  $p = .004$ . The mean (unsped) time up to the double keypress was 1,233 ms; with regard to compatibility, no accuracy differences were found in  $R_1$ , .982 vs. .985, and no time differences in the ROA between the double keypress and  $R_1$ ,  $t \leq 1$ ,  $p > .25$  (343 vs. 341 ms).

Judging from these results, the mere identity or nonidentity of the responses did not seem to influence the identification probability. Compared with Experiment 1, the difference between the compatible and incompatible ensemble

even increased (cf. Figure 2). Perhaps, the individuals verbalized internally during the preparation of  $R_1$ , given that such coding was required for  $R_2$ . This may increase the strength of the  $R_1$  response, as  $R_1$  now contains the press of a right or left key as well as the additional verbalized response, in which case, an increase of effect size can be expected. Nevertheless, the effect as such is unlikely to originate from response identity.

### Experiment 3

Although Experiment 2 rules out a mere motor interpretation based on the repetition of the responses, we cannot exclude that another higher-order strategy was responsible for the effect. It may be assumed that, in uncertain situations, individuals tend to alternate their responses more frequently than to repeat one of them, whatever the reason for this strategy may be. The more this strategy is applied, the more probable the observed difference in the identification probabilities could be: If a compatible response (a repetition) is required, and a participant sometimes replaced that response by an alternation, then the identification probability in the compatible condition decreased. If an incompatible response (an alternation) is required, the same strategy increased the probability in the incompatible condition, just as observed. One possibility to look for such hidden response strategies is to introduce catch trials in which the presentation of an arrow is omitted, and only the mask appears. If there is a response tendency to an alternation in these trials, this would be a hint that the effect is produced more likely by a response strategy than by a real identification error.

### Method

*Stimuli, design, and procedure.* The main test was extended by 96 trials (16 Blocks  $\times$  6 Trials) in which no arrows and only masks were presented after the double keypress. Thus, a left arrow, a right arrow, or an empty field preceded the mask with equal probability. The participants were neither informed about these probabilities nor told that in some trials the arrows were omitted. Again, they were only instructed to guess if they did not identify an arrow. If no arrow was presented, every response was accepted without any specific feedback. In all other regards, this experiment was identical to Experiment 1.

*Participants.* Seventeen adults served as paid participants in this experiment. Their average age was 25.8 years.

### Results and Discussion

Although in the catch trials a slight response tendency toward a key alternation (toward an "incompatible" response) was observed, the difference between this and the key-repetition response (the "compatible" response) is far from significant, .478 vs. .522,  $t \leq 1$ ,  $p > .25$ .<sup>3</sup> The identification rates of  $S_2$  again showed an advantage of the incompatible condition over the compatible condition, .676 vs. .817,  $t = 2.17$ ,  $p = .023$ . An additional analysis of

covariance that removed the concomitant catch-trial variability validates this result,  $F(1, 16) = 4.56$ ,  $p = .05$ .

The mean (unsped) time up to the double keypress was 947 ms with no compatibility differences in the following  $R_1$ , .987 vs. .979, and the corresponding ROA (compatible ROA of 287 ms vs. incompatible ROA of 294 ms) or in the interval between the deletion of the mask and  $R_2$  (compatible IRT of 843 ms vs. incompatible IRT of 885 ms),  $t \leq 1$ ,  $p > .25$ .

Therefore, the findings do not point to a hidden response strategy. Together with the previous experiments and especially with the results of Experiment 2 in which the participants pressed a key and made a verbal response to the masked arrow, the results seem to exclude the possibility that the effect is due to such response biases.

### Experiment 4

In the task used in this study, the participants are allowed to perform the double keypress at any time from presentation of  $S_1$  on. Although the participants were instructed to prepare the double keypress and the following reaction for as long as they wished (average for Experiments 1–3 was 1,060 ms minus 504 ms presentation time), we cannot exclude that the sensory image of the unmasked first arrow  $S_1$  sometimes overlapped temporarily with the presentation of the masked second arrow  $S_2$  (which was triggered by the double keypress) and thus influenced its identification.

From this view, the present effect could be similar or even identical to the repetition-blindness effect (e.g. Kanwisher, 1987, 1991; Kanwisher & Potter, 1989, 1990). This effect refers to the failure to detect repetitions of items appearing one after another in a rapid serial visual presentation task. These items may be symbols, letters, words, and probably arrows, too. Although, in most aspects, the present procedure is different from the repetition-blindness paradigm, the repetition or nonrepetition of the arrows  $S_1$  and  $S_2$  could be critical. In Experiment 4, this was checked by replacing the first arrow ( $S_1$ ) by the written words *left* or *right*. Now, there was no longer any perceptual identity between the two stimuli, thus excluding effects on the basis of stimulus repetition.

### Method

*Stimuli, design, and procedure.* As  $S_1$ , the words *left* or *right* were presented for 504 ms 1.5° below the center of the screen. Their letters measured about  $0.3^\circ \times 0.4^\circ$ . The arrows  $S_2$  were the same as in the previous experiments and were placed 1.5° above the center. Otherwise, the procedure was the same as in Experiment 1.

<sup>3</sup> Of course, this result does not exclude the fact that single participants showed a guessing tendency toward a response alternation or repetition. In fact, both of these tendencies were found in the data, but as they were of equal frequency, they leveled each other out in the mean guessing rate. Importantly though, this cannot explain the much larger compatibility differences in the identification task.

*Participants.* Twenty-one individuals with an average age of 28.3 years were paid to participate in the experiment.

### Results

Incompatible arrows again produced a lower error rate and thus a higher identification probability than compatible arrows. Although the difference between the two conditions is less marked than in the earlier experiments, the effect is clearly significant, .798 vs. .851,  $t = 2.64$ ,  $p = .008$ . This result is accompanied by a corresponding effect in the response time; that is, the interval between the deletion of the mask and  $R_2$  is 77 ms slower for the compatible condition than for the incompatible condition (631 vs. 554 ms),  $t = 2.23$ ,  $p = .038$ . As errors and times have the same direction here, a speed-accuracy trade-off can be excluded.

By contrast with the previous experiments, the participants showed an additional error effect in  $R_1$  (in the response to the word). If the prepared response to the word was compatible with the just presented arrow, the participants tended to make fewer errors than with incompatible responses, .017 vs. .044,  $t = -4.01$ ,  $p = .001$ . Interestingly, the (unsped) times up to the double keypress were relatively short (807 ms), and the ROA between double keypress and  $R_1$  was comparably long (397 vs. 405 ms). However, there were no differences between the compatible and the incompatible conditions,  $t < 1.5$ ,  $p > .20$ .

### Discussion

Apart from replicating the main findings from the earlier experiments, Experiment 4 produced an unexpected error effect in  $R_1$ . It must be remembered that the main difference in the procedure was the use of the words *left* or *right* instead of arrows. One reason for the error effect may be that words do not produce as much preparation of  $R_1$  as arrows do. It should be noted that the mean time up to the double keypress is short as compared with that in the previous experiments. So, it seems plausible that  $R_1$  is less well prepared at that point in time and thus is still sensitive to perceptual information. As a consequence, the error rate in  $R_1$  increased with incompatible perceptual stimulation.

On the other hand, less preparation of  $R_1$  should entail reduced influence on the perceptibility of the masked arrow and that seems to be the case. Compared with the earlier experiments, the compatibility differences in the identification rate of the masked arrow were less pronounced. If anything, the present results may be assumed to underestimate rather than to overestimate the judgment errors, which might account for the small blindness effect.

Thus, the mere perceptual repetition of the stimuli is not responsible for the effect. On the other hand, this experiment does not completely exclude the repetition-blindness challenge. As the results of research by Bavelier and Potter (1992) and Bavelier (1994) indicate, repetition blindness is not restricted to identical visual items but is also observed with a semantic or phonological similarity between them (cf., also, Hochhaus & Marohn, 1991; MacKay & Miller,

1994). Thus, one could still argue that the effect in Experiment 4 is not produced by an interaction between the motor response ( $R_1$ ) and the compatible or incompatible stimulus identification ( $S_2$ ), as we had assumed, but is due to the semantic relationship between the presentation of the written word ( $S_1$ ) and the corresponding arrow ( $S_2$ ).

### Experiment 5

Another strong test of the repetition-blindness challenge is to reverse the stimulus-response mapping of  $S_1$  and  $R_1$  and thus require participants to respond to the left-pointing cue  $S_1$  by pressing the right key as  $R_1$  and vice versa. From the common-coding perspective, this mapping manipulation is irrelevant; one would still expect identification to be worse with  $R_1$ - $S_2$  compatibility than with incompatibility. From a repetition-blindness perspective, however, the prediction would be exactly the opposite. If the repetition of stimuli is important, identification rates should suffer from  $S_1$ - $S_2$  compatibility as compared with incompatibility. This finding would contradict our interpretation of the earlier experiments, in which a disadvantage should have resulted from  $R_1$ - $S_2$  compatibility.<sup>4</sup>

### Method

*Stimuli, design, and procedure.* These were as in Experiment 4 with the following modifications: First, the participants had to reverse the mapping of  $R_1$  onto  $S_1$  so that the arrows pointing to the left required right responses, and the arrows pointing to the right required left responses. The second modification was made to counteract a possible transfer of the reversed mapping between  $S_1$  and  $R_1$  to  $S_2$  and  $R_2$ . Because the instruction asked for pressing the key opposite to the  $S_1$  direction, the use of identical response alternatives for  $R_1$  and  $R_2$  may have induced the tendency to indicate an  $S_2$  direction by pressing the opposite key, as well. To circumvent this problem, a different response device (a computer mouse) was used in this experiment.  $R_1$  responses were carried out by pressing the left or right mouse button.  $R_2$  was changed into a simple pointing task so that after the deletion of the mask (1,008 ms after  $R_1$  offset) and an additional blank interval of 252 ms, a left and a right arrow appeared, one above the other, at the margin of the screen. Vertical arrow positions varied randomly, so that the left-pointing arrow could appear at the top and the right-pointing one at the bottom or vice versa. The participants were to indicate the direction of the masked arrow  $S_2$  by pointing with the mouse to the corresponding arrow and to confirm their choice by clicking both mouse buttons. A new trial began 750 ms later.

*Participants.* Sixteen individuals with an average age of 26.9 years were paid to participate in the experiment.

### Results and Discussion

The (unsped) times to the double keypress increased to 1,452 ms, most likely as the result of the translation process for the response reversion of  $R_1$ ; the ROA between the double keypress and  $R_1$  was normal (315 ms vs. 318 ms)

<sup>4</sup> We are grateful to Nancy Kanwisher for suggesting this experiment.

and did not show any differences between the compatible and the incompatible condition,  $t \leq 1$ ,  $p > .25$ . Accuracy on  $R_1$  was high and independent from the compatibility variation, .983 vs. .979,  $t = -1.42$ ,  $p = .175$ , indicating that the reversion of  $R_1$  was well prepared before execution.

Nevertheless, the identification probability of the masked arrow  $S_2$  decreased when the response  $R_1$  was compatible with  $S_2$  as compared with the incompatible condition, .709 vs. .818,  $t = 3.04$ ,  $p = .004$ . Thus, we can conclude that it is not the preceding stimulus that matters for performance on  $S_2$  (as to be expected from the repetition-blindness account), but the preceding response as predicted by the common-coding approach.

### General Discussion

Five experiments were conducted to test the assumption that performing an action is associated with a temporarily decreased sensitivity to stimuli compatible to it. Experiment 1 yielded evidence for the existence of such an action-effect blindness: When a stimulus is presented briefly before the overt onset of a speeded response, then during the execution phase, identification of the stimulus is more difficult if its identity is related to the response.

Because in Experiment 1 the same response device with a left and right key was used for both the first and the second response, the blindness effect could have been due to a manual response bias. However, this hypothesis is undermined by the findings of Experiments 2 and 5, in which the blindness effect was observed even when the second response was a verbal judgment or a pointing movement. On the contrary, these two experiments with the least degree of similarity between the two critical responses yielded the largest blindness effect. Moreover, in Experiment 3, additional catch trials were used to check for higher-order response tendencies. As this tendency was only weak and statistically unreliable, it does not seem to be responsible for the effect. All this strongly suggests that an account of our results, exclusively in terms of a response-response relationship or response-code refractoriness would be hardly viable.

Experiments 4 and 5 tested a perceptual bias interpretation of the blindness effect assuming that the effect is due to the repetition of the response cue  $S_1$  and the to-be-judged stimulus  $S_2$ . However, as the effect also occurred with decreased similarity between these stimuli in Experiment 4 (written words as  $S_1$  and arrows as  $S_2$ ) and even with stimuli reversal in Experiment 5, such an account is unlikely. Rather, it seems to be response  $R_1$  that affects the probability of identifying  $S_2$ .

In sum, the present results provide substantial support for the assumption that executing a response produces a temporary blindness to its anticipated effects—and to stimuli that share features with them. Additional experiments indicated that this effect is not restricted to identification tasks but can be found in detection tasks as well (Müsseler & Hommel, 1997). Together with the previous findings on S-R and R-S compatibility, this allows us to estimate the time course of stimulus-response interactions.

First, the presence of standard S-R compatibility effects clearly demonstrates that response-compatible stimuli facilitate responding if response selection is not completed. In the same vein, identification of response-compatible stimuli is facilitated if they are presented at about the time response selection occurs (Hommel & Schneider, 1997). Second, even precued and already selected responses are facilitated by compatible stimuli so long as the time point of execution is left uncertain (Hommel, 1995, 1996; Müsseler & Prinz, 1996), that is, stimulus effects do not end with response selection or programming but with execution.

Third, when the execution phase is entered, stimuli cease to affect RT which is clearly indicated by the absence of  $S_2$  effects on  $R_1$ . Note, this lack of a standard S-R compatibility effect cannot be attributed to  $S_2$  being too late; on the contrary, as the RTs ranged between 291 and 401 ms in Experiments 1 to 5, there was ample time for  $S_2$  to intrude into the response-related processes. In contrast with  $R_1$  performance, perceiving  $S_2$  is strongly affected by  $R_1$ - $S_2$  compatibility.

Taken together, this strongly suggests a mechanism that works in two ways: It protects the response from the stimulus effects, and it impairs the perception of response-related stimuli at the same time. Even though these two effects could be logically independent, we prefer the more parsimonious interpretation that they represent two sides of the same coin: Response execution is protected by impairing the perception of response-related stimuli.

At least on first sight, the effect demonstrated in this study bears a strong similarity to other, well-known inhibition effects, such as repetition blindness, inhibition of return, or the psychological refractory period. So, rather than postulating a new kind of phenomenon, one may be tempted to subsume action-effect blindness under one of these headings. However, although we admit that processes producing action-effect blindness may play a role in other effects as well, we doubt that our findings are just another demonstration of already known phenomena. Actually, we think that the additional considerations reveal important differences between action-effect blindness and other inhibitory effects. We will discuss them in turn.

### Repetition Blindness

As already pointed out, *repetition blindness* refers to the finding that the participants often fail to detect the occurrence of a repeated item under rapid serial presentation (e.g., Kanwisher & Potter, 1990). According to Kanwisher's token-individuation theory, items are identified at an abstract type level, but to become available for report, each item must be individuated further into a particular token representation. Repetition blindness reflects the inability to install such a second event. Other authors have localized the effect at the stimulus-encoding stage (e.g., Luo & Caramazza, 1996). They assumed a refractory period that "... refers to a brief period in time in which a recognition system's sensitivity ... is reduced and then recovers to its resting level" (p. 105). Bavelier and Jordan (1993) proposed



a similar approach that is based however on the idea of threshold resetting after a unit fires.

In crucial aspects, the present procedure is different from the repetition-blindness paradigm. Most important, in the repetition-blindness paradigm, two identical items are presented in rapid succession within a series of stimuli; whereas, in the present procedure, a to-be-intended response is coupled with a single stimulus. It is true that Experiments 1 to 4 may be reinterpreted from a repetition-blindness approach purely in terms of stimulus-stimulus effects. So, one might assume that even with highly abstract between-stimulus relationships like those in Experiment 4, it was the perceiving of the response cue  $S_1$  that made perceiving a related—hence, repeated—stimulus as  $S_2$  so difficult (cf. Hochhaus & Marohn, 1991; MacKay & Miller, 1994). Importantly though, Experiment 5 ruled out such an interpretation: The relationship between  $R_1$  and  $S_2$ , but not between  $S_1$  and  $S_2$ , determined the judgment performance. Therefore, if action-effect blindness is produced by code refractoriness, the respective code must be involved in both perception and action, not only in the recognition processes on which some repetition-blindness accounts focus.

### *Inhibition of Return*

*Inhibition of return* refers to the second phase of a biphasic cueing effect. If presented briefly before a target stimulus, spatial cues appearing at or near the location of the target are known to facilitate the target's detection and identification even if the cue-target relationship varies randomly (Posner, 1980). However, if the cue-target interval increases, facilitation turns into interference, that is, detection and identification are worse at cued than at uncued locations (Maylor, 1985; Posner & Cohen, 1984). This latter part of the effect has been taken to reflect a preference for novelty in visual scanning and looking behavior. Already attended (and possibly foveated) locations are tagged as being old and are inhibited thus increasing the likelihood for new locations to attract attention (Klein, 1988; Posner & Cohen, 1984; Rafal et al., 1989).

Obviously, this proposed mechanism serves a function very similar to the refractory period that we claim to be responsible for action-effect blindness. The tagging and inhibition of locations prevents the attentional system from continuously focusing at the same location, just as code refractoriness prevents the perception-action system from producing the same response again and again. In this sense, we propose that the self-inhibition of perception-action codes is a kind of inhibition of return. However, there are several reasons for doubting that action-effect blindness can be understood as a variety of the traditional inhibition-of-return phenomenon and thus be open to available inhibition-of-return accounts.

First, in contrast with the effect of action-effect blindness, the inhibition-of-return effect presupposes that the same spatial position is addressed repeatedly. As Kwak and Egeth (1992) have demonstrated, it is not the repetition of stimulus features, such as color or orientation, that produces

the inhibition but the repetition of spatial locations. Repeating positions does not necessarily imply repeated stimulation of identical retinal locations. For instance, orienting attention to a position defined in object-intrinsic coordinates has been shown to hamper the detection of subsequent targets at the same position, even if the object has been moved or rotated in between (Gibson & Egeth, 1994; Tipper, Driver, & Weaver, 1991; Tipper, Weaver, Jerreat, & Burak, 1994). However, some kind of positional identity between cued location and target location must exist for inhibition of return to occur, and it is difficult to see what kind of relationship might have provided such a critical positional identity in the present series of experiments. The relationship between the two stimuli  $S_1$  and  $S_2$  was always constant and, thus, independent of compatibility, so that no differential effects were to be expected here. The only spatial relationship that varied with compatibility was between  $R_1$  and  $S_2$ . Yet, even in this case, there was no positional identity, not even in relative terms. On the contrary, the location of the to-be-identified stimulus was always the same, whether the stimulus was response compatible or incompatible.

Second, inhibition of return seems to be closely related to the control of eye movements. Rafal et al. (1989) provided evidence that inhibition for a spatial position occurs only if an eye movement to that location is programmed, independently of whether the programming is exogenously or endogenously controlled and of whether the program is actually carried out or not. Again, it is hard to see how such a factor could have played a role in producing the effects that we have found.

Third, although inhibition of a repeated stimulus can occur in discrimination tasks like the present one, this is the case only if the first stimulus or cue does not yield useful information (Pratt, 1995). By contrast, if to-be-attended target stimuli are repeated, facilitation is observed (Terry, Valdes, & Neill, 1994). In our experiments, both  $S_1$  and  $S_2$  were relevant and informative, so no inhibition of return was to be expected anyway. Consequently, the present effects must be due to different mechanisms or processes than those responsible for the inhibition of return.

### *Psychological Refractory Period*

The term *psychological refractory period* was introduced by Telford (1931) to refer to the negative correlation between the RT and the duration of the intertrial interval in a simple S-R task. The basic idea was that after a task is carried out, the processing system needs some rest, and this exhibits refractory behavior just like a single cell. Later studies revealed that the limited ability to carry out two tasks at about the same time is a rather general phenomenon (see Pashler, 1994, or Welford, 1952, for an overview). So, the question arises whether the present findings are anything more than another demonstration of the long-known psychological refractory period.

On the one hand, action-effect blindness is produced by an interaction between temporally overlapping tasks, and in

this sense, it is certainly a dual-task effect. On the other hand, however, most existing accounts of the psychological refractory period would predict only unspecific interference between tasks but not a dependency of identification on the response compatibility of the to-be-identified target. Moreover, some accounts would not predict interference at all.

Response-bottleneck accounts (Pashler & Johnston, 1989; Welford, 1980), for instance, assume that only one response can be selected at the same time, so that the second of two responses would have to wait until the first is selected. Yet, in our tasks, there was no temporal overlap of response selection processes whatsoever; not only could  $R_1$  be selected long before  $S_2$  was presented and  $R_2$  was to be selected, but the selection of both  $R_1$  and  $R_2$  was at leisure anyway. So, a response-selection bottleneck is unlikely to play a role in action-effect blindness.

Other factors considered to be responsible for dual-task decrements are limited cognitive capacity (Kahneman, 1973) and insufficient task preparation (Gottsdanker, 1980). No doubt, there are good reasons to assume that the need to perform a manual response briefly before or even during the identification of a stimulus draws capacity away from identification processes and puts limitations on preparing them. Therefore, although our design lacks a control condition for comparison, we would not be surprised to find a general decrease in identification performance from task overlap as such. Still, without introducing arbitrary assumptions, it would be hard to come up with an explanation in terms of capacity sharing or task preparation for the specific interactions that we found. Similar objections may be raised against an account along the lines of hybrid bottleneck approaches, such as those presented by De Jong (1993) or Pashler (1989).

Somewhat better suited for explaining specific interactions seems to be the outcome-conflict approach of Navon and Miller (1987). Like capacity models, this approach does not state a fixed structural bottleneck but allows for crosstalk between simultaneous tasks. Following Navon and Miller's reasoning, action-effect blindness may be considered to reflect a crosstalk between the outcome of  $R_1$  selection or execution and  $S_2$  identification. In fact, this is little more than rephrasing our own story. The present findings are clearly consistent with a dual-task account in terms of outcome conflict. However, as Navon and Miller did not offer assumptions regarding the representation of stimuli and responses or the dynamics of code activation, their approach is of little help in predicting and understanding the specific interactions that we obtained. Although there is some conceptual overlap between the outcome-conflict approach and our common-coding account, we feel that only the latter is specific enough to provide a satisfactory explanation of action-effect blindness.

In summary, we agree that there are obvious similarities between the present findings and the established effects of repetition blindness, inhibition of return, and the psychological refractory period, as well as similarities between our common-coding approach and at least some of the theories and models put forward to account for these better known effects. However, we have also pointed out some—in our

view crucial—differences in both the empirical and theoretical regards. It may well be that a future, more comprehensive approach may treat some or all of these inhibition-related effects as different reflections of the same basic processing principles. We suspect that such an approach is unlikely to be successful without specific assumptions on the representation of stimuli and responses and on how these representations are used in perception and action. We have done that here in assuming that executing a response is initiated by anticipating its external effects and that (to prevent the system from perseveration) this goes along with a temporary blindness to stimuli that share features with these effects. However, we admit that this does not exclude other interpretations. In any case, the concept of refractoriness will play a major role in interpreting such motor-perceptual interactions. The inhibition phenomena discussed here all point to the same implication that having been busy, even cognitive codes need a little rest.

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