

Varying the response code in the blindness to response-compatible stimuli

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Previous work has indicated that action-control processes can specifically influence perceptual processes. The identification of a left- or right-pointing arrow is impaired when it appears during the preparation and execution of a compatible left–right keypress (Müsseler & Hommel, 1997a, b). The present study examines the role of the response-specifying cue in order to manipulate the coding of the action-control processes. Experiment 1 shows that the size of the perceptual impairment is not affected by whether the cue has high or little feature overlap with the to-be-performed response. Cues were omitted in Experiment 2 and participants generated their responses endogenously, but the perceptual impairment still occurred. Experiment 3 examines in more detail which feature of the response contributes to the effect. The results show that it needs both an intended action goal and a corresponding motor activity to bring about the perceptual impairment.

The present paper is concerned with the question of whether action-control processes can affect perceptual processing. Imagine a dual-task situation where an observer is engaged in a motor task while at the same time she/he has to identify a stimulus. Several studies have demonstrated impairment of perceptual processing, which was attributed to the concurrent demands of action control (e.g., De Jong, 1993; De Jong & Sweet, 1994; Ruthruff, Miller, & Lachmann, 1995). For example, De Jong (1993) found that the identification of a foveally presented letter is postponed when the observer is simultaneously engaged in responding to an auditory stimulus. In these studies, the perceptual task and the motor task typically showed no feature overlap, so that the findings were interpreted to represent a procedural bottleneck shared by both perceptual and

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motor processes. However, these unspecific effects give always rise to the question of whether perceptual sensitivity is actually affected or rather whether the impairment originates only from a reduced attentiveness given the perceptual task. Indeed, De Jong and Sweet (1994) found that the impairment varied substantially, depending on which task had been emphasized in the instruction.

The objection that the observed impairment originates only from reduced attentiveness can only be rejected by findings demonstrating more specific cross-talks, that is, when the impairment can be shown to vary with the relationship between the to-be-executed response and the to-be-identified stimulus. Recent experiments have provided evidence that action-control processes can indeed have such a specific influence on perceptual processes (Müsseler & Hommel, 1997a, b; Müsseler, Steininger, & Wühr, in press). This was shown in a task in which masked right- or left-pointing arrows were presented shortly before an already prepared left or right keypress was executed (Figure 1). Results showed that, for example, the identification of a right-pointing arrow is impaired when it is presented during the execution of a right response as compared to a left response. In other words, perceiving a stimulus (*S*) seems to be more difficult when a to-be-executed response (*R*) is compatible with that stimulus. This finding points to a close relationship between the representations on which perceptual and response-preparing processes operate.

Our interpretation of this result rests on the assumption that initiating an action goes along with a temporary "blindness" to a stimulation that shares common codes with the response within the same cognitive domain. The representation of stimuli and responses within one domain is an implication of the old idea that responses may be cognitively evoked by the (anticipatory) codes of their sensory effects (James, 1890; Lotze, 1852; for more recent discussions of this idea, see Greenwald, 1970; Hommel, 1997; Prinz, 1992, 1997). By repeatedly performing a movement that produces some perceivable external effect, actors may associate the corresponding pattern of motor activity with a code representing the to-be-expected sensory effects. Once established, such a

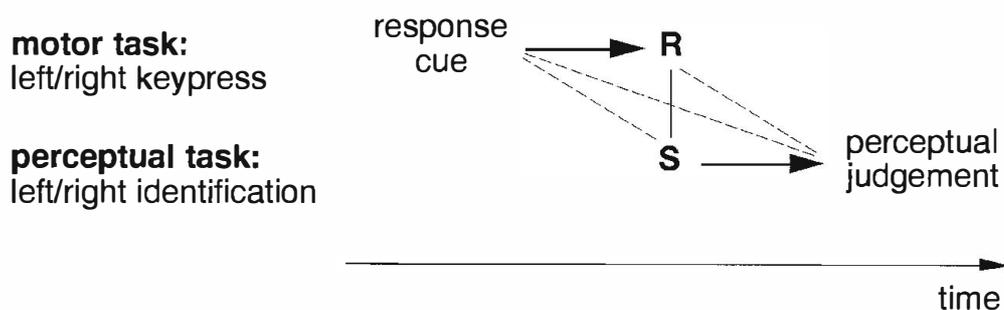


Figure 1. Basic dual-task situation devised to examine whether action control affects specifically perceptual processing. Observers are engaged in a left/right motor task (*R*), while, at the same time, she/he has to identify a left/right stimulus (*S*). The critical empirical test is whether the identification of *S* depends on *R*. Dashed lines indicate other possible *S/R* relationships to be controlled.

link could be used the other way round to select and to activate the motor pattern by activating an effect code first. Therefore, the central assumption is that movements are cognitively represented by their external effects and can be initiated by the activation of these effect codes.

As Prinz (1992, 1997) has pointed out, this assumption implies that not only stimulus codes (i.e., codes of perceived events), but also response codes (i.e., codes of to-be-produced events) represent external events. Accordingly, both types of codes could be commensurate or even identical. If this is true, specific interferences should originate from confronting perceived events with (to-be-produced) motor events. The idea is that in such a situation stimulus processing and action preparation refer to identical codes, that is, both processes overlap on a representational level where features of both perceptual contents and action effects are represented (*common-coding* view, cf., Prinz, 1992, 1997; see also, Hommel, 1997; Hommel, Müsseler, Aschersleben, & Prinz, 2000; Müsseler, 1999).

Several neurophysiological findings of the last decade have also pointed to common modules of perception and action control. Examples are the so-called “visual-and-motor neurons” (e.g., Taira, Mine, Georgopoulos, Murata, & Sakata, 1990) found in the parietal cortex of monkeys and the so-called “mirror neurons” (e.g., Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) located in the monkeys’ premotor cortex. Visual-and-motor neurons are active while the monkey manipulates a specific type of object and/or while that object is merely fixated (Sakata, Taira, Murata, & Mine, 1995; Taira et al., 1990). Mirror neurons become active when the monkey both performs a given action and observes a similar action performed by the experimenter (Di Pellegrino et al., 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1990). Both types of neurons are suggested to play an important role in matching the perceived characteristics of objects or movements to the execution of appropriate or corresponding movements. An activation within the premotor cortex during the perception of goal-directed movements has also been reported recently in human PET studies, which can be interpreted as supporting a common-coding account (for an overview, see Decety & Grèzes, 1999).

The suggested common-coding approach put forward by Prinz and colleagues (Prinz, 1992, 1997; see, also, Hommel, 1997; Hommel et al., 2000; Müsseler, 1999) can also account for more specific perceptual cross-talks, as discussed above. The only assumption to add is that an additional activation of a code is limited when it is already involved in preparing an action (Müsseler, 1995, p. 102; for a similar idea applied to two action codes, see Stoet, 1998; Stoet & Hommel, 1999). If, for example, a keypress with the right hand is required in response to an arrow pointing to the right, the RIGHT code could be one feature; it is used when the stimulus is processed or when the corresponding action is generated. As a consequence, if the RIGHT code is involved in the selection and initiation of a right keypress *R* and if at this point in time a

rightpointing stimulus S appears, then the perceptibility of this stimulus should be decreased during the generation period of the central movement command. This is exactly what the blindness phenomenon represents (Müsseler & Hommel, 1997a, b).

In this paper we explore whether and how variations in the response-specifying stimulus (response cue) lead to different codings of R , and how they could affect the occurrence and/or the size of the blindness effect. Therefore, we need to sketch our assumptions about the structure of the cognitive representations of actions and about the processes taking place between response-cue presentation and overt execution of R . Of course, actions are not sufficiently described by the LEFT and RIGHT code mentioned above; instead, the complete representational structure of a specific action is compromised in a so-called *action-event code* (cf., “action concept,” Hommel, 1997; Hommel et al., 2000). It consists of a set of features of anticipated action effects, with the relative activation of these codes varying with factors like stimulus conditions, task demands, and action goals. Thus, there is a relative weighting between these codes (Hommel, 1998).

For an example, consider the task used by Müsseler and Hommel (1997a, b), where participants perform single keypresses with the index and middle finger of one hand in response to a left- or right-pointing arrow (response cue). An action-event code in such a situation contains anticipated action effects like proprioceptive and kinesthetic feedback of the index or middle finger, but also possible acoustic or visual information, which usually accompanies a keypress. Additionally, these rather concrete features of response-contingent stimulation are assumed to be tagged with rather abstract features like being either LEFT or RIGHT. A keypress with the middle or index finger of one hand is presumably neither LEFT nor RIGHT *per se*. However, because the relative leftness or rightness of these movements is stressed both by the instruction given to the participants and by the left- or right-pointing arrows used as response cues, it is suggested that these spatial features are integrated into the corresponding action-event code. As the identification of the arrows involves the determination of their abstract spatial meaning, we attribute the blindness effect to the access of perceptual processes on representational structures (representing the spatial concepts of LEFT and RIGHT) that are already involved in response-preparing processes.

These considerations suggest that, besides the compatibility relationship between the to-be-executed R and the to-be-identified stimulus S , also the compatibility relationship between the response cue and R could be important for the blindness effect (cf., Figure 1). But, as the matter stands, it still can not be excluded that the blindness effect is, at least partially, due to a more direct interaction between the processing of the response cue and the processing of S . In the blindness experiments reported so far (Müsseler & Hommel, 1997a, b) the response cues and the to-be-identified stimuli S were similar in two important

ways: Both stimuli were presented visually and both shared, at least in the compatible trials, the semantic feature LEFT or RIGHT. Although a direct cross-talk is not very likely (see Müsseler & Hommel, 1997a), it is possible that participants maintain a visual representation of the response cue until response execution. Alternatively, a brief revisualization of the response cue during the initiation and execution of *R* cannot be excluded. This latter possibility is plausible if one assumes that the response cue gets integrated or connected to the action-event code of *R*. In both cases, the blindness effect would originate from an intramodal stimulus-stimulus interference (see also Hoffmann, 1993).

However, there is already some evidence against this possibility. In one of their experiments, Müsseler and Hommel (1997a) reversed the instruction to the response cues (i.e., if the response cue was “<”, *R* had to be a right keypress and *vice versa*) and still observed the blindness to response-compatible stimuli. Yet, one could still argue that participants mentally rotated the cues in order to achieve correspondence between cue and response. A strong test of all these perceptual-interference accounts of the blindness effect is to present the response cues and the to-be-identified stimuli *S* in different modalities or to give no response cues at all.

The scenarios described previously dealt with possible interactions between the processing of the response cue and of the to-be-identified stimulus *S*, due to their similarity with respect to the modality of presentation and to their meaning. Another relationship involving the response cue—and probably modulating the blindness effect—is its compatibility relation to *R*. Compatibility is often defined as “observed variations in human performances that are based on the specific pairings of elements of stimulus and response alphabets” (Alluisi & Warm, 1990, p. 21), or is attributed to “the correspondence, similarity, or match between two or more entities” (Kornblum, 1992, p. 745). Several studies indicate that a compatibility relation between stimuli and responses not only affects the temporal requirements for response selection, but also modulates the coding of this response (e.g., Greenwald & Shulman, 1973; McCann & Johnston, 1992). According to our framework, the coding of *R* is modulated by the relative activation of different parts of the action-event code (effect-code weighting). That is, the more similarity or “feature overlap” (Kornblum, 1992) exists between the response cue and *R*, the more activated the critical feature of being “LEFT” or “RIGHT” should be. In the experiments conducted so far, there was always this symbolic compatibility between response cue and *R*. What remains to be tested is, what happens to the blindness effect if the degree of compatibility between the response cue and *R* is manipulated or even eliminated.

If there is high feature overlap then the response cue is able to activate the corresponding (action-event code of) *R* almost automatically (cf., Hommel, 1997; Kornblum, 1992; Kornblum, Hasbroucq, & Osman, 1990; Prinz, 1990). However, if there is little or no feature overlap, then an additional *translation process* is needed that links the perceptual information with the corresponding

action-event code. Unfortunately, it is still unclear what constitutes high similarity or overlap between the features of stimuli and responses (cf., Kornblum, 1992). We assume that the symbolic stimuli, which so far have been the response cues in our experiments (e.g., left- or right-pointing arrows, written words “left” or “right”), always require a translation into a response code prior to response execution. Of course, the speed of this translation is affected by the compatibility relationship between cue and response (e.g., Fitts & Seeger, 1953; McCann & Johnston, 1992). The question is, whether the ease or difficulty of this translation mechanism affects the codings of *R*. Does the amount of activation of a hypothetical LEFT or RIGHT code differ with respect to the relationship between response cues and *R*? In other words, is a high degree of similarity between a response cue and *R* able to produce a response tendency almost automatically and thus to produce a somewhat stronger LEFT or RIGHT code, and could this result in an increased blindness effect?

The subsequent experiments were designed to manipulate the response cue in order to induce different codings of *R* and to examine its influence on the blindness effect. Experiment 1 examines the influence of the amount of feature overlap between response cues and responses. In Experiment 2 the response cues are omitted and responses have to be initiated endogenously. Experiment 3 aims at separating single response features by combining two stimuli to a response cue.

GENERAL PROCEDURE

The basic experimental procedure was as follows. Participants first had to press two mouse keys simultaneously with the index and middle finger of the right hand (double keypress). Fingers were then lifted, and a speeded left or right keypress *R* was performed that was signalled previously by a response cue (a left tone in Figure 2). The double keypress triggered the presentation of a masked arrow *S* (“<” in Figure 2), the identification of which was then indicated by moving a mouse to a corresponding field. This identification response was given at leisure after completing the speeded response sequence. As the speeded left–right response *R* could be selected and prepared in advance, the identification of the masked arrow *S* fell into the execution phase of *R*.

This design has the following relevant features: First, the early presentation of the response cue allows for the selection and preparation of *R* prior to *S* presentation. And second, the double keypress always directly precedes *R* and thus serves as a measurable indicator of the beginning of *R*'s execution phase. Using the overt double press as a trigger signal ensures that *S* really appears during *R* generation and execution.

The critical empirical test is whether the identification of the masked arrow *S* depends on the compatibility between the speeded left–right response *R* and the

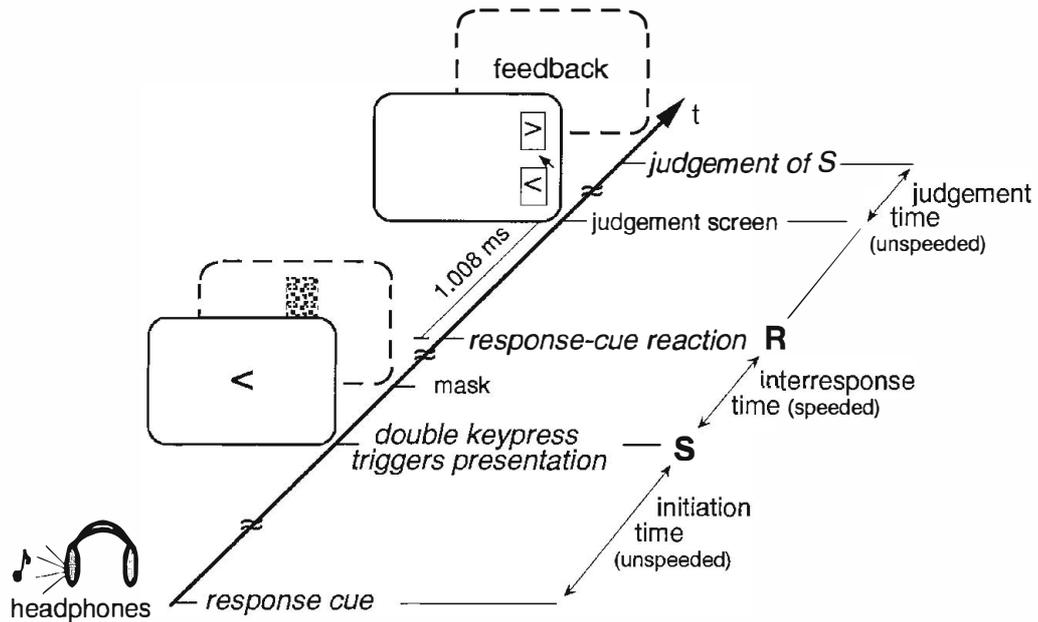


Figure 2. The series of events in the experiments: Participants pressed both keys simultaneously before performing the response *R* (here a left keypress) to a response cue (here a left tone). While doing this a masked stimulus *S* was presented (an arrow for an individually adjusted presentation time). The trial was completed with an unspeeded identification judgement.

direction of the masked arrow. Usually we observe more identification errors with compatible than with incompatible arrows. This is the blindness effect.

EXPERIMENT 1

In this experiment response cues are tones, whereas the to-be-identified stimuli *S* are visually presented left- or right-pointing arrows. This allows to test whether the blindness effect also occurs if the response cues and the to-be-identified stimuli are presented in different modalities. Additionally, the response-cue tones are either *spatially-coded*, that is, they sound to the left or right of the participants and, thus, indicated a to-be-executed left or right *R*, respectively; or they are *frequency-coded* tones, that is, a low tone indicates a to-be-executed left *R*, a high tone a to-be-executed right *R*.

A spatially coded tone can be assumed to have an left/right feature overlap with a corresponding spatial response *R* as well as with the arrows *S*. A spatial feature overlap with *R* is assumed to activate a corresponding response almost automatically (cf., Hommel, 1997; Kornblum et al., 1990; Prinz, 1990). This might also affect the strength of the response *R*, not only with respect to an overt increase of its execution speed or pressure (e.g., Romaguere, Hasbroucq, Possamaie, & Seal, 1993), but also regarding the degree of activation of the RIGHT or LEFT code. If that is the case, it could affect the overlap between *R*

and S and, hence, the identification of S . On the other hand, it is also plausible that in the present experimental setup mainly the translation process establishes the contact to the LEFT and RIGHT code of S . In the experiments conducted so far (Müsseler & Hommel, 1997a, b), the symbolic response cues used always required this actively produced translation, and it remains to be clarified whether this is a precondition for the blindness effect to occur.

A frequency-coded response cue shows neither a feature overlap to S nor to R . The latter indicates that a translation process is needed accordingly. If a blindness effect is still observed with this condition, features of R primarily seem to affect S identification. This could be taken as evidence that the blindness effect originates from an internally generated activation involved in the preparation of the responses.

Method

Apparatus and stimuli. The experiments were carried out on a laboratory computer (Rhothon rho-prof 200). The auditory signals were a low or a high tone (440 vs. 880 Hz, each about 80 dB [A]), which were presented binaurally for 20 ms via headphones (AKG K240, 600 ohm). Visual presentations were black-on-white projections and were synchronized with the vertical retrace of a 71 Hz monitor. The monitor's luminance was approximately 39 cd/m². The arrows ("<" or ">") measured 0.6° × 1.0°. The mask was a rectangle of 0.7° × 1.3° in which every pixel was set with two-thirds probability in each trial.

The participant's head was placed on a chin and forehead rest 50 cm in front of the monitor. Two microswitches of a computer mouse that were pressed by the index finger and middle finger of the right hand served as response keys.

Design. The experiment was run in two blocks resulting from the presentation modes of the response cue. Either (1) the low tone was presented spatially to the left or right ear, indicating a to-be-executed left or right R , or (2) the low or the high tone was presented to both ears, where the low tone indicated a left response and a high tone a right response R . Half of the participants were confronted with one presentation mode in a first session, and with the other presentation mode in a second session. This order was reversed for the other half of the participants. In both modes the response cue indicated with equal probability a left or a right to-be-executed response R .

R was paired with the presentation of a to-be-identified arrow S , that also pointed with equal probability to the left or right and thus was compatible or incompatible to R . The design yielded 2 (spatially- vs. frequency-coded tones) × 2 (compatible vs. incompatible) combinations. All participants were confronted with all conditions. Overall, they worked through 10 blocks of 16 trials (4 conditions × 4 repetitions). The identification probabilities of the masked

arrows were the main dependent variable, but inter-response times were analysed as well.

Procedure. The sequence of events is shown in Figure 2: First, a (spatially or frequency-coded) tone was presented for 20 ms. Before responding to this tone participants were instructed to perform the obligatory double keypress and to give the following response *R* as quickly and accurately as possible. To speed up *R*, an additional written feedback was presented after one trial if the response was given later than 1 s after the double keypress. Instruction, however, stressed that the time up to the double keypress (initiation time, cf., Figure 2) was unsped to enable sufficient preparation of the response sequence.

By pressing both keys the to-be-identified *S* was presented at the screen centre. It was replaced by the mask after an individually adjusted presentation time (see later). After the deletion of the mask (1008 ms after *R* offset) and a further blank interval of 252 ms, a left and a right arrow appeared one above the other at the margin of the screen (judgement screen, cf., Figure 2). Vertical arrow positions varied randomly, so that the left-pointing arrow could appear at the top, and the right at the bottom or *vice versa*. Participants then indicated the direction of the masked arrow *S* by pointing with the mouse to the corresponding arrow and confirmed their choice by clicking both mouse buttons. They were instructed to guess if they had not been able to identify an arrow. A written feedback was presented immediately after a trial if *R* and/or the identification judgement were incorrect. A new trial began 750 ms later.

In a pretest, participants were trained with to-be-identified masked stimuli, but without performing the accompanying response *R*. Here, the participant's task was to indicate the direction of the arrow by a left or right keypress. The pretest consisted of 8 blocks of 12 trials, during which the presentation time of the arrows was adjusted. It started with 70 ms and was decreased by 14 ms if the error rate within one block was smaller than 10% and was increased by 14 ms if the error rate was higher than 40%. The presentation time of the main test started with the average presentation times of the last three pretest blocks. In the main test, too, presentation time was adjusted between the blocks if the error rate increased or decreased too much. The experiment took approximately 75 min including warming-up trials and short breaks between the blocks.

Participants. Thirteen adults with an average age of 26.7 years served as paid participants. They reported to have normal or corrected-to-normal vision.

Results

The mean presentation time of *S*, which were self-adjusted to the participants' error rate, increased from 20.6 ms in the last three blocks of the pretest to 32.3 ms in the main test, $t = 3.67$, $p = .002$, one-tailed. This increase was presumably

caused by the additional demands due to the accompanying motor task of the main test and replicates the unspecific interference findings of the studies mentioned in the introduction. However, in the present context, identification differences with respect to compatibility are of greater importance.

For each participant the probabilities for identifying the masked arrows were determined. Additionally, the choice errors in the response *R* were calculated. If an error was observed here these trials were excluded from further analysis. This was necessary in 2.1% of the trials and did not depend on the presentation mode of *S* or on the compatibility between *R* and *S* (always $F \leq 1, p > .20$).

Contrary to this finding, the identification rates of arrows *S* showed a clear disadvantage in the compatible condition compared with the incompatible condition (.704 vs. .798), that is, the identification was reduced when the to-be-executed response was compatible with the presented arrow (Figure 3). In a 2×2 ANOVA only this compatibility factor was significant with $F(1, 12) = 7.78, p = .016$, that is, the results are independent of whether the response cue is presented as a spatially coded or frequency coded tone. Additionally, there was no hint at all for an interaction between both factors (each $F < 1, p > .20$).

The following mean response times were observed: The double keypress was initiated 812 ms after the onset of the left–right response-cue tone and 951 ms with the high–low tone (initiation time, cf., Figure 2). This difference was significant, $F(1, 2) = 5.44, p = .038$. The mean inter-response time between the double keypress and the onset of *R* was 337 ms; the identification judgement was performed 802 ms after the deletion of the mask (judgement time). There

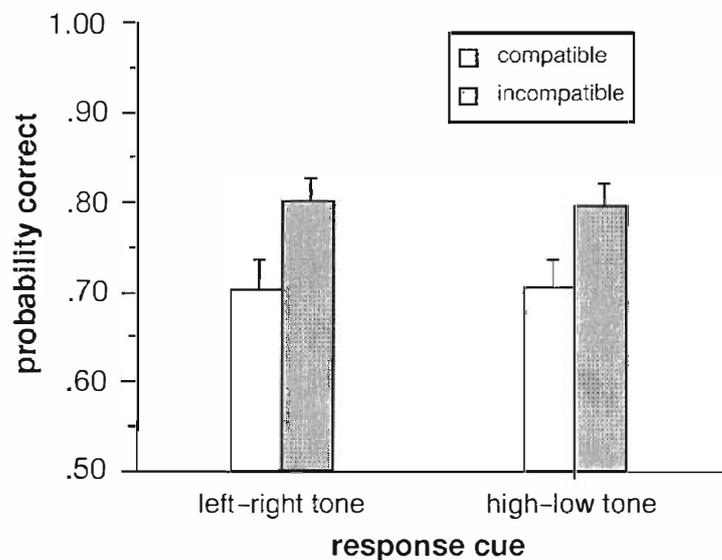


Figure 3. Mean identification probabilities (and standard errors between participants) of response-compatible or response-incompatible masked arrows. Chance level is .5 (Experiment 1, $N = 13$, each bar is based on 520 observations).

were no further statistical effects in these response times as to compatibility or condition (always $F \leq 1$, $p > .20$).

Discussion

The results of Experiment 1 revealed substantial blindness effects of approximately equal size, independent of whether the response R was instructed by a frequency-coded or a spatially-coded response cue. A frequency-coded response cue shows no feature overlap to S indicating that the blindness effect does not originate from this relationship. Further, it was assumed that both conditions would differ in the amount of activation of the critical spatial code involved in the action-event code of R . However, response cues with high or with little feature overlap do not seem to activate differentially the corresponding response-feature codes. This points to the possibility that a substantial amount of activation of these codes comes from internal sources (cf., Hommel, 1997). Accordingly, in the subsequent experiment, response cues will be omitted and participants will have to respond according to a memorised rule.

Further, the results suggest that the translation process, which is certainly necessary to translate high- or low-pitch tones into left- vs. right-response codes, does not essentially contribute to the blindness effect. This translation probably took place before the double keypress was given, as is indicated by the longer initiation times in the condition with frequency-coded tones. A further difference as compared to previous experiments investigating the blindness effect is that the response cue and the to-be-identified stimulus S were not presented within the same modality. Even so, a substantial blindness effect showed up in this experiment. This finding is additional evidence against intramodal stimulus–stimulus interference between the visual processing of the response cue and that of S as a plausible account for the blindness effect. An even more straightforward test for the role of stimulus–stimulus interference effects in the blindness to response-compatible stimuli is again to omit the response cues completely, as will be done in Experiment 2.

EXPERIMENT 2

The results of Experiment 1 suggest that response cues with a high or low degree of feature overlap to left or right keypresses are not able to activate differentially the corresponding action-event code. Thus, primarily features of R seem to affect S identification. This was interpreted as evidence for the notion that a substantial amount of activation involved in the preparation of the responses comes from internal sources (Hommel, 1997). A more straightforward test for this conclusion is to omit the response cue and to use responses only that are endogenously triggered by the participants.

An important—but not easily established—precondition for such a test is that there is actually access to the LEFT or RIGHT code during the internal generation of the response. As mentioned in the introduction, a keypress with the index or middle finger of the right hand is not a “left” or “right” keypress *per se*; if it is performed with the left hand, for example, the mapping of index and middle finger is reversed. Therefore, it is unclear whether a LEFT or RIGHT code is involved at all when keys are pressed with the middle or index finger. To ensure both that the LEFT or RIGHT response codes are used at all and that left and right *R*'s are performed equally frequently, participants had to alternate *R* in every second trial. In other words, participants should generate two identical *R*s for the first two trials, then switch to the alternative response for the subsequent two trials, and so forth.

Method

Stimuli, design, and procedure. These were basically as in Experiment 1 but without presentation of response cues. Instead, in every trial the neutral summons “Left or right key!” was presented for 2 s at the screen centre. After its offset participants could continue with the double keypress and a self-generated left–right response *R*. However, they were instructed to alternate *R* in every second trial, that is, participants should select and generate two identical *R*'s for the first two trials, then the two alternative responses for the subsequent two trials and so forth.

By pressing both keys the to-be-identified *S*, which pointed at random to the left or to the right, was presented 1.5° above screen centre. Each participant performed a total of 192 trials (16 blocks of 12 trials). Half of them were compatible; the other half were incompatible with respect to the *R*–*S* relation.

Participants. Twenty-nine participants with an average age of 27.3 years were paid to perform the experiment.

Results and discussion

There were no statistical compatibility effects in the initiation times (843 ms) or in the judgement times (1093 ms), both $p > .25$. If the masked arrow *S* was compatible with the self-generated response *R*, it was again less often identified correctly than when it was incompatible, 757 vs. 794, $t = 1.97$, $p = .029$, one-tailed. However, this advantage of incompatibility was clearly smaller than in the previous experiment. The rather small identification effect in the present experiment is accompanied by a corresponding effect in the inter-response times. These were slightly, but significantly slower in the compatible than in the incompatible condition, 308 vs. 302 ms, $t = 2.42$, $p = .022$, two-tailed. Hence, this difference could indicate that the disadvantage in the identification task is rather more underestimated than overestimated. However, it is questionable

whether this small latency difference can account for the small difference observed in the identification rates between compatible and incompatible *S*. Possibly the procedure in the present experiment did not emphasise so much the leftness or rightness of *R*. As mentioned before, it is not necessary to involve the LEFT or RIGHT code in an index or middle finger-keypress. Rather, an endogenously generated keypress could be initiated simply by the command to press the index or middle finger or by an alternation or repetition command with respect to the preceding *R*. In Experiment 1, in contrast, the rule to transform a tone into a left or right keypress is to be applied in every trial, which might have strengthened the effect.

Still, a left or right *R* generated completely endogenously is sufficient to produce the blindness effect. Thus, the blindness effect is not caused by a stimulus-stimulus interference between the processing of the response cue and the processing of the to-be-identified *S*, but by an interference that originates from an overlap of features of *R* and of *S*. Experiment 3 examined whether the intended overt feature or rather a covert feature of *R* produces the blindness effect.

EXPERIMENT 3

This experiment was designed to manipulate the assumed number and types of response features that are integrated into the action-event code of *R*. This allows to test whether the interference between *S* and *R* originates indeed from the left or right keypresses. More precisely, the sensitivity for an arrow sharing the LEFT or RIGHT code with the intended keypress *R* was assumed to be decreased during the generation period of the central movement command. However, the effect may not have originated from the overt *press* of the intended finger but from the covert *release* of the other one. This becomes even more plausible if we assume that the most natural response tendency to a double keypress is to repeat it again (cf., the procedure in Figure 2). In order to prevent the system from doing so, the other finger is released and that is the even more demanding motor command (cf. Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992). As a consequence, although the intended response may be a second press on the LEFT, the more demanding motor activity may be the release of the RIGHT finger (and *vice versa*). In that case, the effect does not owe to an interference originating from the intended pressing of *R*, but to a facilitation originating from the release of the opposite *R*.

One possibility to decide between these opposite accounts is to study the two different finger movements in isolation and to compare their ability to interfere or to facilitate with the identification of compatible and incompatible stimuli. Therefore, in Experiment 3 electronic sensor contacts instead of mouse keys were used, together with two different response cues. The first cue, two short tones or one long tone, specified the movement to be performed and the second

cue, the written word “left” or “right,” designated the finger to be used. Two short tones meant that first both keys had to be contacted simultaneously, which mimics the obligatory double keypress. Then the finger designated by the word contacted its key again while the other finger could simply rest on its contact (condition “to repeat the contact”). In the other condition, a long tone instructed the participants also to contact both keys simultaneously, but then to maintain the finger designated by the word on its key, which implied to release the other finger instead (condition “to maintain the contact”). A presumably important difference between both conditions is that in the condition “repeat the contact” the side designated by the response cue and the side where the movement has to take place correspond, unlike the condition “maintain the contact”.

As a result of this design, it is possible to study the action-perception cross-talks of two different finger movements in isolation. If the motor demands of releasing a keypress are necessary and sufficient to facilitate the perception of compatible stimuli, then there should be better identification performance for stimuli compatible with the released finger in the condition “maintain the contact”, but no blindness effect in the condition “repeat the contact”. Conversely, if the motor demands of performing a finger keypress are necessary and sufficient to interfere with the perception of compatible stimuli, there should be the usual blindness effect with the condition “repeat the contact” but no interference with “maintain the contact”.

As mentioned previously these two alternative hypotheses have in common that they explain the blindness effect as exclusive consequences of very specific motor responses (either to “maintain contact” or to “release” the key). A third hypothesis states that it is not the characteristic of a specific motor response that is responsible for the blindness effect, but rather the relative weighting of activation corresponding to the different movements that have to be performed simultaneously. Accordingly, this hypothesis would predict opposite effects in both conditions, irrespective of whether the to-be-identified stimuli are compatible to the repeat-and-maintain movement in the condition “repeat the contact” or to the maintain-and-release movement in the condition “maintain the contact”.

Method

Apparatus and stimuli. Response cues now were an auditory signal that determined the response type, and the written word “left” or “right” that determined the key. The auditory signal was either a single tone of 200 ms duration or two successive tones of 40 ms duration separated by an intertone interval of 120 ms (each tone 880 Hz, 80 dB[A] presented binaurally by headphones). The single tone indicated to maintain the contact after the obligatory double contact (and to release the other key, respectively), while two tones indicated to repeat one contact (and to maintain the other key, respectively).

Each trial started with the auditory signal (one or two tones) and after an interval of 500 ms the written words “left” or “right” appeared 1.5° below screen centre a further 500 ms. By pressing both keys the to-be-identified arrow was presented 1.5° above screen centre and was replaced by the mask after an individually adjusted presentation time (cf., the adjustment procedure in Experiment 1). As before, the mask disappeared from the screen 1008 ms after *R* offset and the judgement screen was presented after a further blank interval of 252 ms.

In this experiment electronic sensor contacts served as response switches. They ensured that the motor activity necessary to perform the response *R* was focused on one finger only, that is, the opposite finger remained relaxed on the switch without needing any pressure.

Design and procedure. The experiment was based on a 2 (response-cue combination) × 2 (compatibility) design. All participants were confronted with all conditions in a completely randomized order. Each one worked through 14 blocks of 16 trials (4 conditions × 4 repetitions).

After the presentation of the response cues participants were instructed to perform the double contact, that is, to put first their index and middle finger on the contact switches. Then, if the response-cue combination indicated to repeat a contact (two tones together with the word “left” or “right”), they immediately had to repeat the contact indicated by the word while maintaining the other key. If the response-cue combination indicated to maintain a contact (one tone together with the word “left” or “right”), participants had to maintain the key indicated by the word while immediately releasing the other key. In all other respects, the procedure was the same as in Experiment 1.

Participants. Fifteen male and female students at the University of Munich with a mean age of 27.7 years were paid to participate.

Results

Choice errors in *R* were observed in only 2.7% of the trials and were independent from *R*–*S* compatibility as well as from response-cue combinations. However, the identification rates of arrows *S* seem to be affected by both factors: A 2 × 2 ANOVA revealed a significance of their interaction with $F(1, 14) = 8.53$, $p = .011$ (Figure 4). When response cues indicated to repeat a contact, compatible identifications of *S* were worse than incompatible ones (.792 vs. .851). Indeed, a *t*-test for this comparison yielded $t = 2.38$, $p = .016$, one-tailed. On the other hand, when response cues indicated to maintain a contact (i.e., to release the opposite key), this pattern of result was reversed, although it was far from significant, .821 vs. .809, $t < 1$, n.s.)

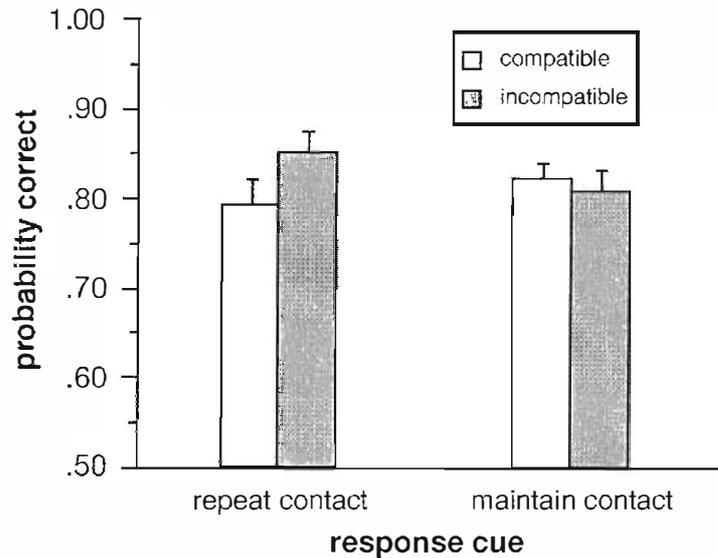


Figure 4. Mean identification probabilities (and standard errors between participants) of response-compatible or response-incompatible masked arrows. Chance level is .5 (Experiment 3, $N = 15$, each bar is based on 840 observations).

The following response times were observed: The mean initiation times were 1796 ms and did not differ between response-cue conditions. The inter-response times did differ, that is, if participants had to maintain a contact, it took 341 ms to release the opposite key; if they had to repeat a contact, inter-response times, measured from the onset of the double keypress to the onset of the repetition, were only 231 ms, $F(1, 14) = 14.55, p = .002$. Judgement times for S were 1175 ms. There were no statistically significant effects in the response times as to compatibility (always $p > .15$).

Discussion

In this experiment participants had to respond to a combination of two response cues. If participants heard two short beeps and read the words “left” or “right” they had to repeat the contact with the designated finger while leaving the other finger relaxed on its key (condition “repeat the contact”). If participants heard one long tone and read one of the words, they had to maintain the contact with the designated finger and to release the other finger from the key instead (condition “maintain the contact”). In the condition “repeat the contact”, participants were significantly worse in identifying stimuli compatible to the side of the single repetition as compared to incompatible stimuli. Since the other finger could simply rest on its contact, this finding rules out the possible alternative that the standard blindness-effect reported so far emerges from the covert release

movement of that finger. In the condition “maintain the contact”, identification performance did not differ in dependence of compatibility.

An obvious explanation of this pattern of results is that the action code to perform the task in the condition “maintain the contact” involve both a LEFT and RIGHT code, one of which is connected with a MAINTAIN tag and the other with a RELEASE tag. As thus the action code contains inconsistent tendencies, one that represents the motor activity and one that represents the overt instructional action goal, they seem to nullify each other. If they represent consistent tendencies—which is the more usual situation in the condition “repeat the contact”—the standard blindness effect is observed. Although this condition implicitly requires also to “maintain the opposite contact”, the main difference to the previous condition is that the overt response and the instructional component correspond.

Another critical test of this idea would be a condition that reverses not only the motor demands but also the instructional goal; that is, instead of “maintain the contact” it would be explicitly stated to “lift the opposite finger”. Then both components are also consistent, but contradict the response cue. In fact, a nearly identical condition has already been realized in an experiment conducted by Müsseler and Hommel (1997a, Exp. 5). In that experiment, the response cue was a left- or right-pointing arrow, but the instruction required to respond with the opposite *R*; so, if the response cue was “<”, *R* had to be a right keypress and *vice versa*. The result was that the blindness effect went with this reversal, that is, the identification of *S* was impaired when it was compatible with the to-be-executed response. Obviously, crucial for the blindness effect is both motor activity, necessary to perform the overt response, and a consistent instructional and accordingly intended action goal.

A final question concerning the results of Experiment 3 is whether the identification rates are affected by the different inter-response times. Surprisingly, after the double contact participants are 110 ms faster to repeat the contact than to release the opposite finger in the condition to maintain it. Note that the repetition response includes the release of the contact switch in between, so that the maintained response seems to be even more slowed down. Nevertheless, for two reasons we assume that this decline is only a matter of the different response types and does not owe to the processes that translate the response cues into the demanded response. First, because the instruction stressed to maintain the keypress, introspective reports from several observers indicates that the system tends to “wait” for the afferent signals of the to-be-maintained contact before it proceeds with lifting the opposite finger. And second, in this condition the end posture of the response is rather uncomfortable (ie., maintaining one finger while lifting the other). This might also increase the inter-response times (cf., Rosenbaum et al., 1992). In any case, the large initiation times of nearly 1800 ms clearly point to a prior translation process.

GENERAL DISCUSSION

When participants are engaged in action-control processes, previous studies have shown a general impairment in a perceptual task that has no or only little feature overlap with the action-control task (De Jong, 1993; De Jong & Sweet, 1994; Ruthruff et al., 1995). The present study is concerned with more specific impairments recently observed by Müsseler and Hommel (1997a, b). In particular, when participants performed a left or right keypress (*R*) and were asked to identify a left or right arrow (*S*) in parallel, they performed worse with compatible relationships of keypress and arrow than on incompatible trials ("blindness to response-compatible stimuli"). The question was whether and how variations in the response-specifying stimuli (response cues) lead to different codings of *R* that thus affect the occurrence and/or the size of the perceptual impairment.

Experiment 1 shows that the blindness effect occurred independent of whether a translation process is necessary prior to response execution or not. *R* was specified by a spatially coded or frequency-coded response cue. A frequency-coded tone has to be translated into a LEFT or RIGHT code prior to response execution, whereas a spatially coded tone shows an inherent feature overlap with the to-be-generated *R* and is thus assumed to generate *R* almost automatically (e.g., Hommel, 1997; Kornblum, 1992; Prinz, 1990). As the results show substantial blindness effects of approximately equal size, more inherent features of *R* seem to affect *S* identification. In order to support this conclusion, in Experiment 2 the response cue was omitted and participants had to intend and to generate *R* endogenously. Because the blindness effect should not result from stimulus-stimulus interference and should not be affected by the *S*-*R* translation mode, the blindness effect was expected again. The results confirmed this prediction suggesting that the critical activation responsible for the blindness effect comes from endogenous sources.

Finally, Experiment 3 was designed to separate the feature of *R* that is responsible for the effect. In the experiments so far, the observed blindness effect has been interpreted with respect to the instructionally intended keypress, which was performed after an obligatory double keypress. However, in order to perform this task, participants had to lift their opposite finger in parallel which could also have been the critical movement for the effect to appear. As a consequence, although the instructionally intended response may be "left," the more demanding motor activity could have been that for lifting the "right" finger and *vice versa*. In that case, the effect would not owe to an interference resulting from the intended pressing of *R*, but to a facilitation from lifting the opposite *R*. The findings of Experiment 3 clearly rules out this possibility. In the condition "repeat the contact" the motor activity necessary to perform *R* can be focused on the intended finger only, while the opposite finger can stay relaxed on the sensor contact. Nevertheless, the blindness effect was

observed under this condition, showing that the effect is not due to facilitation from lifting the opposite *R*.

In the condition “maintain the contact”, identification performance showed no comparable tendency for the lifting movement. An obvious explanation of this result is that the action code to perform this task involves both an instructional LEFT or RIGHT tendency to maintain the keypress and an opposite LEFT or RIGHT tendency to lift the other finger. Thus, the action-event code was assumed to consist of both spatial components, one of which is connected with the MAINTAIN tag, the other with the RELEASE tag. Because the action code thus contains inconsistent tendencies, they nullify each other. If they represent consistent tendencies—which is the more usual situation in the condition “repeat the contact”—the standard blindness effect is observed. This pattern of results shows that it needs both motor activity for performing the overt response and a consistent instructional and accordingly intended action goal for the blindness effect to occur.

That an intended action goal as well as a corresponding motor activity is crucial, can be easily integrated in the effect-oriented view of action control mentioned earlier. However, the idea that actions are selected and initiated by anticipating their intended sensory effects, needs the extension that action effects could refer to any kind of response- or action-contingent events (e.g., Aschersleben & Prinz, 1997; Hommel, 1997; Meltzoff, Kuhl, & Moore, 1991; Müsseler & Hommel, 1997a; Prinz, 1997; Ziebler, 1998). Only this extension allows to postulate a feature overlap between a spatial keypress and a symbolic arrow, that is, between the present *R* and *S*. According to Greenwald and Shulman (1973), symbolic arrows are even ideomotorically compatible to a left or right response, that is, their stimulus code resembles features that also exist in the response feedback. On the other hand, a spatial left or right response is much less “left” or “right” than it appears at first sight. The “leftness” and “rightness” of a response is also determined by the experimental and instructional context. A stimulus can be compatible to a response with reference to the observer’s left or right arm, to his/her left or right finger of one hand, or to some left or right landmark in his/her extra-personal space. So the present findings take some overburden in the stimulus–response relation for granted (Greenwald, 1970).

From that, the question immediately follows why the present blindness effect reveals an impairment and not a facilitation with a compatible *R*–*S* relationship. Since the seminal work of Fitts and colleagues (Fitts & Deininger, 1954; Fitts & Seeger, 1953) the opposite is well known, that is, compatible *S*–*R* mappings generally reveal better performance than an incompatible mapping. The basic difference in the procedure is that in a standard *S*–*R* compatibility task observers are confronted with a single-task situation, that is, they are confronted with a stimulus for which they select and execute a response as fast and correctly as possible. As a result a compatible mapping between *S* and *R* allows

for much faster and less error-prone responses than an incompatible mapping. Note that in the dual-task situation where the blindness effect is observed *R* is selected and prepared in advance, and only thereafter *S* is presented. Additionally, the main dependent measure is identification probability, not response latency.

Thus, several aspects can account for the discrepancy observed between the standard *S*–*R* compatibility task and the identification task of this paper: With regard to a first account, both tasks base on and have access to different levels of representations. Therefore, dissociations between perception and action come with no surprise and are indeed often found (e.g., Aglioti, DeSouza, & Goodale, 1995; Aschersleben & Müsseler, 1999; Neumann & Müsseler, 1990; but see Franz, Gegenfurtner, Bühlhoff, & Fahle, 2000). These dissociations do not necessarily contradict our idea of a common representation of both domains (see earlier); the account only postulates that response generation and perceptual judgement also take into account other stages of processing. However, within such a view it remains to be clarified why the results between both tasks are even reversed.

With regard to a second account, both the blindness task and the standard *S*–*R* compatibility task measure two sides of the same coin and differ only in their temporal characteristics. It is possible that the access to the LEFT or RIGHT code is impaired only when the response is already selected and prepared—in other words, when the code is already bound to other action features forming the action-event code (Hommel, 1997; Hommel et al., 2000; Müsseler, 1999). Before that it can be integrated into the action plan, thus enabling facilitation. Indirect hints for this temporal account come from a series of experiments recently conducted by Stoet (1998; Stoet & Hommel, 1999). His starting point was that preparing a response should not only interfere with the perception of feature-sharing stimuli, but with the preparation and execution of another feature-sharing response as well. He used a dual-task paradigm in which one two-choice task was nested into a second two-choice task. The results showed that the response latency to a second stimulus is reduced when it is presented in close temporal succession with a first, feature-sharing stimulus. However, when the stimuli were temporarily more separated, this response was significantly delayed. Thus, facilitation and interference could depend on the temporal characteristics of presentation; however, the facilitation effects in the study of Stoet (1998; Stoet & Hommel, 1999) were always small and less clear than the corresponding interference effects.

Finally, with regard to a third account, both tasks recruit mostly independent mechanisms. In this view, the blindness effect demonstrated in this study is not so much a matter of compatibility, but a matter of inhibition well-known from other phenomena. For example, the term *repetition blindness* refers to the effect that participants often fail to detect the occurrence of a repeated item under rapid serial visual presentation (e.g., Kanwisher, 1987, 1991; Kanwisher

& Potter, 1989, 1990; Park & Kanwisher, 1994). Among others, Luo and Caramazza (1995, 1996; see, however, Chun & Cavanagh, 1997) localize this effect at the stimulus-encoding stage, assuming that the sensitivity of a recognition unit is briefly reduced before recovering to its resting level. At first sight, this formulation of a brief period of insensitivity seems to be able to account for the present blindness effect as well (see Müsseler & Hommel, 1997a). Recent evidence, however, shows that this is not very likely (Wühr & Müsseler, 2000). Using a timed-response method, where participants had to synchronize *R* with the third of three beeps, Wühr and Müsseler (2000) found the blindness effect for response-compatible stimuli within a period of 2 s before the execution of *R*. This finding clearly contradicts a brief period of insensitivity and suggests that the present blindness effect is due to a more durable state of the cognitive system when it is involved in response preparation.

Other possibly related phenomena are the so-called inhibition-of-return or the negative-priming effect. *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. If the cue-target interval increases, however, facilitation turns into interference, that is, detection and identification is worse at cued than at uncued locations (e.g., Posner & Cohen, 1984). This latter part of the effect has been taken to reflect a preference for novelty in visual scanning and looking behaviour: Already attended (and possibly foveated) locations are tagged as old and are inhibited, that way increasing the likelihood for new locations to attract attention. However, there are at least two reasons for doubting that the blindness effect can be understood as a variant of the inhibition-of-return phenomenon: First, as Kwak and Egeth (1992) have demonstrated, it is not the repetition of stimulus features, such as colour 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. Second, inhibition of return seems to be closely related to the control of eye movements. Rafal, Calabresi, Brennan, and Sciolto (1989) provided evidence that inhibition for a spatial position only occurs if an eye movement to that location is programmed, independent of whether the programming is exogeneously or endogeneously controlled, and of whether the programme is actually carried out or not. It is hard to see how such spatial factors could have played a role in producing the effects we have found since the location of the to-be-identified stimulus was always

the same, independent of whether the stimulus was response compatible or incompatible.

Negative priming refers to the finding that observers are often slower to respond to stimuli they have just ignored than to stimuli they have not seen at all (for an overview, see Fox, 1995). For example, observers are presented with displays containing two superimposed figures; the target figure is printed in red, whereas the to-be-ignored distractor figure is presented in green. Observers' task is to name the target as rapidly as possible. When in the subsequent trial the distractor becomes the target, naming latencies are slower than they are when the present target and the previous distractor are unrelated (e.g., Tipper, 1985). This slowing down is assumed to reflect residual inhibition applied to the irrelevant stimulus in the preceding trial and this inhibition seems to be limited to features relevant for the task or the response, respectively.

However, it is difficult to identify a comparable inhibition mechanism in our experiments. One might argue that the lateralized response to the response cue must be temporarily suppressed before execution because a double keypress is required before. Thus, the left and right direction is transiently inhibited and the blindness effect could reflect a residuum of this inhibitory mechanism. On the other hand, there is ample evidence that the effect emerges also without the double keypress (Wühr & Müsseler, 2000), making this inhibitory mechanism not very likely.

Nevertheless, it cannot be excluded that phenomena such as repetition blindness, inhibition of return, negative priming, and the present blindness effect are different reflections of the same basic processing principle. Further research is clearly needed to clarify the relation between these various phenomena.

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