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Action-feature integration blinds to feature-overlapping perceptual events: Evidence from manual and vocal actions

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Previous studies showed that the identification of a left- or right-pointing arrowhead is impaired when it appears while planning and executing a spatially compatible left or right keypress (Müsseler & Hommel, 1997a). We attribute this effect to stimulus processing and action control operating on the same feature codes so that, once a code is integrated in an action plan, it is less available for perceptual processing. In three pairs of experiments we tested the generality of this account by using stimulus–response combinations other than arrows and manual keypresses. Planning manual left–right keypressing actions impaired the identification of spatially corresponding arrows but not of words with congruent meaning. On the contrary, planning to say "left" or "right" impaired the identification of corresponding spatial words but not of congruent arrows. Thus, as the feature-integration approach suggests, stimulus identification is impaired only with overlap of perceptual or perceptually derived stimulus and response features while mere semantic congruence is insufficient.

According to Neisser's (1967) classical characterization, the task of cognitive psychology consists in the investigation and reconstruction of the fate of stimulus information through the human information-processing system. Although this task definition differs from the viewpoint of behaviouristic psychology in many ways, both approaches share the idea that the relationship between perception and action is best conceived of as a one-way street: Perception informs and generates action, but proceeds independent of it. In the present article, we are dealing with phenomena that are inconsistent with this idea. As we have demonstrated recently, planning and executing an action can impair the concurrent perception of action-compatible stimuli (Müsseler & Hommel, 1997a, 1997b), suggesting that information processing can, in a sense, work backwards from action to perception (see also, e.g., Caessens & Vandierendonck, 2002; Müsseler & Wühr, 2002; Oriet, Stevanovski, & Jolicœur, 2003; Stevanovski, Oriet, & Jolicœur, 2002).

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Action-effect blindness

In the Müsseler and Hommel (1997a) study, participants performed two overlapping tasks. For one task, they were signalled by a stimulus (S1) to prepare a left or right keypress (R1). Whenever they felt well prepared, they indicated this by pressing both the left and the right response key simultaneously (the "ready response") and then immediately carried out the prepared response (i.e., R1). For the other task, a masked stimulus (S2)—a left- or right-pointing arrowhead—was presented and later identified at leisure by means of another left–right keypress (R2). Importantly, the experiment was designed such that the ready response triggered the presentation of S2, so that its presentation fell into an interval where the activation of the plan to perform R1 should be at maximum. The outcome was very consistent across five variations of this basic task: Identification of S2 was impaired when it corresponded to R1 (e.g., if a left-pointing arrowhead appeared while planning a left keypress) relative to when it did not correspond (e.g., if a left-pointing arrowhead appeared while planning a right keypress). In a follow-up study, Müsseler and Hommel (1997b) observed that even the detection of S2 is worse with R2–S1 correspondence than with noncorrespondence. That is, planning an action hampers the perception of an object that the action shares features with. As action planning must be in terms of yet to-be-produced features, hence, intended action effects, Müsseler and Hommel called their observation *action-effect blindness* (AEB).

The findings of Müsseler and Hommel raise two important questions: Why does action planning affect object perception at all, and why is this effect negative (e.g., as opposed to positive effects of stimulus–response compatibility; see Hommel & Prinz, 1997)? As to the first question, Müsseler and Hommel (1997a; Hommel, Müsseler, Aschersleben, & Prinz, 2001a) have suggested that the cognitive coding of perceptual features and of (to-be-produced or anticipated) action features may take place in the same representational medium (common coding: Prinz, 1997), so that the same code would be involved in coding, say, a left-side object and a left-hand action. If so, code activation in the process of perceptual coding is likely to produce side effects for the planning of feature-overlapping actions (as demonstrated by stimulus–response compatibility effects) and vice versa. Such a view runs counter to the separation of perceptual and action-related domains in most available stage models of human information processing, and it challenges the commonly accepted assumption of a unidirectional information flow from perception to action. But it can easily account for why action planning can affect perceptual processes.

As to the second question of why the effect of action planning on perception is negative rather than positive, two explanations have been suggested so far. One explanation assumes that the activation and use of a feature code in the process of planning and executing an action leads to a temporary self-inhibition of this code (Müsseler & Hommel, 1997a, following MacKay, 1986). Accordingly, using the code LEFT, say, for planning a left keypress would result in a suppression of this code below baseline activity as soon as the planning process is completed, and the action is carried out. If so, and given the common-coding principle, this would mean that the LEFT code would be temporarily unavailable for coding processes, so that "left" objects would be more difficult to code than "right" objects. If this explanation would hold, AEB effects should be restricted to an interval that begins with the transition from planning to execution and ends some time (that depends on the code's refractory phase) after execution. This prediction has been tested by Caessens, Lammertyn, Van der Goten, De Vooght, and Hommel (1997) and Wühr and Müsseler (2001) by presenting S2 at several points in time before or after execution of R1. However, findings revealed that, first, effects on perception begin briefly after R1 planning starts and, second, post-execution presentation of S2 does not yield bigger effects than preexecution presentation—if anything, the effect decreases after execution.

Obviously, this rules out an interpretation of AEB in terms of code (self-)inhibition.

Another, more tenable, explanation of why the effect of action planning on perception is negative is based on the idea that action planning consists of two phases: the first involving the specification of action features and the *activation* of their codes, and the second the *integration* of activated feature codes into a coherent action plan (Hommel, 1998; Hommel et al., 2001a; Stoet & Hommel, 1999). According to this two-phase model, feature overlap between action plans and perceptual objects yields positive effects during the activation phase, because an already activated feature code should facilitate feature coding. However, once a code is integrated into an action plan, it "belongs" to, or is "occupied" by it until the structure gets disintegrated—which is presumably the case after the action is executed. Given the common-coding principle, this means that an integrated code is not, or at least not that easily, available for other coding processes, so that planning a "left" action should impair the perceptual coding of "left" objects or events. Clearly, such an integration account of AEB is more consistent with the observation that perception is impaired from the beginning of action planning all the way to execution. Moreover, the code-occupation or integration account is supported by, and provides, a general framework for accounting for a whole number of negative correspondence effects, be it from action planning on planning another action (Stoet & Hommel, 1999), from stimulus perception on perceiving another stimulus event (Wühr, Knoblich, & Müsseler, 2005; Wühr & Müsseler, in press), or from perception on action planning (Stoet & Hommel, 2002).

Aim of present study

Up to now, AEB has been investigated with manual actions defined in terms of left and right, and with to-be-identified or to-be-detected left- and right-pointing arrows. Arrows as stimuli have several advantages. Importantly, they have a perceptual, directional, and deictic feature that can be varied to create spatial feature overlap or nonoverlap with a planned response. Recent studies indicate indeed that left or right arrows can induce automatic shifts of spatial attention (Hommel, Pratt, Colzato, & Godijn, 2001b; Pratt & Hommel, 2003) and activate corresponding responses in a more automatic fashion than, say, the letters L and R do (Kopp, Mattler, & Rist, 1994; Wascher, Reinhard, Wauschkuhn, & Verleger, 1999). Even more importantly, the fact that arrows possess intrinsic spatial features means that the location of the arrow does not need to vary. Had previous studies varied the arrow's location, it would have been difficult to attribute the occurrence of AEB to feature overlap. Assume, for instance, that we would have presented some stimulus without intrinsic spatial features (a letter, say) at a left or right location and would have found that preparing a response is associated with poorer identification of such stimuli if appearing on the corresponding side. If so, this might have been due to feature overlap but it may also have resulted from attentional factors, such as inhibiting representations of stimuli appearing on the same side of the planned response. Yet, as the stimuli of choice were centrally presented arrows, an attentional account can be ruled out from the beginning.

However, arrow stimuli have some disadvantages as well. Namely, even if (and, perhaps, because) in everyday life arrows are often used directionally and deictically (e.g., to direct navigation or to point to objects), arrows' associations with their spatial meaning must be highly overlearned. Consequently, we cannot be sure that what was crucial for producing AEB was actually a perceptual feature and its overlap with the planned response. Instead, it may have been the arrow's meaning and its relation to the meaning of the planned response (cf. Stevanovski, Oriet, & Jolicœur, 2003). On the one hand, this would not necessarily rule out an account in terms of feature integration and code occupation—after all, there is no reason to exclude the possibility that abstract features like the meaning of a stimulus or response are integrated in the course of perception or action planning. On the other hand,

however, it is clear that a model that only applies to highly abstract features has a much more limited scope than a model that allows for any kind of perceptual and action features to interact with each other. Therefore, the present study aimed at testing whether interactions between action planning and perception can be demonstrated for perceptual features instead of meanings. Moreover, we wanted to see whether AEB can be demonstrated for stimulus–response combinations other than arrows and manual left–right keypresses. This purpose is of considerable importance for the generality of the integration approach.

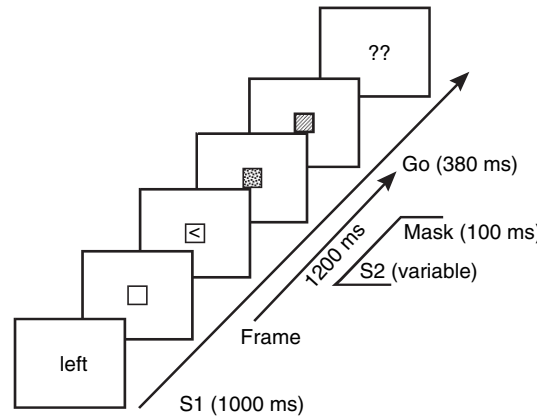

Figure 1. *Schematic diagram of the sequence of events in Experiment 1. The interval between frame onset and Go signal (a coloured frame) was always 1,200 ms, resulting in an interval between S1 and Go signal of 2,200 ms. The masked S2 could appear 800, 400, or 0 ms before Go signal onset, or 400 ms thereafter.*

EXPERIMENT 1

In Experiment 1 we tested whether the overlap in meaning between R1 and S2 is sufficient to create AEB or whether the overlap must be related to perceptual (stimulus and response) features. Experiment 1A was an attempt to replicate AEB with a slightly simplified design that allowed us to abandon Müsseler and Hommel's (1997a) "ready response". The sequence of events is shown in Figure 1: The word *left* or *right* was the signal to prepare a left or right keypress response that was carried out as soon as a "Go" signal (a red frame) appeared. A pattern-masked arrow was presented either before the Go signal (response-signal–stimulus onset asynchrony, RSOA[1] = −800 or −400 ms), simultaneously with it (RSOA = 0 ms), or shortly after (RSOA = 400 ms). After carrying out the prepared response, participants were asked to identify the direction in which the arrow (S2) pointed. In view of the findings of Müsseler and Hommel (1997a) we expected identification to be impaired with spatially compatible R1–S2 pairings as compared to incompatible pairings. Moreover, given the observations of Wühr and Müsseler (2001) this compatibility cost should be present from the beginning—that is, as soon as R1 is sufficiently prepared.

In Experiment 1B we modified R1, the to-be-planned response: Participants did not prepare a manual keypress but the vocal utterance "left" or "right", while the remaining procedure was as in Experiment 1A (Table 1 provides an overview of stimulus and response modes in Experiments 1–3). If only the correspondence in meaning between R1 and S2 mattered for AEB then this modification should not change the results. That is, preparing a left keypress, say, should impair the identification of a left-pointing arrow just as much as preparing the vocal response "left". However, if the overlap of perceptual features played a role in AEB, using vocal responses—which do not share any perceptual spatial features with arrows—should eliminate or at least reduce the compatibility effect.

[1] Note that this measure refers to the interval between the onset of S2 and the onset of the Go signal, not the onset of R1 itself. As the mean reaction time (RT) to the Go signal was greater than zero, the actual interval between onset of S2 and onset of R1 was greater by this difference. In other words, our measure underestimates the S2–R1 interval by up to 380 ms, the maximum RT in Experiment 1. However, given the negligible effects of the S2–R1 interval on AEB that we obtained in previous studies (e.g., Müsseler & Hommel, 1997a, 1997b; Müsseler & Wühr, 2002; Wühr & Müsseler, 2001), we can safely ignore this issue.

Table 1. *Overview of stimulus and response modes in Experiments 1–3*

Experiment	*Stimulus 1*	*Response 1*	*Stimulus 2*
1A	word	manual	arrow
1B	word	vocal	arrow
2A	word	vocal	arrow
2B	digit	vocal	arrow
3A	arrow	manual	word
3B	arrow	vocal	word

Method

Participants

A total of 52 adults were paid to participate, 24 in Experiment 1A and 28 in 1B. Experiments were run in single sessions of about 45 min.[2] Participants reported having normal or corrected-to-normal vision and audition, and they were not familiar with the purpose of the experiment.

Apparatus and stimuli

The experiment was controlled by a Hewlett Packard PC, attached to an Eizo 9080i monitor for stimulus presentation. Manual responses were performed by pressing the left or right shift key of the computer keyboard with the left and right index finger, respectively. To measure vocal responses, the PC was interfaced with an A/D card (Data Translation 2821) for the sampling of vocal input and was connected with a terminal (used by the experimenter) via serial interface. Participants wore headphones with an integrated microphone (Sennheiser HMD 224), which registered the onset of the vocal R1. Response content was monitored and checked online by the experimenter.

Viewing distance was about 60 cm. There were four types of relevant stimulus: S1, S2, a mask, and a Go signal. S1 indicated the first response (R1) and appeared in white at the centre of the black screen. It consisted of the words "Links" and "Rechts" (German for left and right). S1 was followed by a white frame of 10 × 10 pixels at screen centre. The change of the colour of the frame into red signalled the performance of R1. The frame also circumscribed the area where S2 could appear. S2 consisted of a single arrowhead presented in white at screen centre, and it was followed by a mask consisting of a varying, randomly determined black-and-white pixel pattern filling the frame area. S2 was to be identified at leisure after performing R1.

Design and procedure

Each session consisted of 4 practice blocks and 12 experimental blocks. Each block was composed of 16 randomly ordered trials, resulting from the combinations of two types of R1 (left vs. right), two types of S2 (left vs. right), and four RSOAs. After an intertrial interval of 3 s each trial began with the presentation of S1, the R1 cue, for 1 s. The left- and right-hand keypresses (in Experiment 1A) or the vocal utterances "left" and "right" (in Experiment 1B) were indicated by the German words for "left" and "right", respectively. Participants were informed that the Go signal would appear soon after S1 and were urged to prepare R1 as well and as quickly as possible. S1 was then replaced by the empty frame, followed by the Go signal that appeared 1.2 s after S1 offset.

If a response was registered before the Go signal, or if R1 was not registered 380 ms after the onset of the Go signal, the trial was interrupted immediately and repeated later in the block. S2 was presented 800 or 400 ms before the Go signal, together with, or 400 ms after, the onset of the Go signal, corresponding to the RSOAs of −800, −400, 0, and 400 ms. After a variable presentation time the mask appeared for 100 ms, followed by a blank screen. Presentation time was set to three screen cycles (42 ms) at the beginning of the experiment and then adjusted after every 16-trial block. If identification errors were

[2] For reasons that are unrelated to the present study, participants of Experiment 1B also took part in a second session on another day. However, here we report only results from the first session, so that the findings can be directly compared to the other experiments.

made in more than 40% of the preceding trials then presentation time was increased by one screen cycle, and if in less than 20% it was decreased by one screen cycle (if possible). Note that each block comprised all possible conditions, so that conditions and presentation time were not confounded.

If R1 was given in time, 1.5 s later two question marks appeared on the screen to request an unspeeded identification response to S2. Left- and right-pointing arrows were identified by pressing the left- and right-hand response keys, respectively. There was no feedback about the accuracy of S2 identification. However, if R1 turned out to be incorrect, feedback was given, and the trial was repeated at a random position at the remainder of the block (i.e., identifications accompanied by incorrect R1s were not analysed). Participants could take a break after the four practice blocks and after the first half of the experimental blocks.

Results

For each experiment, the percentage of correct S2 identifications was calculated as a function of compatibility between R1 and S2, and of RSOA (see Table 2).[3] Analyses of variance (ANOVAs) were run on these data with compatibility and RSOA as within-participants variables. The significance criterion was set to $p < .05$ for all analyses.

In Experiment 1A, the main effects of compatibility, $F(1, 23) = 5.48$, $MSE = 396.50$, $p < .05$, and RSOA, $F(3, 69) = 5.56$, $MSE = 82.49$, $p < .01$, were significant, whereas the interaction fell short of the significance criterion, $F(3, 69) = 2.33$, $MSE = 43.66$, $p = .082$. Identification performance was worse with compatibility between R1 and S2 than with incompatibility, and this effect tended to decrease with increasingly positive RSOA (Table 2).

In Experiment 1B, the main effects of compatibility, $F(1, 27) = 4.84$, $MSE = 678.92$, $p < .05$, and RSOA, $F(3, 81) = 5.35$, $MSE = 99.88$, $p < .01$, were significant, whereas the interaction fell short of the significance criterion, $F < 1.3$. In contrast to Experiment 1A, identification performance was better with compatibility between R1 and S2 than with incompatibility (cf. Table 2). The RSOA effect was due to performance being better with the longest negative and positive RSOAs than with RSOAs of −400 or 0 ms.

Table 2. *Identification accuracy[a] in Experiments 1–3 as a function of compatibility between Response 1 and Stimulus 2, and of the interval between Go signal for Response 1 and Stimulus 2*

		Response-signal–stimulus onset asynchrony[b]			
Experiment	*R1–S2*	*−800*	*−400*	*0*	*400*
1A	Compatible	77.1	80.0	83.3	86.6
	Incompatible	85.9	89.6	87.0	91.5
1B	Compatible	87.8	83.6	84.4	88.4
	Incompatible	80.1	73.1	78.1	82.3
2A	Compatible	72.9	85.5	–	–
	Incompatible	65.9	82.6	–	–
2B	Compatible	83.6	86.2	90.6	89.0
	Incompatible	84.4	87.9	89.9	91.9
3A	Compatible	84.5	86.6	89.4	91.7
	Incompatible	86.5	84.2	90.6	92.5
3B	Compatible	84.1	80.1	86.1	87.7
	Incompatible	88.6	86.8	87.0	92.0

Note: S2 preceded the Go signal with negative RSOAs and followed it with positive RSOAs. R1 = Response 1. S2 = Stimulus 2.
[a]Percentage correct. [b]In ms.

Discussion

The results are clear-cut. First, the findings of Müsseler and Hommel (1997a) were fully

[3] Given that numerous previous investigations revealed no interesting (e.g., compatibility) effects on R1 (Müsseler & Hommel, 1997a, 1997b; Müsseler & Wühr, 2002; Wühr & Müsseler, 2001) we did not record reaction times and errors for this response. However, note that the setup of the experiment made sure that only trials with a fast and correct R1 were considered—that is, only trials of which we can assume that the planning of R1 really took place.

replicated with a simplified procedure in Experiment 1A. That is, preparing a spatially defined manual response impaired the identification of a spatially corresponding stimulus. Second, in line with Wühr and Müsseler (2001) this effect was clearly present from the earliest RSOA on. That is, it was by no means restricted to the time after the response, as a code inhibition account of AEB would predict. If anything, the effect tends to become smaller when S2 comes after the Go signal. Third, and most important for our present purpose, AEB was only observed in Experiment 1A and not in Experiment 1B. This suggests that some abstract, meaning-based relationship between R1 and S2 is insufficient to produce AEB. Rather, the effect seems to depend on the overlap of perceptual features, as implied by a feature-integration/code-occupation account. Surprisingly, however, the compatibility effect in Experiment 1B was not just absent but positive, and significantly so, an observation that we investigated in the following experiment.[4]

EXPERIMENT 2

To explain the positive compatibility effect in Experiment 1B one may first think of a priming account that focuses on the relationship between S1 and S2. Indeed, in several studies on AEB, either S1 and S2 were of the same format (e.g., Müsseler & Hommel, 1997a) or they at least varied on semantically related dimensions—such as the direction words used as S1 and the arrows used as S2 in Experiment 1B. These choices have obvious reasons: On the one hand, S2 needs to overlap with R1 in some way to produce AEB; on the other hand, the compatibility between S1 and R1 is thought to minimize S1–R1 translation demands so to allow for fast and efficient planning of R1. Yet, dimensional overlap of S1 and R1, and of R1 and S2, necessarily implies overlap of S1 and S2. However, as S1 and S2 are presented in short sequence it may be that S1 primes semantically related S2, which would in fact lead to a positive compatibility effect.

Importantly, there are a couple of reasons to exclude the idea that priming played a role in previous studies. Clearly, the very existence of AEB (i.e., a negative compatibility effect) shows that, if anything, S1–S2 priming must produce an effect that is small enough to be more than compensated by AEB. Moreover, Müsseler and Hommel (1997a, Exp. 5) used arrows both as S1 and as S2 but instructed participants to plan the R1 opposite to the direction of S1—that is, a left keypress for a rightward pointing arrow and vice versa. Nevertheless, the size of AEB was the same as that with normal instruction, which rules out any role of the relationship between S1 and S2. AEB has also been found with a completely neutral S1 (low vs. high tones; Müsseler, Wühr, & Prinz, 2000, Exp. 1) and with a self-chosen R1, hence without any S1 (Müsseler et al., 2000, Exp. 2).

However, even though S1–S2 priming can be excluded as a factor in the original task with manual responses (and, thus, in Experiment 1A as well), it may play a role with vocal responses. Given the strong and highly overlearned relationship between words, which in Experiment 1B served as S1, and the corresponding vocal response it may well be that participants did not fully plan R1. Instead, they may have merely maintained the phonetic representation of S1 until the Go signal appeared and only then completed R1 planning. However, holding a word in working memory is likely to continuously activate the word's conceptual representation (Warren, 1972), which in our case might have been responsible for priming the conceptually related S2. In short, S1–S2 priming might have been a result of our participants remembering S1 instead of the prepared R1. If so, introducing conditions that increase the

[4] Here and in the following we neglect the theoretically less interesting RSOA effects. With two exceptions these effects all followed the same pattern: an increase of accuracy with increasing (positive-going) RSOA, most likely a reflection of the increasing probability of S2 presentation (from .25 at the first to 1.0 at the last RSOA slot). Only in Experiments 1B and 3B was there an indication of relatively good performance at the first RSOA. However, given that these two experiments differed in all the design features that we manipulated in the present study, we do not consider this a systematic pattern.

likelihood that R1 is planned upon presentation of S1 should decrease or even eliminate the positive compatibility effect obtained in Experiment 1B.

Experiment 2, which used the same basic task as that in Experiment 1B, sought to increase the likelihood of fully preparing R1 in two ways. In Experiment 2A, participants were instructed with a strong emphasis on R1 speed (as measured by the reaction time to the Go signal), and they received monetary reward for quick responses. An obvious way to increase R1 performance is to fully prepare it before the Go signal is presented, so that this manipulation should increase the likelihood that S2 meets an already planned R1. According to our considerations, this should reduce or eliminate the positive compatibility effect.

Experiment 2B followed the same reasoning. If, in Experiment 1B, R1 was not fully planned, and if this was a consequence of the high compatibility between S1 and R1, replacing S1 by less compatible stimuli should make immediate planning of R1 more likely, thus reducing or eliminating the positive compatibility effect. In Experiment 2B we therefore used the numbers 1 and 2 to signal the vocal *left* and *right* responses, respectively. Lower and higher numbers are known to be associated with left and right responses, respectively (Dehaene, 1992; Dehaene & Akhavein, 1995), so that some degree of S1 and R1 compatibility still existed. However, these numbers did not share any feature overlap with the vocal utterances. Therefore, it would not be reasonable to maintain some representation of S1 instead of immediately planning R1 upon S1 onset, nor would maintaining such a representation be likely to prime the left- and right-pointing arrows used as S2.

Method

A total of 63 adults were paid to participate, 32 in Experiment 2A and 31 in 2B. They fulfilled the same criteria as those in Experiment 1. The method was the same as that in Experiment 1B, with the following exceptions. In Experiment 2A, only the RSOAs of −800 and −400 ms were used. Each block contained two replications of each condition, so that block size was still 16, as in the other experiments. The maximum reaction time for R1 was increased from 380 to 500 ms, but participants received a strict speed instruction and a monetary reward for fast R1s. Additionally, they were informed after every second experimental block about their mean reaction times in the preceding two blocks and in the two blocks before. In Experiment 2B, the only modification was that S1 did not consist of words but of the digits "1" (cuing the utterance "links") and "2" (cuing the utterance "rechts").

Results

In Experiment 2A, only the main effect of RSOA was reliable, $F(1, 31) = 62.93$, $MSE = 6{,}988.57$, $p < .001$, due to higher identification rates with the shorter RSOA. However, the compatibility effect approached significance, $F(1, 31) = 3.59$, $MSE = 742.71$, $p = .068$, indicating better identification performance with compatible than with incompatible R1–S2 pairings (see Table 2). In Experiment 2B, only RSOA produced a significant effect, $F(3, 90) = 12.30$, $MSE = 47.07$, $p < .001$, while compatibility or the interaction did not, Fs < 0.9. The RSOA effect indicated that identification performance increased with increasingly positive RSOAs.

Discussion

Experiment 2 was conducted to clarify why positive compatibility effects were obtained in Experiment 1—instead of the expected null effect. We considered the possibility that the high degree of compatibility between S1 and R1 has tempted subjects to maintain a memory of S1 or the spatial S1 feature rather than to plan R1 right away. This may have had two consequences. First, the spatial feature was not bound but activated, which can be assumed to prime (rather than interfere with) a feature-overlapping S2. Second, maintaining S1 may have activated semantic representations of its content, which again should have primed (rather than interfere with) a feature-overlapping S2.

Experiment 2A tested whether increasing the motivation to plan R1 would reduce the positive

compatibility effect and, indeed, the 7.6% effect of Experiment 1B dropped to a no longer reliable 5.0%. Although we hesitate to make much of the fact that the significance criterion was (just) missed, a comparison with the first two RSOAs in Experiment 1B confirmed that the reduction was significant, $F(1, 58) = 4.87$, $MSE = 1{,}360.78$, $p < .05$. That is, the motivation to prepare R1 upon presentation of S1 does decrease positive priming. Experiment 2B tested whether reducing the compatibility between S1 and R1 (and, by implication, between S1 and S2) would matter and, indeed, the compatibility effect was entirely gone.

On the one hand, the natural confound between S1–R1 compatibility and S1–S2 compatibility (with a constant R1–S2 relation) does not allow us to determine whether the positive effect in Experiment 1B was due to the reluctance to plan R1, S1–S2 priming, or both. The outcome of Experiment 2A suggests that motivation to plan makes a difference, but it does not provide unequivocal evidence that planning is all that matters. Experiment 2B, in turn, eliminated the compatibility effect by means of a manipulation that can be assumed to affect both planning motivation and S1–S2 priming. Moreover, even if we could be sure that S1–S2 priming plays a role, we are unable to tell whether this is bound to rehearsing or maintaining S1.

On the other hand, however, Experiment 2 does provide strong support for the assumption that the positive effect in Experiment 1B is not related to the compatibility between R1 and S2—which varied the same way as here. In other words, the presence of a positive compatibility effect in Experiment 1B points to an interesting methodological issue but does not affect the validity of the integration hypothesis under investigation.

EXPERIMENT 3

Although Experiment 1 yielded preliminary evidence for a critical role of perceptual features in AEB, alternative interpretations are possible. Vocal actions may be planned in a fundamentally different fashion from manual actions, in ways that preclude any impact on perception in principle. If so, it would be premature to take the absence of AEB in Experiments 1B and 2 to indicate that interactions between action planning and perception are feature specific. To resolve this issue it is important to determine whether vocal actions can produce AEB at all. According to a feature-overlap approach this should be more likely the greater the representational overlap of action (here R1) and perceptual event (S2)—that is, the more features that action and perceptual event share. This consideration makes word stimuli an obvious choice: Visual words are assumed to activate phonological structures according to overlearned grapheme–phoneme correspondence rules (cf. the dual-route assumption of word recognition; e.g., Ellis, 1982; Humphreys & Evett, 1985), and word production operates on phonological structures to sequence syllables and segments (e.g., Roelofs, 1997). Accordingly, we again had participants plan and perform manual left–right responses (in Experiment 3A) or vocal responses consisting of the words "left" and "right" (in Experiment 3B) but paired these responses with the words "left" and "right" (i.e., their German equivalents) as S2—the masked, to-be-identified stimulus. The other aspects of the task stayed the same, except that we cued the to-be-prepared R1 by means of arrows.[5] As our modifications left the semantic relationships between R1 and S2 untouched, a meaning-based approach would predict AEB in both Experiments 3A and 3B. In contrast, if the overlap of perceptual and action codes would matter as much as a feature

[5] One may object that combining arrows (as S1) and location words (as S2) again introduces the possibility of S1–S2 interference as suggested by the outcomes of Experiments 1B and 2. However, Baldo, Shimamura, and Prinzmetal (1998) have shown that interference between arrows and location words depends strongly on the response modality. For example, when a task-relevant location word (left/right) is presented with an irrelevant (left/right) arrow, reaction times were mainly affected in a manual-response task, but hardly affected in a vocal-response task. Hence, there is little reason to expect S1–S2 interference, especially with the unspeeded identification task used in the present experiments. In fact, we see that the outcome of Experiment 3 does not provide any evidence that arrow–word priming played a role.

account suggests, we would expect AEB in Experiment 3B but not in Experiment 3A.

Method

A total of 47 adults were paid to participate, 24 in Experiment 3A and 23 in Experiment 3B. They fulfilled the same criteria as those in Experiment 1. The experiments were run in single sessions. The method was the same as that in Experiments 1A and 1B, respectively, with the following exceptions: S1 consisted of three left- or right-pointing arrowheads, and it was followed by a larger frame (100 × 40 pixels). S2 consisted of the words "links" and "rechts" (German for left and right). They appeared in white centred at a position that varied randomly within a range of 5 (horizontally) by 10 (vertically) pixels around the centre of the screen. A total of 18 different, randomly varying VGA fonts from the Eizo standard set were used to make S2 identification more difficult: Helvetica, Courier, Times, Modern, Script, and Roman, each with letter sizes of 10 × 16, 8 × 18, and 12 × 20 pixels.

Results

In Experiment 3A, the only significant finding was the main effect of RSOA, $F(3, 69) = 9.25$, $MSE = 57.98$, $p < .001$, again indicating better performance with more positive RSOAs (cf. Table 2). The other effects were far from significance, Fs < 1.12.

In Experiment 3B, the main effects of both compatibility, $F(1, 22) = 7.31$, $MSE = 106.83$, $p < .05$, and RSOA, $F(3, 66) = 6.17$, $MSE = 51.60$, $p < .01$, were significant, while the interaction was not, $F < 1.40$. Compatibility between R1 and S2 produced worse performance than did incompatibility—hence, the opposite effect to that obtained in Experiment 1B. The RSOA effect indicated that identification was easier with positive than with negative RSOAs.

Discussion

The outcome of Experiment 3 is clear-cut: As expected, AEB was restricted to Experiment 3B, where R1 and S2 were hypothesized to overlap in terms of phonetic codes, but did not occur in Experiment 3A, where only the meanings of R1 and S2 were related. This pattern has important theoretical implications. One is that AEB can in fact be demonstrated for other than manual responses and for other than arrow stimuli. This means that the failure of Experiment 1B to produce AEB cannot be attributed to the response mode per se, but must have something to do with the relationship between R1 and S2. As suggested by the presence of AEB in Experiment 3B but not 3A, AEB seems to be restricted to R1–S2 combinations that either directly share perceivable features (as in Experiment 1A) or overlap in perceptual features not directly given but strongly associated with the perceived features (as in Experiment 3B). In contrast, mere overlap in meaning does not suffice to produce AEB.

GENERAL DISCUSSION

The aim of the present study was twofold. First, we wanted to see whether AEB is based on the overlap between R1 and S2 in terms of meaning, or whether a more specific overlap in terms of perceptual features is necessary. The outcome allows for an answer to this question in favour of the latter alternative. When R1–S2 overlap was restricted to meaning, as in Experiments 1B, 2, and 3A, no evidence of AEB was obtained. In contrast, when perceptual or perceptually derived features overlapped, as in Experiments 1A and 3B, AEB did occur. Obviously, then, AEB reflects a problem that arises from the fact that perceptual or perceptually derived codes are shared by processes of action planning and perceptual processes.

Second, we wanted to see whether AEB occurs with manual actions only or with other actions as well. Here we compared manual left–right keypresses and vocal "left"–"right" responses, and evidence of AEB was obtained for either response mode under the appropriate conditions. In view of the considerable difference between both the two response types and the two types of R1–S2

relationship, this is an outcome that encourages us to think of AEB as a rather general effect.

Theoretical implications

Taken together our findings provide support for an account of AEB in terms of feature integration. Figure 2 gives an overview of how this account explains the results (cf. Stoet & Hommel, 1999). In case of a manual action, the action plan includes a spatial feature (here: LEFT for a left keypress) as well as some other features describing the planned action (here: F1 and F2, e.g., representing speed and force). If the stimulus is an arrow, it also has a spatial feature, among other features (here: F3 and F4, e.g., representing shape and colour). In case of an incompatible condition (see first row), hence if the manual R1 and the S2 arrow do not overlap, the representation of S2 does not share any feature with the plan of R1, so that no AEB is to be expected. However, with a compatible condition (see third row) the feature needed to represent S2 has already been integrated into the action plan for R1, so that it is more difficult to access.[6] This difficulty delays the integration of S2 features so that, when it eventually takes place, the mask will sometimes have already overwritten the spatial information. Accordingly, it is not available for judging the direction of S2, which is reflected by the higher error rate in compatible than in incompatible conditions as observed in Experiment 1A.

Things are similar, although a bit more complicated, in the case of a vocal R1. Uttering a word is a sequential action, so that the critical action features will be more than one. In Figure 2 we have assumed that they consist of phonetic letter codes with inhibitory forward associations to produce the sequence in the correct order—an adaptation of Rumelhart and Norman's (1982) typing model.[7] Again, there is no coding problem with an incompatible condition, such as if the R1 "left" is paired with the visually presented

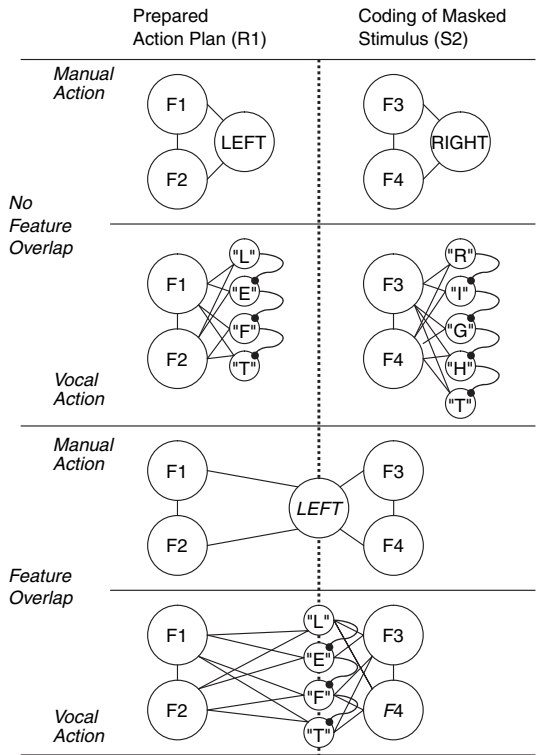

Figure 2. *Accounting for the findings in terms of feature integration. Action plans (of R1) are shown in the left column, stimulus (S1) representations in the right column. The examples refer to a left manual action paired with either a rightward pointing arrow (first row) or a leftward pointing arrow (third row), and to the vocal utterance "left" paired with either the word "right" (second row) or the word "left" (fourth row). Note that spatial or phonetic features are shared in case of R1–S2 feature overlap.*

[6] In which way the access is complicated and how it is eventually mastered depend on how one envisions feature integration to be realized in the brain. One possibility would be that integration entrains the neural codes so to oscillate in a synchronous fashion (e.g., Singer, 1994; for an overview, see Traub, Jeffreys, & Whittington, 1999). This would allow more than one network of codes (i.e., integrated representation) to be active at one time by introducing a phase lag between the activity of different networks. If so, the access problem in representing S2 might consist in entraining a spatial code that is already integrated into another network (the plan of R1) and therefore oscillates in a wrong phase. However, the neurophysiological details of feature integration are under heated debate, so that we hesitate to commit ourselves to a particular mechanism or more detailed functional description.

[7] Note that preferring another, for instance, hierarchical model of speech control (e.g., Gordon & Meyer, 1984) does not touch the basic logic of our approach.

and phonetically encoded word "right" (see second row). However, with compatibility between R1 and S2 (see fourth row), representing S2 requires access to codes that are already integrated into the plan of R1. Again, solving this problem requires time, so that the integration of S2 will be delayed and error prone, consistent with our findings in Experiment 3B. With other combinations, such as manual actions and words or vocal actions with arrows, no spatial or phonetic features are shared between the plan of R1 and the representation of S2. Hence, no compatibility effect is expected, and, indeed, none is obtained.

There are several alternatives for how to deal with the role of semantics. One possibility is that action planning always takes place at the level of perceptually defined feature codes. These feature codes are likely to be associated with related semantic nodes, so that activating a semantic node will spread activation to the feature codes, but the semantic node will not become an integral part of the action plan. In other words, action planning may involve the binding of features but not of meanings. Accordingly, planning an action blocks other processes from using plan-related feature codes but not plan-related semantic nodes. Another possibility is that the level of planning changes with what is being planned. For instance, one may consider that planning the production of a sentence or a dance involves assigning particular meanings to particular elements of the action sequence. This may bind semantic nodes to representations of these elements and thus occupy the respective meanings. The available evidence does not allow us to decide between these possibilities but systematic manipulations of the level of abstraction on which action planning takes place will provide us with the necessary information.

It is interesting to note that our scenario is consistent with recent findings from neuroimaging studies. Schubotz and von Cramon (Schubotz, Friederici, & von Cramon, 2000; Schubotz & von Cramon, 2001, 2002) observed that a purely perceptual oddball task (monitoring a visual or auditory sequence for an event that violates the sequential structure) makes use of neural structures in the premotor area, as indicated by increased BOLD activity. More specifically, anticipating a perceptual oddball in terms of shape, location, or rhythm recruited premotor structures that are known to be involved in grasping, pointing, and tapping actions, respectively. According to Schubotz and von Cramon (2003), this may suggest that premotor areas house both efferent codes taking care of the motor aspects of actions and afferent codes specifying the perceptual consequences that these actions are expected to have. This consideration has received support from a recent PET study on the representation of learned action effects (Elsner et al., 2002). Subjects were presented with action-contingent tones before performing a tone-monitoring task in the scanner. In contrast to neutral tones, listening to the previously self-produced tones activated premotor areas that are known to be involved in voluntary action planning. Hence, there is increasing evidence that the same neural structures are involved in perception and action planning, which makes it plausible that planning an action can impair the perception of an object to the degree that action and object make use of the same neural codes.

This approach has widespread implications, and it fits nicely with Stoet and Hommel's (1999) findings. In their study, participants first planned a movement with the left or right hand (Action A) and then performed a speeded left–right binary-choice response (Action B), before eventually carrying out A. Most interestingly, performance on B was impaired if its features overlapped with A, such as when both actions were carried out with the same hand or with hand and foot on the same side of the body. Indeed, this is what a feature-integration approach would suggest: If planning A integrates a spatial feature that is also required for plan B, the time needed to plan B should be prolonged.

This idea can be also applied for processing two visual events. If perceiving an event A integrates a spatial feature that is also required for perceiving an event B, the identification needed to perceive B should be impaired. In the study of Wühr and colleagues (Wühr & Müsseler, 2005, see also Wühr & Müsseler, in press), participants were presented with two left- or right-pointing arrows, one appearing above and the other appearing below fixation.

After a brief presentation period, one of the two stimuli was pattern masked. The participants' task was to respond to the masked stimulus (the target) and to ignore the unmasked stimulus (the distractor). When presented before the target, identical distractors impede target processing due to code integration. However, when presented simultaneously with the target, identical distractors provide common code activation and thus facilitate target processing.

Relation to other approaches

Our approach is based on the ideomotor notion that actions are cognitively represented in terms of their perceived effects (James, 1890; Lotze, 1852), which rather directly leads to the expectation that perception and action planning interact (Greenwald, 1970). Indeed, the outcome of the present study strongly suggests that AEB only occurs if the action and the to-be-perceived stimulus are ideomotor compatible. However, as we have argued elsewhere (Hommel et al., 2001a), this characterization only holds if the original ideomotor account is enriched by a number of further assumptions. Three additional assumptions are essential for present purposes:

First, we need to assume that actions are not, or not only, represented by codes of their proximal features (an assumption that has been made by some ideomotor approaches and has been attributed to even more) but by codes of their distal features (as well). Without such an assumption, ideomotor approaches could not explain why moving a right finger is compatible with perceiving a right-pointing arrowhead: These two events refer to the same relative distal location, but the kinaesthetic feedback from the finger bears no similarity to the retinal pattern evoked by the arrowhead (cf. Prinz, 1992).

Second, we need to assume that perceptual events and action plans are represented in a distributed fashion—that is, in terms of the features of these events and by feature codes that can be addressed independently of each other. Without this assumption, it would be difficult to explain why mere similarity (i.e., feature overlap) is sufficient to create compatibility phenomena and even harder to explain why blindness effects occur.

Third, we need to assume that planning an action has consequences for the feature codes involved that are negative for the processing of other, feature overlapping, events. Up to now, no ideomotor or ideomotorically inspired approach other than the theory of event coding (TEC; Hommel et al., 2001a) can account for the blindness effects demonstrated here. For instance, the well-established dimensional overlap model of S–R compatibility (Kornblum, Hasbroucq, & Osman, 1990) provides no mechanism that could explain why such interactions produce negative effects.

In a broader sense, the present code-occupation/integration account is consistent with compatibility models that distinguish between multiple-processing systems, commonly one responsible for spatial stimuli and manual–spatial responses and another for verbal stimuli and vocal responses (Barber & O'Leary, 1997; Glaser & Glaser, 1989; Lu, 1997; Virzi & Egeth, 1985). The assumption is that stimuli and responses interact only, or at least more heavily, if they are processed in the same system. Again, this fits nicely with our observation that blindness effects only occur for the combinations of spatial stimuli and spatially defined manual responses and of verbal stimuli and vocal responses. The theoretical weakness of systems approaches is that the definition of, and the distinction between, systems is commonly driven by the data but not by a principled theoretical framework. However, in view of Schubotz and von Cramon's (2003) observation of systematic relationships between particular action categories and action-related stimulus dimensions, a marriage between ideomotor and systems approaches seems both feasible and promising: Functional and neural "processing systems" may be neural networks integrating the efferent codes of a particular type or class of action with the afferent codes representing the perceptual feedback that actions of this type have been learned to produce.

To summarize, planning a manual or vocal action impairs the concurrent identification of a feature-overlapping visual event. In contrast, mere overlap in meaning does not suffice to affect perception. As it seems, planning an action comprises the temporary

integration of codes representing the features of that action. Once a feature code is integrated, its accessibility for other representational processes is reduced, and, thus, the formation of the corresponding representation is impaired. Together with previous findings along these lines, our observation represents a major challenge of the idea that human information processing is a one-way street from perception to action. Instead, action can affect perception just as it is affected by it—a fact that is only beginning to receive the attention it deserves.

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REFERENCES

Baldo, J. V., Shimamura, A. P., & Prinzmetal, W. (1998). Mapping symbols to response modalities: Interference effects on stroop-like tasks. *Perception & Psychophysics, 60*, 427–437.

Barber, P., & O'Leary, M. (1997). The relevance of salience: Towards an activational account of irrelevant stimulus–response compatibility effects. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus–response compatibility* (pp. 135–172). Amsterdam: Elsevier.

Caessens, B., Lammertyn, J., Van der Goten, K., De Vooght, G., & Hommel, B. (1997, December). *Temporal characteristics of action planning*. Paper presented at the 6th Wintercongres van de Nederlandse Vereniging voor Psychonomie, Egmond aan Zee, The Netherlands.

Caessens, B., & Vandierendonck, A. (2002). Inhibition and blindness to response-compatible stimuli: A reappraisal. *Acta Psychologica, 111*, 45–57.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44*, 1–42.

Dehaene, S., & Akhavein, R. (1995). Attention, automaticity, and levels of representation in number processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 314–326.

Ellis, A. W. (1982). Spelling and writing (and reading and speaking). In A. W. Ellis (Ed.), *Normality and pathology in cognitive function* (pp. 113–146). London: Academic Press.

Elsner, B., Hommel, B., Mentschel, C., Drzezga, A., Prinz, W., Conrad, B., & Siebner, H. (2002). Linking actions and their perceivable consequences in the human brain. *Neuroimage*, *17*, 364–372.

Glaser, W. R., & Glaser, M. O. (1989). Context effects in Stroop-like word and picture processing. *Journal of Experimental Psychology: General, 118*, 13–42.

Gordon, P. C., & Meyer, D. E. (1984). Perceptual-motor processing of phonetic features in speech. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 153–178.

Greenwald, A. G. (1970). Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. *Psychological Review, 77*, 73–99.

Hommel, B. (1998). Automatic stimulus–response translation in dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1368–1384.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001a). The theory of event coding (TEC). A framework for perception and action. *Behavioral & Brain Sciences, 24*, 849–937.

Hommel, B., Pratt, J., Colzato, L., & Godijn, R. (2001b). Symbolic control of visual attention. *Psychological Science, 12*, 360–365.

Hommel, B., & Prinz, W. (Eds.). (1997). *Theoretical issues in stimulus–response compatibility.* Amsterdam: Elsevier.

Humphreys, G. W., & Evett, L. J. (1985). Are there independent lexical and nonlexical routes in word processing? An evaluation of the dual-route theory of reading. *Behavioral and Brain Sciences, 8*, 689–740.

James, W. (1890). *The principles of psychology* (Vol. 2). New York: Dover Publications.

Kopp, B., Mattler, U., & Rist, F. (1994). Selective attention and response competition in schizophrenic patients. *Psychiatry Research, 53*, 129–139.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus response compatibility. A model and taxonomy. *Psychological Review, 97*, 253–270.

Lotze, R. H. (1852). *Medicinische Psychologie oder die Physiologie der Seele.* Leipzig, Germany: Weidmann'sche Buchhandlung.

Lu, C. H. (1997). Correspondence effects for irrelevant information in choice-reaction tasks: Characterizing the stimulus–response relations and the processing dynamics. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus–response compatibility* (pp. 85–118). Amsterdam: Elsevier.

MacKay, D. G. (1986). Self-inhibition and the disruptive effects of internal and external feedback in skilled behavior. In H. Heuer & C. Fromm (Eds.),

Generation and modulation of action patterns (pp. 174–186). Berlin: Springer.

Müsseler, J., & Hommel, B. (1997a). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 861–872.

Müsseler, J., & Hommel, B. (1997b). Detecting and identifying response-compatible stimuli. *Psychonomic Bulletin & Review, 4*, 125–129.

Müsseler, J., & Wühr, P. (2002). Response-evoked interference in visual encoding. In W. Prinz & B. Hommel (Eds.), *Attention and performance XIX: Common mechanisms in perception and action* (pp. 520–537). Oxford, UK: Oxford University Press.

Müsseler, J., Wühr, P., & Prinz, W. (2000). Varying the response code in the blindness to response-compatible stimuli. *Visual Cognition, 7*, 743–767.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton Century Crofts.

Oriet, C., Stevanovski, B., & Jolicoeur, P. (2003). Congruency-induced blindness: A cost–benefit analysis. *Acta Psychologica, 112*, 243–258.

Pratt, J., & Hommel, B. (2003). Symbolic control of visual attention: The role of working memory and attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 835–845.

Prinz, W. (1992). Why don't we perceive our brain states? *European Journal of Cognitive Psychology, 4*, 1–20.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9*, 129–154.

Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition, 64*, 249–284.

Rumelhart, D. E., & Norman, D. A. (1982). Simulating a skilled typist: A study of skilled cognitive-motor performance. *Cognitive Science, 6*, 1–36.

Schubotz, R.I., Friederici, A.D., & von Cramon (2000). Time perception and motor timing: A common cortical and subcortical basis revealed by event-related fMRI. *NeuroImage, 11*, 1–12.

Schubotz, R.I., & von Cramon, D.Y. (2001). Functional organization of the lateral premotor cortex: fMRI reveals different regions activated by anticipation of object properties, location and speed. *Cognitive Brain Research, 11*, 97–112.

Schubotz, R. I., & von Cramon, D. (2002). Predicting perceptual events activates corresponding motor schemes in lateral premotor cortex: A fMRI study. *NeuroImage, 15*, 787–796.

0Schubotz, R. I., & von Cramon, D. Y. (2003). Functional–anatomical concepts on human premotor cortex: Evidence from fMRI and PET studies. *NeuroImage, 20*, 120–131.

Singer, W. (1994). The organization of sensory motor representations in the neocortex: A hypothesis based on temporal binding. In C. Umiltà & M. Moscovitch (Eds.), *Conscious and nonconscious information processing. Attention and performance XV* (pp. 77–107). Cambridge, MA: MIT Press.

Stevanovski, B., Oriet, C., & Jolicoeur, P. (2002). Blinded by headlights. *Canadian Journal of Experimental Psychology, 56*, 65–74.

Stevanovski, B., Oriet, C., & Jolicœur, P. (2003). Can blindness to response-compatible stimuli be observed in the absence of a response? *Journal of Experimental Psychology: Human Perception and Performance, 29*, 431–440.

Stoet, G., & Hommel, B. (1999). Action planning and the temporal binding of response codes. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1625–1640.

Stoet, G., & Hommel, B. (2002). Interaction between feature binding in perception and action. In W. Prinz & B. Hommel (Eds.), *Attention & performance XIX: Common mechanisms in perception and action* (pp. 538–552). Oxford, UK: Oxford University Press.

Traub, R. D., Jeffreys, J. G. R., & Whittington, M. A. (1999). *Fast oscillations in cortical circuits.* Cambridge, MA: MIT Press.

Virzi, R. A., & Egeth, H. E. (1985). Toward a translational model of Stroop interference. *Memory & Cognition, 13*, 304–319.

Warren, R. E. (1972). Stimulus encoding and memory. *Journal of Experimental Psychology, 94*, 90–100.

Wascher, E., Reinhard, M., Wauschkuhn, B., & Verleger, R. (1999). Spatial S–R compatibility with centrally presented stimuli. An event-related asymmetry study on dimensional overlap. *Journal of Cognitive Neuroscience, 11*, 214–229.

Wühr, P., Knoblich, G., & Müsseler, J. (2005). *An activation-binding model (ABM) for the processing of multiple visual stimuli*. Manuscript submitted for publication.

Wühr, P., & Müsseler, J. (2001). Time course of the blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 1260–1270.

Wühr, P., & Müsseler, J. (in press). When do irrelevant visual stimuli impair processing of identical targets? *Perception & Psychophysics.*