

## Chapter 6

### **How Independent from Action Control is Perception? An Event-Coding Account for More Equally-Ranked Crosstalks<sup>1</sup>**

Jochen Müsseler

*Max Planck Institute for Psychological Research, Munich, Germany*

There is an ongoing controversy in the study of visual perception as to how closely visual processes are tied to cognitive processes. The present paper extends this controversy in that it considers crosstalks between the starting and the end point of the information stream, that is, between visual and action-control processes. Though it is usually admitted that action-control processes affect which information is picked up, accentuated, disregarded, or rejected, the traditional view continues to espouse a predominantly one-way route for visual information processing. In the present contribution, an alternative view is developed that allows for more equally-ranked crosstalks. It is based on the idea that actions are controlled by the anticipation of their intended effects, and that perception and action control therefore share codes in the same representational domain. As a consequence, action-control processes are capable affecting and modifying visual processes in a more elementary manner. Theoretical, neurophysiological as well as behavioral evidence supporting this view will be presented.

#### **1 Introduction:**

##### **Traditional Views on the Relation between Perception and Action**

More than three decades ago Kahneman and colleagues stated that "A driver who is engrossed in conversation is likely to miss a stop sign" (Kahneman, Beatty, & Pollack, 1967, p. 218; see, also, Kahneman, 1973). The situation described by this sentence is an excellent example of what the present paper is concerned with: The impact of action upon perception, or more specifically, whether and how action-control processes are actually able to affect perceptual processing.

Introspectively, perception and action seem to fulfill different cognitive functions: Perception processes pick up and analyze events in the environment (mainly by afferent mechanisms) while action processes are internally generated and might produce and affect events in the environment (mainly by efferent mechanisms).

---

<sup>1</sup> This research was partially supported by a grant from the Deutsche Forschungsgemeinschaft (DFG Mu 1298/2). I thank Scott Jordan for his helpful criticism, suggestions, and comments on an earlier version of this paper.

Although perception and action processes are highly interactive under most ecological conditions (*e.g.*, in sensorimotor tasks like pointing or grasping), they seem to operate relatively independently from one another. Observations from everyday-life, like the one mentioned by Kahneman and colleagues, give reason to doubt this independence; but these observations are most often considered to be exceptions to the rule.

Vision researchers basically adopt this view. Although they admit to a certain degree that action-control processes are able to affect perceptual processes (see below), the basic visual information stream is seen to be largely independent. There was and is accordance in the view that perceptual processes end where response selection and execution processes begin. On the other hand, it is known since the *New Look*, at least, that knowledge-based information and even values and needs contribute to what is seen (*cf.* Bruner & Postman, 1947; Erdelyi, 1974; McGinnes, 1949). The influence of knowledge-based information on perception becomes obvious when looking at certain types of illusions, for example, looking at an Ames room (Ittelson & Ames, 1968) or at an Escher painting. The fact that we see the walls of the Ames room in a rectangular arrangement takes into account our multiple experiences with walls that are rectangular to the floor. But even if observers are aware of this illusion, it still looks as though a person on the 'narrow' side of the room is much taller than one on the 'distant' side. In other words, cognitive knowledge about an illusion does not make it disappear. This is one reason why perception is believed to be largely independent from cognition. However, there is an ongoing controversy in the study of visual perception as to how closely cognitive processes are tied to visual processes. One view is that at late processing stages cognitive processes 'evaluate' the early perceptual input. Pylyshyn (*in press*), for example, claims an early-vision stage and a later evaluation, selection, and inference stage. Both stages determine what is seen, but the early-vision stage is seen to be encapsulated from cognition, or, according to Pylyshyn, early vision is cognitively impenetrable.

The present paper extends this controversy in that it considers potential crosstalks between the starting and the end point of the information stream, that is, between visual and action-control processes. Specifically, we have doubt in the idea that perception ends where motor processes begin (*cf.* Figure 1). This view was perpetuated in the 1950s to the 1970s, when linear stage models dominated the *information-processing view* – a view that is traditionally concerned with the processes that are settled along the information stream from the receptors to the stages of response generation at the effectors (*e.g.*, Sanders, 1971, 1998). These early models considered the processing stages to be arranged in a linear sequence in that the subsequent stage began to work when the previous stage had completed its job (*e.g.*, Donders, 1868/1969; Massaro, 1990; Sanders, 1983; Theios, 1975). Nowadays, the constraint of a strict linear sequence is dropped and the stages are more and more seen to overlap in time. In vision research, for example, neuropsychological and neurophysiological findings indicate two separate pathways in which information is processed in a parallel and distributed fashion (*e.g.*, Desimone & Ungerleider, 1989; Goodale & Milner, 1992; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). After a first 'low-level' feature analysis in the striate cortex (V1), 'higher-level' analyses occur in the parietal and temporal lobes in parallel. The ventral pathway (the '*what*'-pathway in the temporal lobe) is seen as crucial for identifying objects (inferotemporal cortex via V4),

whereas the dorsal pathway (the '*where*'-pathway in the parietal lobe) is crucial for locating objects (mediotemporal cortex). Milner and Goodale (1995) more specifically assume that the dorsal pathway is used online to coordinate the visual guidance of actions. Accordingly, dissociations between perceptual judgment and action performance are often seen to reflect differences between these pathways (e.g., Aglioti, DeSouza, & Goodale, 1995).

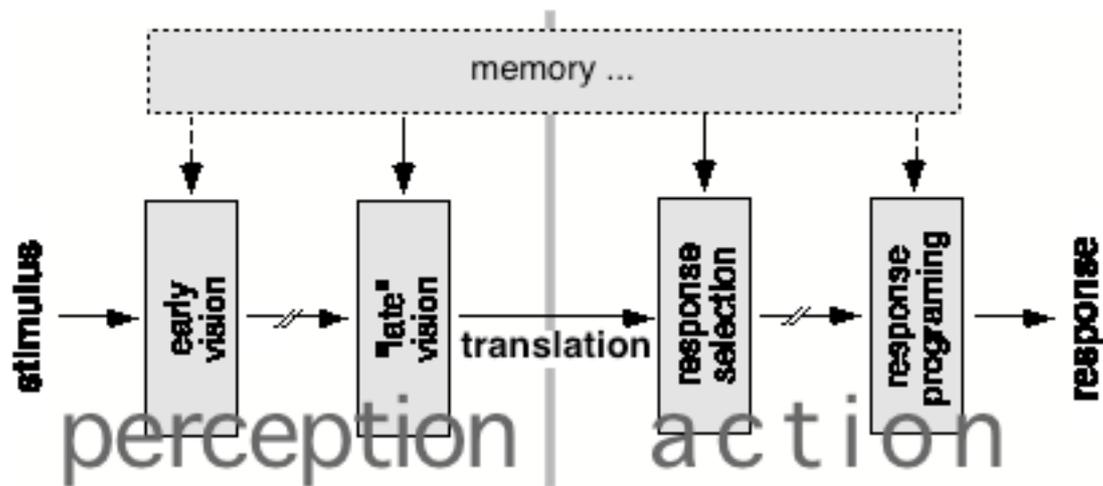


Figure 1: Traditional linear stage account with a strict separation between perception and action. A translation process (or a special translation stage, *cf.* Massaro, 1990) is needed to bridge the gap between both mental functions.

Thus, the last decades have gained an enormous knowledge on how people perceive their environment and how this can be modeled using elaborated flow charts of information processing. Nevertheless, while the flow charts of perception to action are well discussed, the influences of action upon perception are documented only rarely. Of course, it is admitted that sensorimotor coordination in tasks like pointing or grasping requires a high degree of interaction between both perception and action (for overviews see Jeannerod, 1997; Müsseler, Prinz, & Aschersleben, 1996), but in these cases research focuses on perceptual information that is needed to guide the motor behavior. A reversed influence of actions on perception is mainly considered in the context of perceptual learning, of perceptual adaptation, and of selective attention. These issues will be discussed in the subsequent paragraph. We will see that actions serve to establish and to (re-)calibrate to what is seen; however, once formed, perception remains even within these views a one-way route on how visual information is processed.

## 2 Challenges for the Traditional View of Perception

Since the early days of the information-processing approach, the view prevails that perception ends where motor processes begin. From time to time a few hesitant attempts have been made to burst a pure perceptual view. We will focus here on only those attempts that show the importance of actions upon perception and which deny a

strict separation of both mental functions. These attempts mainly stem from studies concerned with perceptual learning, perceptual adaptation, and attentional selection.

### 1.1 Perceptual Learning

It is known that sensory stimulation by itself is not sufficient to evoke reasonable perceptions. There is ample theoretical and empirical evidence that the acquisition of perceptual skills depends on the active interaction with the environment, that is, behavioral components are needed to evaluate or even to establish perceptual impressions. In his ecological approach Gibson (1979) already claimed that behavioral differentiations are a necessary precondition for *perceptual differentiations*. According to his work perceptual learning consists in the extraction of invariants from our environment, which become apparent – among others – by eye, head, and body movements. Furthermore, observers can develop very specialized perceptual abilities as a function of different response demands.

This latter issue was also examined in various experimental studies in the 1950s and 1960s. The question was whether more sophisticated behavioral differentiations lead also to more differentiated perceptual judgments (*e.g.*, Miller & Dollard, 1941; Postman, 1955; for overviews, see Cantor, 1965; Hall, 1991). One assumption was that during an *S-R* acquisition phase the stimulus information is associatively enriched with 'response-produced cues' yielding to more differentiated perceptions. Such response-produced cues could stem from, for example, proprioceptive byproducts of an action. Although the empirical results were quite promising, this line of research has lost most of its importance in recent decades.

### 1.2 Perceptual Adaptation

Even if once established, perception is not a rigid and inflexible mental function that is unable to correct for unnaturally or artificially produced distortions. This is demonstrated – at least in part – by research in prism adaptation (for overviews, see Kohler, 1962; Redding & Wallace, 1997; Welch, 1986). Kohlers' most impressive finding was with mirrored goggles that transposed the visual field from left to right or from top to bottom: After an adaptation phase of several weeks observers 'recalibrated' their reversed world and were even able to drive a motorcycle while wearing such goggles. These adaptations are not only observed with spatial distortions, but also with color fringes evoked by prism lenses (Kohler, 1962). However, while prism-adaptation research has provided overwhelming evidence for *sensorimotor adaptation*, evidence for *perceptual adaptation* is less clear (*cf.* Welch, 1978, 1986). The problem with these studies is always that it is a matter of interpretation, what is 'actually' seen. On the other hand, there are at least hints that explorative saccades reduce initially perceived distortions evoked by prism-contact lenses (*e.g.*, which causes straight lines to appear curved) or by geometrical optical illusions (Festinger, Burnham, Ono, & Bamber, 1967; Slotnick, 1969). Such perceptual adaptations are mostly correlated with corresponding adaptations in the motor behavior (*i.e.*, in the eye-movement behavior,

*cf.* Festinger, White, & Allyn, 1968). Thus, it is worth noting that explorative motor behavior promotes both the sensorimotor and the perceptual adaptation process.

What can be concluded from the studies of perceptual learning and perceptual adaptation? It might be the case that the perceptual system is recalibrated with respect to the motor system, or the motor system is recalibrated with regard to the perceptual system. It might also be the case, however, that perceptual adaptation and motor adaptation are two sides of one and the same coin. Regarding spatial perception, for example, it has been already assumed that the system of perception and of motor behavior (above all, of the eye-movement behavior) seems to establish perceived space via an interaction with the environment. Then, the system in charge of the guidance of motor movements is also the system that contributes to the metric in perceived visual space (Koenderink, 1990; Müsseler, Van der Heijden, Mahmud, Deubel, & Ertsey, in press; Van der Heijden, Müsseler, & Bridgeman, 1999; Van der Heijden, Van der Geest, De Leeuw, Krikke, & Müsseler, in press; Wolff, 1987, 1999; see Lotze, 1852, for an early example of this idea).

This last conclusion implies that the influence of actions upon perceptions is not only a matter of a learning or acquisition phase, but that the perception-action relationship is present in almost every perceptual process. Especially, a spatial error in a perceptual task should have its correspondence in a behavioral task. For example, consider the Müller-Lyer illusion. It was shown that this illusion has its correlation in the eye-movement behavior, that is, a perceptual overestimation of the 'wing-out' part corresponds to an overshoot of saccades, while a perceptual underestimation of the 'wing-in' part corresponds to an undershoot of saccades (Festinger *et al.*, 1968; Yarbus, 1967). When the perceptual illusion is reduced as a result of saccadic exploration, the saccadic over- and undershoot shows a comparable reduction as well (for further obvious correlations between perceptual judgment and saccadic behavior, see Müsseler *et al.*, in press; Van der Heijden *et al.*, in press).

### 1.3 Attentional Mechanisms: Selection for Action

While perceptual learning and perceptual adaptation are concerned with the long-term consequences of the perception-action exchange, the attentional account considers also short-term consequences. As mentioned, linear stage models dominated the information-processing view from the beginning in the 1950s. Attentional theories of that epoch mimicked this view of information flow, but they additionally took into account two conceptualizations. The first conceptualization was concerned with the *capacity limitation* that was seen as the restricted transmission rate of a perceptual stage (the P-channel, *cf.* Broadbent, 1958) and that functionally described a central bottleneck in the flow of information. The second conceptualization was a *selection mechanism* in shape of a filter, which rejected specific stimulus features from further processing. Later on, with the progress of attentional research, this view was extended: Single-channel conceptions were contrasted with multiple-channel conceptions, early-selection with late-selection mechanisms, capacity-demanding with capacity-free processes, and specific with unspecific capacity limitations (for overviews, see Neumann, 1987, 1996; Van der Heijden, 1992). One main doctrine within this view

remained amazingly constant until the early 1980s. It was the doctrine of capacity limitations being an inherent feature of the system and therefore, selection mechanisms were needed to handle these limitations. Thus, capacity limitation was the central concept and selection was only treated as a functional consequence of it. This view had important implications on how to investigate and on how to theorize attentional mechanisms (Neumann, 1987, 1996).

In the last two decades selection has come to the fore and lost its theoretical role of being only the functional consequence of the capacity limitation. One reason is that empirical research interests were focussed on perceptual selection, for example, in visual search tasks (*e.g.*, Treisman & Gelade, 1980) or in tasks on the validity of spatial cueing (*e.g.*, Posner, 1982). In the wake of this emphasize the functional relation between capacity limitations and perceptual selection mechanisms was reversed by an action-oriented reconstruction: Perceptual selection were no longer seen to be the inevitable consequence of a system-inherent capacity limitation, instead selection mechanisms were seen to evoke capacity limitations in order to enable goal-directed actions. This view has been put forward in the last years by Allport (1987), Neumann (1987, 1996), and Van der Heijden (1992).

The general principle of this *selection-for-action view* is that specific aspects of the environment have to be selected and integrated in actions, whereas irrelevant aspects have to be ignored and excluded from processing. This principle works not only under ecological conditions but even in experimental situations where actions are not obvious. Note, first, that perceptual selections are already given by the orientation of the organism (*e.g.*, by head and/or by body movements) and by the orientation of the receptor system (*e.g.*, by eye movements). Second, beneath these overt selections observers can orient covertly, that is, they are able to focus on certain aspects within the visual field while they are fixating others (*e.g.*, Posner, 1982). This covert orienting normally interacts with overt orienting – mainly with overt eye movements – in order to specify objects' localizations (necessary for programming saccades' amplitude and direction, *cf.* Müsseler, 1994; Umiltá, Riggio, Dascola, & Rizzolatti, 1991; Wolff, 1987). However, both covert and overt orienting can be observed independently by inhibiting the overt-action part (Rizzolatti & Craighero, 1998; Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Umiltá *et al.*, 1991).

The selection-for-action view reveals that the necessity for perceptual selection can stem from the action part of processing, which produces – in an indirect manner – limitations in processing. In addition, it demonstrates that action-control processes can have an important impact on what is perceived from our environment. Nevertheless, it is a process-oriented view on how and what information is picked up, accentuated, disregarded, or rejected and therefore remains a one-way route on how visual information is processed. What it adds is only the *functional* perspective in which perception is dedicated to goal-directed actions. Thus, the selection-for-action view contributes very little to the question of what the perception-action interface represents. It also addresses neither the *representational* structures lying behind these processes nor their role in action control. As a consequence, this view skips more equally ranked crosstalks between perception and action, which enable the formation of both mental functions.

## 1.4 Conclusions

So far, traditional views on perception suggest mainly a unidirectional information flow from perception to action with a high degree of separation between both mental functions. While the contribution of perception to action is well investigated, the influence of action to perception is less clear. If at all, action is admitted to function (1) as a corrective long-term element, which establishes and (re-) calibrates the perceptual system (as indicated by views on perceptual learning and perceptual adaptation) and (2) as a short-term attentional mechanism which enables goal-directed actions (as indicated by the selection-for-action view). However, both views indicate a strong coupling of perception and action that might also result in representational consequences.

## 2 An Event-Coding Account of Perception and Action

In this section an account is introduced which rejects a strict separation between perception and action, and which instead assumes that perceiving a stimulus or planning an action operate on identical codes. It is fair to stress that this account takes up components from old theories and combines them with recent ideas. Moreover, precursor versions of this account have been published before (*cf.* Hommel, 1997; Hommel, 1998b; Hommel, Müsseler, Aschersleben, & Prinz, 1999; Müsseler, 1995; Prinz, 1992, 1997; Prinz, Aschersleben, Hommel, & Vogt, 1995). But while these versions put their focus on action-control processes (*e.g.*, on stimulus-response compatibility or on ideomotor phenomena), the present paper focuses the consequences for the perceptual domain; further, it diverges in critical points from the precursor versions and elaborates them.

In the present section, our consideration starts with an excursion into the motor theories of cognition that was so broadly discussed a century ago (for an overview, *cf.* Scheerer, 1984). We continue with the basic assumptions of the so-called event-coding account, and then cite empirical support in Section 4. Finally, the account will be theoretically elaborated in Section 5.

### 2.1 Action Control by Anticipating Action Effects

How do voluntary actions come into being? This question has already been debated, for example, by Lotze and James in their introspective psychology of the will. The answer they offered was that responses may be cognitively evoked by the anticipatory codes of their sensory effects (James, 1890; Lotze, 1852). By repeatedly performing an arbitrary movement that produces some perceivable sensory effect, actors may associate the corresponding pattern of motor activity with a code representing the to-be-expected sensory effects. Once established, such a 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 was that movements are cognitively represented by their external effects and, thus, could be initiated by the activation of the corresponding *effect codes*.

Modern authors of behavioral sciences as well as of robotics took up the idea to control actions by anticipating their effects (see Greenwald, 1970; Hommel, 1997; Jordan, 1999; Prinz, 1992, 1997; Wolff, 1987, 1999; for robotics, see an overview in Steininger, 1999). They elaborated on two important extensions of this idea: First, while the earlier authors considered action effects to contain mainly body-related afferent feedback (*i.e.*, proprioceptive and kinesthetic feedback), recent authors stressed that action effects could refer to any kind of response- or action-contingent events (Aschersleben, 1999a; Hoffmann, 1993; Hommel, 1997; Meltzoff, Kuhl, & Moore, 1991; Steininger, 1999; Zießler, 1998). In other words, switching on a light produces not only a body-related tactile and kinesthetic feedback at the hand, but also an afferent visual feedback from the light emissions of the bulb which represents an action effect as well.

Second, as Prinz (1992, 1997) has pointed out, the assumption of action control by anticipating action effects implies that not only stimulus codes (*i.e.*, codes of perceived events) represent external events, rather response codes do as well (*i.e.*, codes of to-be-produced events). Accordingly, both types of codes could be commensurable or even identical. The idea is that stimulus processing and action preparation refer to and operate on a common distal representation, that is, both processes have access to a processing level where codes of both perceptual contents and action effects are available (*common-coding* view, cf. Prinz, 1992, 1997).

## 2.2 An Event-Coding Account

The assumptions that action effects refer to action-contingent events and that perceiving a stimulus or planning an action operates on identical codes, can be used to specify a more elaborated perception-action account. It has the following characteristics (Figure 2): In the environment and the corresponding internal distal representation, this account does not differentiate basically between stimulus events and response events. Because each distal event could – in principle – result from an action<sup>2</sup> or a stimulus, there is no need to differentiate between the two at a representational level. At least, there is no qualitative difference between action-produced or stimulus-produced events. It does not matter, for example, that typical visual stimulus events have a specific color, shape, and intensity. In principle, all these features or their specific combination could be evoked by an action which was generated by the anticipation of the action effect, that is by features which refer to color, shape, or intensity. Accordingly, every external event is simply represented in an *event code*, which refers either to a stimulus event or to a response event. Therefore, the present

---

<sup>2</sup> ... or a response, respectively. In the present context it is exiguous, whether the motor act results from a pure internal generation (*i.e.*, from an action) or from a reaction to a stimulus (*i.e.*, from a response).

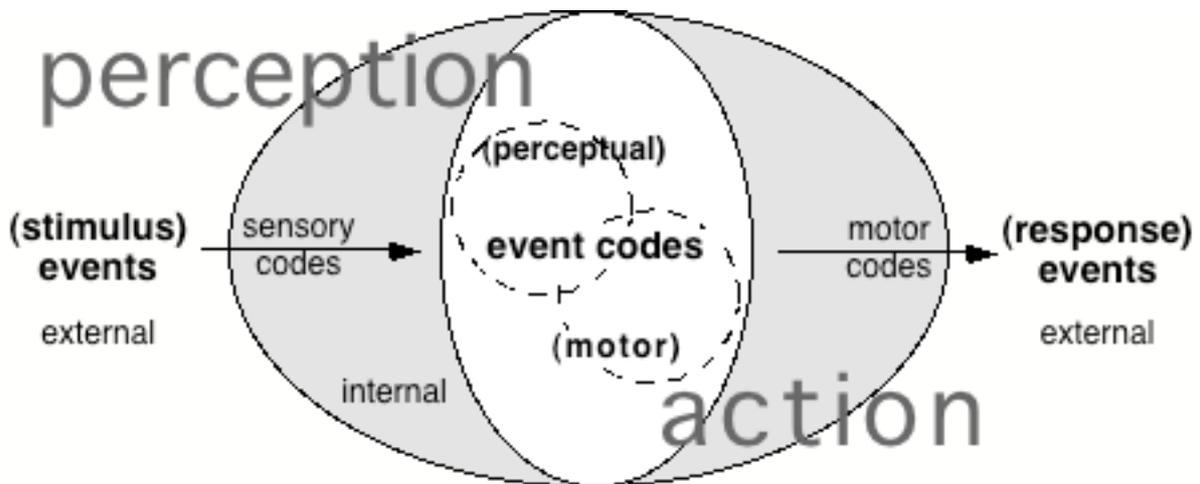


Figure 2: At a common distal representation, *event codes* refer to external stimulus or response events, that is, perceiving a stimulus and planning a response operates on identical event codes. Moreover, perception is determined by specific *sensory codes* and action by specific *motor codes*. For further explanations see text.

perception-action account is an event-coding account (Hommel *et al.*, 1999; see also Müsseler, 1995, p. 13-34).

As indicated, an event code is not seen as a single, uniform whole, but comprises different *feature codes*. It is well established that visual stimuli are represented by distributed features, preferably in different areas of the brain (*e.g.*, Singer, 1994; Treisman & Gelade, 1980). The assumption of distributed action features is also not entirely new (Jeannerod, 1997; Keele, Cohen, & Ivry, 1990). What is new, is the assumption that these features are represented in the same domain and can contribute to the formation of a perceptual or a motor event code (*cf.* Hommel, 1998a).

At this point in the discussion it is worth clarifying the format of the assumed event and feature codes. The example that color, shape, and intensity could serve as anticipated distal effects, which are able to evoke actions, suggests a basically sensory format. This suggestion would be as misleading as the suggestion that codes at the common level would be represented in a motor format. At a cortical level there are only different levels of activation and the format of activated codes can be determined – if at all – by the connections they exhibit. Codes at the common representational level shared by perception and action are assumed to receive and to spread their activation from and to sensory and motor sources. In this sense, event codes are surely cognitive codes.

An example for a temporary state at the common coding level is depicted in Figure 3. Feature codes (small circles) are activated and combined to a perceptual or to a motor event code (large circles), which might show or might not show an overlap of their features. In another context, a feature code, which was previously integrated in a perceptual event code, could be integrated in a motor event code (and vice versa). In principle, this notion holds for whole perceptual and motor event codes as well; in other words, in a different context the same combination of feature codes representing a perceptual event code could refer to a motor event code (and vice

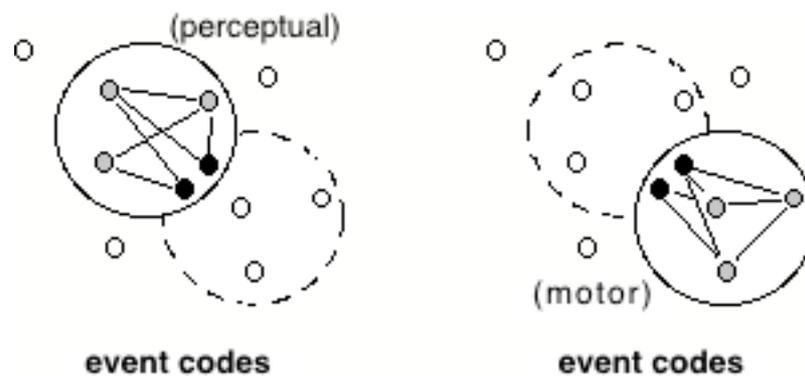


Figure 3: *Feature codes* (dots) are integrated into perceptual or motor *event codes* (large circles) which evolve from common structures. Moreover, identical feature codes could be bound into a perceptual event code (black dots on the left) or in a motor event code (black dots on the right). In another context, it is even imaginable that a previously bound perceptual event code serves as a motor event code (and vice versa).

versa). Thus, perceptual and motor event codes are not entities of a different kind, but only refer to different events of the temporary specific context.

If the last idea is correct, then the question immediately follows, how the system is able to differentiate between perceptual and motor event codes. Or in other words, can it differentiate between perception and action? An answer is already indicated in Figure 2. Of course, perception is not only a matter of activated perceptual event codes as well as action is not only a matter of activated motor event codes. Perception is seen to comprise the activation of specific sensory codes *and* event codes, just like action took also into account the specific motor codes. With this in view, the question how the system differentiates between perception and action is superfluous because the 'role' of the specific event code is determined by its actual connections.

Another question is how do cognitive structures like the assumed event codes come into being. At least some of them are probably not given from birth, but are created by repeated couplings of perceived events and action-produced events. This idea has been proposed by Wolff (1987, 1999) as a possible mean of addressing the problem how visual space is created. He postulates that initially arbitrary saccades serve to 'explore' the visual environment and that a representation of perceived space is established as soon as the infant is able to control his/her intended saccadic effects. Thus, the more generalized version of this idea suggests that the motor system initially produce arbitrary 'motor babblings' and that the correlation to the intended distal effects consolidates representational structures (*cf.* Aitken, 1994; Hommel, 1997). Thus, action-contingent couplings establish cognitive representations by learning. Of course, higher vertebrates are also able to form arbitrary *S-R* mappings quite fast, for example, when they are confronted with the typical lab instruction to press the index finger when a green light flashes or the middle finger when a red light flashes. Thus, this ability is not banished from the system, but higher cognitive processes accomplish it.

*Neurophysiological considerations.* Let us initially clarify the terms 'sensory code,' 'motor code,' and 'event code' with respect to their neuroanatomical content. At first sight, the terms 'sensory' and 'motor code' suggests a more peripheral localization, while 'event codes' are assigned to be more central. Such an assignment would be misleading, since specific sensory codes might be also located at the cortical level, for example, in the primary visual cortex or in the ventral pathway. A sensory code is determined by its almost exclusive afferent stimulation, while a motor code produces efferent stimulation.

More important in the present context is whether there is a neuroanatomical substrate of the common-coding representation on which perceptual and action planning processes are assumed to operate. Several neurophysiological findings of the last decade have pointed to *common modules* which are used by perception and action control and which are often seen to represent the sensorimotor interface. Examples are the so-called 'visual-and-motor neurons' (e.g., Taira, Mine, Georgopoulos, Murata, & Sakata, 1990) found in the monkeys' parietal cortex and the so-called 'mirror neurons' (e.g., Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) located in the premotor cortex. Visual-and-motor neurons are active while a 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 a monkey both performs a given action and observes a similar action performed by an 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 to the execution of appropriate movements.

These findings of single-cell recordings point to populations of neurons which seem to fulfill both perceptual and motor functions, and which could be considered as a neuroanatomical substrate of the assumed common codes. However, localizing such modules is not the only possibility to look for a common-coding implementation in the brain. Another possibility is to look for a mechanism which accomplishes a *coactivation* of distributed brain areas. Recent studies have encouraged speculations that the problem to bind cortically distributed visual activity can be solved by a temporary cell synchronization, that is, by a mechanism which binds stimulus features into a coherent whole (40-Hz oscillations, *cf.* Eckhorn, Frien, Bauer, Woelbern, & Kehr, 1993; Gray, Engel, Koenig, & Singer, 1992; for overviews see Singer & Gray, 1995; Singer, Engel, Kreiter, Munk, Neuenschwander, & Roelfsema, 1997; *cf.* also Müller & Elliott, 1999). These synchronizations even seem to bridge the gap between the visual hemispheres (Engel, König, Kreiter, & Singer, 1991; Nelson, Salin, Munk, Arzi, & Bullier, 1992). In the present context, findings are also worth noting that report synchronizations between distributed motor areas (Conway *et al.*, 1995; Riehle, Gruen, Diesmann, & Aertsen, 1997) and – most interestingly – between sensory and motor areas of the brain (Roelfsema, Engel, Koenig, & Singer, 1997).

### **3 Behavioral Evidence for More Equally-Ranked Crosstalks**

The present paper is primarily guided by the attempt to establish functional domains. This aim should be also achievable with behavioral data. The question of

whether and how action-control processes actually affect perceptual processing could be put to test by using a dual-task paradigm, in which observers are engaged in a motor task while at the same time they have to identify a stimulus. The basic paradigm is depicted in Figure 4: When a reaction  $R$  is performed in response to a cue, a stimulus  $S$  is presented. The framework provided by the event-coding account predicts that simultaneous access to common codes should reveal elementary interactions; in other words, motor processes of  $R$  should exert an influence on perceptual identification of  $S$ . Thus, the critical empirical test is whether the identification of  $S$  depends on the execution of  $R$  and/or the relationship between  $R$  and  $S$ .

### 3.1 Unspecific Perceptual Impairment

By using a dual-task situation as depicted in Figure 4, several studies were able to demonstrate unspecific impairments of perceptual processing, that is impairments, which are attributed to more general demands of action control. An early example of these studies comes from Kahneman, Beatty, and Pollack (1967): Participants performed a digit transformation task, in which they first heard a string of four digits (*e.g.*, 8340) and then verbally responded with another string by adding 1 to each digit that they had heard (*e.g.*, 9451). At the same time flashed letters were to be detected. The results indicate a genuine loss of perceptual sensitivity in the response phase, which Kahneman *et al.* (1967) attributed to the mental aspects of the response demands.

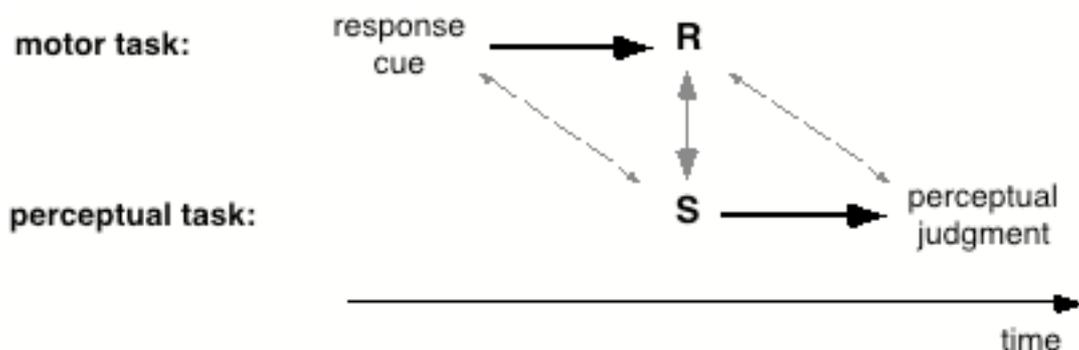


Figure 4: Basic dual-task situation devised to examine whether action control affects perceptual processing. Observers are engaged in a motor task ( $R$ ) while at the same time she/he has to identify a stimulus ( $S$ ). The critical empirical test is whether the identification of  $S$  depends on  $R$  (straight line with double arrow). Dashed lines with double arrows indicate other relevant  $S/R$  relationships, which will be discussed in Section 4.2.

Other authors explicitly attribute the perceptual impairment to the concurrent demands of action control. They use the paradigm of the *Psychological Refractory Period* (PRP) from which it is well known that humans encounter limitations when they attempt to carry out two tasks simultaneously (for overviews, see, *e.g.*, Pashler,

1994b; Smith, 1967; Welford, 1980). Most of these studies investigated dual-task interference by analyzing latencies of speeded responses given to two motor tasks. Accordingly, observed costs are assumed to originate from a bottleneck at the response stage, that is, from the inability to select and/or to execute two motor responses in parallel (*e.g.*, De Jong, 1993; Pashler, 1989, 1994a; Welford, 1952, 1980). Only a few authors were interested in the question of whether processing in a motor task also affects processing in a perceptual task and, indeed, they found perceptual impairments caused by the motor task (De Jong, 1993; De Jong & Sweet, 1994; Ruthruff, Miller, & Lachmann, 1995). For example, De Jong (1993; see also De Jong & Sweet, 1994) reported that the identification of a foveally presented letter is postponed when the observer is simultaneously engaged in responding to an auditory stimulus (but see Pashler, 1989). It was suggested that the bottleneck, instead of being identical to the response-selection mechanism, encompasses more general processes necessary for complex perceptual analyses and for response-preparing activities.

In these studies, however, the perceptual task and the motor task typically showed no feature overlap. Accordingly, these unspecific effects always beg the question of whether the perceptual impairment really reflects a reduction in perceptual sensitivity caused by the motor task or whether it rather originates 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 instructions.

### 3.2 Specific Perceptual Impairment

The argument that the perceptual impairment originates only from a reduced attentiveness given the perceptual task can, however, be rejected by findings demonstrating a more specific crosstalk, that is, when the impairment can be shown to vary with the relationship between the to-be-executed *R* and the to-be-identified *S*. It is known from compatibility research that the amount of *feature overlap* between responses and stimuli affects the temporal requirements for response selection (for overviews, see Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990). If – in a dual-task situation like that described above – the amount of feature overlap between *R* and *S* would also affect the perceptual identification, then this result would demonstrate that the attentiveness given the perceptual task cannot be the only critical factor. It would indicate that the impairments originate indeed from structures shared by perceptual and action-control processes. Therefore, a demonstration of specific interferences is needed which establishes perceptual differences that are dependent on the action performed.

Recent series of experiments in our lab revealed such a specific impact of actions on perception. In these studies, participants performed an unspeeded *R* to a response cue (motor task) and – while doing this – a tachistoscopically presented *S* appeared which had to be judged at the end of a trial at leisure (perceptual task). More specifically, participants performed a prepared, unspeeded right or left keypress and saw a tachistoscopically presented, masked arrow. Feature overlap between *R* and *S* is assumed to originate from a RIGHT (or LEFT) code at the common-coding level: This code is considered to be used when a right (left) keypress is generated as well as when an

arrow pointing to the right (left) is perceived. Thus, the RIGHT (LEFT) code is assumed to be activated when the stimulus is visually processed or when the corresponding action is generated (Müsseler, 1995; Müsseler & Prinz, 1996). Another, more specific assumption is that when the LEFT (or RIGHT) code is involved in response generation, its sensitivity for a left-pointing (or right-pointing) stimulus is reduced. Thus, the systems sensitivity to stimulus events that share features with the response is assumed to be decreased. In other words, the assumption is that the perceptual and the motor event code come into conflict with respect to the overlapping feature code in the compatible condition, while they can coexist without any conflict in the incompatible condition (*cf.* Figure 5A and B).

Indeed, this is what we were able to demonstrate in independent series of experiments. A typical result is shown in Figure 5C, which is based on data reported in Experiment 1 by Müsseler, Steininger, and Wühr (1999a). The first finding is that the perceptual task is much easier when the masked *S* is presented alone versus when it is presented during the planing or execution of *R*. Accordingly, single-task performance was better than performance in each of the consecutive dual-task blocks, which points to an unspecific impact of response generation upon perceptual identification (see above; *cf.* De Jong, 1993; De Jong & Sweet, 1994; Ruthruff *et al.*, 1995). More important from an event-coding point of view is the finding of specific impairment, that is, observers were consistently better with incompatible relationships between response and arrow (*e.g.*, left keypress *R*, right-pointing arrow *S*) than with compatible relationships (*e.g.*, left keypress *R*, left-pointing arrow *S*). In other words, the identification of a right-pointing arrow was reduced when presented during the execution of a right response as compared to that of a left response and vice versa ('blindness to response-compatible stimuli'). This impairment remained stable throughout the experiment, although it was less sharp in the last blocks.

This basic finding was further established by ruling out alternative interpretations (*cf.* dashed lines with double arrows in Figure 4). We found no evidence that the finding is provoked only by the relationship between response cue and masked *S* (*i.e.*, by an *S-S* relationship), or by the relationship of *R* and perceptual judgment (*i.e.*, by an *R-R* relationship, *cf.* Müsseler & Hommel, 1997a). Further, we were able to show that the perceptual impairment came up not only in an identification task or a detection task (Müsseler & Hommel, 1997b), but even when the data were analyzed in terms of the signal detection parameter  $d'$  (Müsseler *et al.*, 1999a). Consequently, it seems to be primarily features of *R* that affect identification of *S*. A more straightforward test of this conclusion was to omit the response cue and to use responses only that were endogenously triggered by the participants. Indeed, as a further experiment showed, it does not matter whether participants perform an arbitrarily selected left or right response or whether they responded to a response cue (Müsseler, Wühr, & Prinz, 1999b).

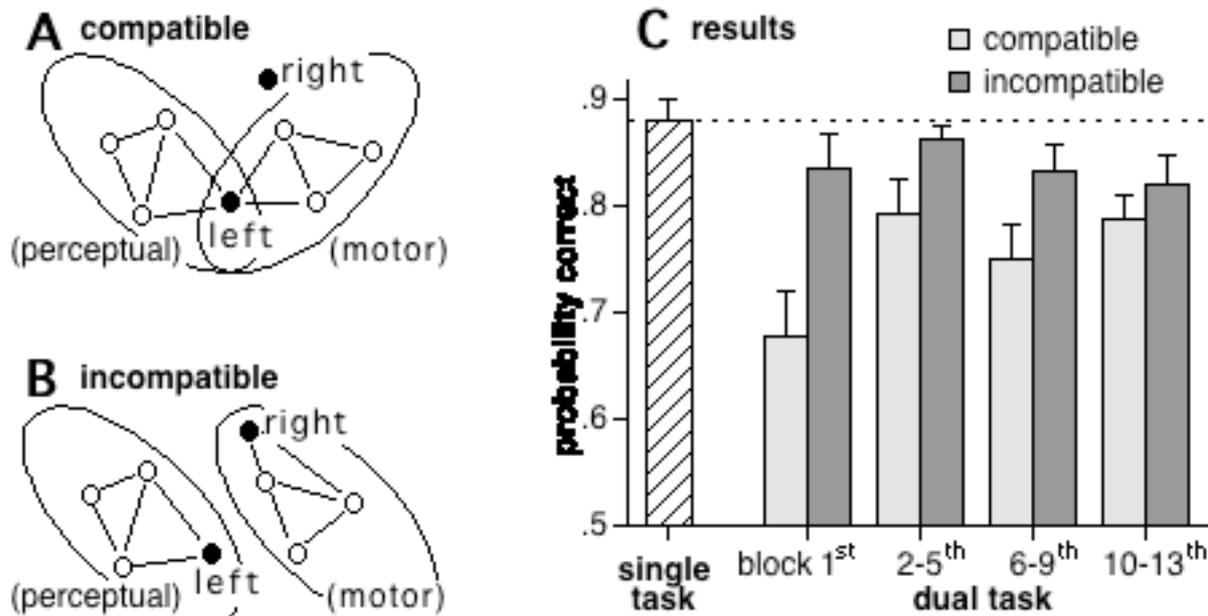


Figure 5: (A) and (B): Assumed feature overlap and non-overlap of event codes in a compatible and incompatible dual-task situation (*cf.* Müsseler, 1995, Figure 23, p. 108). Participants see a tachistoscopically presented left or right masked arrow (here left) while performing an already prepared, unspeeded left or right keypress. The perceptual and the motor event code come into conflict with respect to the overlapping feature code in the compatible condition, while they coexist in the incompatible condition.

(C) Typical findings of the blindness to response-compatible stimuli. Bars represent the mean probabilities of correct identified arrows (with standard errors between participants) in different phases of the experiment. The difference between the single- and dual-task conditions is significant with  $t_{17} = 4.43$ ,  $p < .001$ . Additionally, in the dual-task condition a 2 x 4 ANOVA shows a significance of compatibility with  $F_{1,17} = 8.22$ ,  $p = .011$ , and of block with  $F_{3,51} = 3.31$ ,  $p = .027$ . The interaction showed a tendency only with  $F_{3,51} = 2.53$ ,  $p = .067$  (data based on Müsseler, Steininger, & Wühr, 1999a, Experiment 1).

By studying the time course of the blindness effect we demonstrated that it exists over quite a large period before response execution. Using a timed-response method, in which participants had to synchronize *R* with the third of three beeps, Wühr and Müsseler (1999) found the blindness effect for response-compatible stimuli within a period of two seconds before the execution of *R*. Thus, the blindness effect reflects a conflict that is already apparent during the planning phase of an action.

Finally, evidence was gathered that the overlap between features of the stimuli and of the anticipated *action effects* contribute to the perceptual impairment. This was shown in a task in which proximal spatial feedback was eliminated, but distal action effects were added. For example, in one of her experiments Steininger (1999) replaced the left and right keypresses by one and two keypresses with the consequence that *R* shares no longer the proximal feature with *S* of being LEFT or RIGHT. However, when *R* produces a distal left or right action effect in form of a left or right perceptual event, the impairment was still observed (for details see Steininger, 1999). Additionally, it seems to need the overt intention to produce these action effects, otherwise the blindness effect disappears (Steininger, 1999; see also Müsseler *et al.*, 1999b). Both findings fit well to the effect-oriented view of action control mentioned above.

### 3.3 Perceptual Induction

According to the framework provided by the event-coding account, perception and action control are based on codes, which are shared by both processes. If this assumption holds it is also imaginable that the activation of a (motor) event code not only interferes with a (perceptual) event code, but – at least occasionally – induces the activation of a (perceptual) event code. Thus, particular actions might also facilitate specific perceptions. Before the theoretical implications of this opposed influence will be discussed in more detail, evidence will be described which demonstrate such a perceptual induction.

Imagine a situation in which an observer performs a manual left or right wheel rotation  $R$  and is confronted with the presentation of an ambiguous rotatory apparent motion  $S$ . Such an induction display has been recently used by Wohlschläger (1999) to demonstrate that the proximity principle that usually organizes perception in such a situation is overruled by spatially oriented actions. The direction of perceived motion followed the direction of the spatially oriented action, that is, a wheel rotating to the right was observed when a right wheel rotation was performed and vice versa, although the stimulus situation presented was identical in both tasks. This was even true when the actions were just planned rather than actually executed.

Another related demonstration for perceptual induction by actions can be taken from mental-rotation tasks, in which observers are typically asked to decide whether two 2- or 3-dimensional stimuli differing in orientation are identical or mirror-versions of each other. The most intriguing result of these tasks is the monotonous increase of reaction times with angular stimulus disparity between stimuli. So far, mainly perceptual terms have been used to describe this imagined mental rotation. However, Wohlschläger and Wohlschläger (1998) were able to show that a manually rotatory task, which allowed observers to turn the stimuli by means of a knob, yields nearly identical reaction-time functions as the original mental-rotation task. Again, these effects occur even when the (manual) actions were just planned rather than actually executed.

## 4 Further Considerations of the Event-Coding Account

So far, the event-coding account has gained considerable support from various research areas which debate the issue of how stimulus features are able to bring about action-control processes. This question is central for research on, for example,  $S$ - $R$  compatibility, ideomotor action, and sensorimotor synchronization (for overviews from an event-coding point of view, see Hommel, 1997; Hommel *et al.*, 1999; Prinz, 1997). The previous section also revealed that actions could influence perceptual processing. However, in some studies perceptual impairment and in others perceptual induction was observed. The event-coding account as outlined in Section 3.2 is clearly too vague to account for these various observations. Therefore, specific problems will be elaborated and discussed in the following section, leaving general questions, on how feature binding might be realized by the system, unconsidered (*e.g.*, the questions, how and what features are bound to an event code; for overviews in this respect, see

Singer & Gray, 1995; Singer et al., 1997). Instead, we will focus on basic mechanisms that might contribute to the question of when perceptual impairment or induction is indicated.

#### 4.1 Encapsulation and Accumulation

To explain the blindness effect within a common-coding account we start with the simple idea that when the LEFT or RIGHT code is involved in response generation, the code is insulated against other use (*cf.* Müsseler, 1995). This corresponds to a transient *encapsulation* mechanism, which becomes effective when event codes are bound. From a functional point of view encapsulation is necessary to protect the system from integrating other, irrelevant feature codes. Let us further assume that activation is *accumulated* in the features codes before event codes are encapsulated.<sup>3</sup> Thus, the basic mechanisms, on which our consideration based, are encapsulation and accumulation. Encapsulation is assumed to be the mechanism of perceptual impairment, accumulation the mechanism of perceptual induction. What needs to be clarified is the interplay of both mechanisms.

Additionally, our explanation of the blindness effect works only with the extension that action effects refer also to distal response events. Only this allows us to postulate a feature overlap between a spatial keypress and a symbolic arrow, that is, between the *R* and *S* used in the blindness-effect paradigm. 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 flexibility in the stimulus-response relation for granted (Greenwald, 1970).

From that, the question immediately follows why the blindness effect reveals an impairment (caused by encapsulation) and not an induction (caused by accumulation) with a compatible *R-S* relationship. Since the seminal work of Fitts and colleagues (Fitts & Deininger, 1954; Fitts & Seeger, 1953) the opposite effect is well known, that is, compatible *S-R* mappings generally reveal better performance than an incompatible mapping. In this sense, the perceptual induction reported by Wohlschläger (1999) fits much better with the *S-R* compatibility research than the blindness effect. The inconsistencies between perceptual impairment on the one hand and *S-R* compatibility findings and perceptual induction on the other hand, probably originate from several differences in the experimental procedure, which might modify the interplay between encapsulation and accumulation. Three possible causes, the amount of temporal

---

<sup>3</sup> Of course, it is also likely that previously inactive feature codes are integrated into the pattern of activation during event-code generation. So far, little is known about details of feature binding. In the present context, only two states of event codes are important to note (and the transition of one state to the other): One, in which activation is accumulated and one, in which information is encapsulated.

overlap, the amount of feature overlap, and the strength of baseline activation will be discussed in the following sections.

## 4.2 The Amount of Temporal Overlap

Both the blindness task and the standard *S-R* compatibility task might measure two sides of the same coin and differ only in their temporal characteristics. In a standard *S-R* compatibility task observers are confronted with a stimulus for which they select and execute a response as fast and correctly as possible. Our account would assume that the presentation of *S* accumulates activation in the overlapping feature codes, which facilitate the formation of the corresponding motor event code. This formulation is in accordance with the assumption of a direct, automatic, and stimulus-induced activation of the response (*e.g.*, Kornblum *et al.*, 1990). If a feature code receives activation from two converging sources (*e.g.*, in a Simon task: a left-sided presentation and a color indicating a left response), activation can be accumulated even faster, thus enabling induction. As a result a compatible mapping between *S* and *R* allows for much faster and less error-prone responses than an incompatible mapping.

On the other hand, once a motor event code has been formed, a transient encapsulation of the feature codes is postulated. This implies that at this point in time feature codes should be less available for forming other event codes. Note that this is the situation, in which the blindness effect is observed: *R* is selected and prepared in advance, and only thereafter *S* is presented – with the consequence that the access to the feature codes is impaired, because the LEFT (or RIGHT) code is already bound to other action features forming the motor event code (Hommel, 1997; Hommel *et al.*, 1999). As a result, the perceptibility of response-compatible stimuli should be decreased only during the short period directly following the central movement command, that is during encapsulation of the motor event code (*cf. refractory hypothesis*, Müsseler & Hommel, 1997a). Thus, this temporal explanation enables impairment *and* induction, depending on the point in time when event codes of *S* and *R* are formed and when the transition from accumulation to encapsulation occurs.

Indirect hints for this temporal explanation come from a series of experiments recently conducted by Stoet (1998; Stoet & Hommel, in press). He assumed that preparing a response should not only interfere with the perception of feature-sharing stimuli (as in the blindness-effect paradigm), but with the preparation and execution of another feature-sharing response as well. Thus, he used a dual-task paradigm in which a two-choice task was nested within another two-choice task. The results showed that the response latency to the second stimulus *B* is delayed when this response showed a feature overlap to the response which is required to the first stimulus *A*. This corresponds to the blindness effect. However, Stoet and Hommel (in press, Experiment 3) were able to show that this impairment only occurred when response *A* was intentionally prepared, otherwise feature overlap produced a decrease in response latency of *B*, thus an induction effect. Thus, accumulation or encapsulation processes, leading to induction or impairment, respectively, seem to depend on the planning characteristics of response generation. On the other hand, when varying the temporal characteristics in the blindness task, we failed to produce an induction effect (Wühr &

Müsseler, 1999). Thus, there is – at least up to now – insufficient empirical evidence for a pure temporal explanation, which can account for perceptual impairment and induction.

### 4.3 The Amount of Feature Overlap

With regard to a second explanation, the transition from accumulation to encapsulation depends on the amount of feature overlap between perceptual and motor event codes. For example, the feature overlap between listening to a self-produced spoken word and speaking the same word is probably higher than between perceiving a left arrow and pressing a left key. Listening to and speaking the word is similar with respect to the frequency range, intonation, or semantic content, while a left arrow and a left keypress share the abstract LEFT feature only. It is likely that the amount of feature overlap affects the transition from accumulation to encapsulation and thereby the observed impairment or induction. At least, it is known that the amount of feature overlap affects standard *S-R* compatibility effects (e.g., Hommel, 1997; Kornblum *et al.*, 1990).

### 4.4 Strength of Baseline Activation

So far, an event code is seen to be established with the binding of feature codes. The precondition for binding is the accumulation of evidence in the feature codes and, thereafter, encapsulation takes places. A variable, which might modify the binding process itself as well as its time course, is the strength of baseline activation. An account that stresses this view has been recently proposed by Hochhaus and Johnston (1996). It starts from the classical Weber's law, according to which the size of the just noticeable difference between two stimuli is a constant fraction of the size of the (smaller) standard stimulus. This means that a constant increment imposed on a higher baseline activation level is harder to perceive than when it is imposed on a lower baseline. Hochhaus and Johnston (1996) proposed that this rule could hold for code activation as well. If a code has a higher activation level to start from, it is harder to tell whether this code has gained an increment in activation from the another stimulation.

The authors applied this idea to the so-called *repetition blindness* which refers to the phenomenon that participants often fail to detect the occurrence of a repeated item under rapid serial visual presentation (e.g., Kanwisher, 1987, 1991). According their view, the activation associated with the single occurrence of a target item is easy to detect, compared with the difference between activation levels that results from the repeated presentation of the same item within a short period of time. The same logic could hold for codes like LEFT or RIGHT in our blindness task. Given that LEFT or RIGHT stimulus and response features have a common mental representation, it is more difficult to detect whether this code has gained an increment in activation from the presentation of *S*, if it has a higher activation level to start from. This baseline activation may be due to the preparation of a compatible response.

However, in crucial aspects the blindness effect discussed here is quite different from the repetition-blindness paradigm, for example, with respect to timing of presentation (for details, see Müsseler & Hommel, 1997a). Moreover, the assumption of an influence of strength of code activation alone is not able to solve the inconsistencies between perceptual impairment and induction.

#### 4.5 Multiple Causes

The present section aims at an explanation for the divergent outcomes of impairment and induction. The mechanisms discussed are based on factors which might modify the critical point of transition time between accumulation and encapsulation; among others this could be the amount of temporal overlap, the amount of feature overlap, or the strength of baseline activation. However, it is likely that the transition between accumulation and encapsulation is not only affected by one of these factors, but by a combination of them. Unfortunately, multiple causes have the disadvantage of being empirically difficult to evaluate, so that the empirical resume is less definite at present.

Moreover, there are other factors, which might contribute to the discrepancy between impairment and induction. For example, in studies concerned with induction (above all with standard *S-R* compatibility) the dependent measure is mainly response latency, whereas in studies concerned with impairment (*e.g.*, repetition blindness or the blindness to response compatible stimuli) the dependent measure is mainly identification probability. Response latencies could reflect a processing, in which the output of early stimulus stages directly feeds into the motor system whereas essential perceptual stages based on later integrative mechanisms are left unconsidered (Aschersleben, 1999b; Aschersleben & Müsseler, *in press*; Neumann, 1990; Neumann & Klotz, 1994). On the other hand, the mask in an identification task could add further processes, which affect identification in a specific way. As a consequence, different processing routes are used in identification and response-latency tasks. Therefore, there is some doubt in the general comparability of both outcomes.

However, there are obvious intra- and interphenomenal similarities between the concepts used to explain perceptual impairment and induction. For example, both the repetition-blindness phenomenon and the blindness to response-compatible stimuli refer to assumed (cognitive) codes, which are accessed in close succession. The blindness to response-compatible stimuli refers additionally to the concept of feature overlap, which is prominent in standard *S-R* compatibility accounts (*e.g.*, Hommel, 1997; Kornblum *et al.*, 1990).

### 5 Conclusion

The present paper considers crosstalks between the starting and the end point of the information stream, that is, between visual and action-control processes. Despite the fact that in traditional views on perception, theoretical space for crosstalks between both domains is rare, its necessity is demonstrated by studies indicating evidence for more equally-ranked interactions. We have shown that these studies originated from

and can be integrated into an event-coding account in which perception and action control are assumed to share codes in a common representational domain. As a consequence, action-control processes are capable of affecting and modifying visual processes in a more elementary manner. However, the event-coding account needs additional specifications to integrate both empirical types of crosstalks, that is, perceptual impairment and induction. Thus, another aim of the paper was to take further steps towards an approach, which treats impairment and induction as different reflections of the same basic processing principles (*i.e.*, encapsulation and accumulation).

To conclude, action-control mechanisms are able to affect perceptual processing in an elementary manner so that perception can be studied more gainfully when the motor part of processing is included. Our considerations suggest that this is true, at least, for the so-called 'cognitive' part of vision (because event codes are simply cognitive codes, *cf.* Section 3.2). And what about the 'early' part? Is early vision also penetrable by action control? An answer to this question would need more specific knowledge about what 'early' and 'cognitive' vision represent (*cf.* Pylyshyn, *in press*). At present, however, this discussion is in danger to run into an endless debate. In the information-processing view comparable debates are well-known, for example, the fruitless discussion on 'early' vs. 'late' visual selection (*cf.* Van der Heijden, 1992). In our view, it would be more fruitful to take into account the action-control demands with which every perceiving system is confronted.

## References

- Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology*, 5, 679-685.
- Aitken, A. M. (1994). An architecture of learning to behave. In D. Cliff, P. Husbands, J.-A. Meyer, & S. W. Wilson (Eds.), *From animals to animats 3. Proceedings of the Third International Conference on Simulation of Adaptive Behavior* (pp. 315-324). Cambridge, Mass.: MIT Press.
- Allport, D. A. (1987). Selection for action: Some behavioral and neurophysiological consideration of attention and action. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 395-419). Hillsdale, NJ: Erlbaum.
- Aschersleben, G. (1999a). *Knowledge of results and the timing of actions*. (submitted for publication).
- Aschersleben, G. (1999b). Task-dependent timing of perceptual events. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events*. Amsterdam: Elsevier (this volume).
- Aschersleben, G. & Müsseler, J. (in press). Dissociations in the timing of stationary and moving stimuli. *Journal of Experimental Psychology: Human Perception and Performance*.
- Broadbent, D. E. (1958). *Perception and communication*. New York: Pergamon Press.
- Bruner, J. S., & Postman, L. (1947). Emotional selectivity in perception and reaction. *Journal of Personality*, 16, 69-77.
- Cantor, J. H. (1965). Transfer of stimulus pretraining to motor paired-associate and discrimination learning tasks. In L. P. Lipsitt & C. C. Spiker (Eds.), *Advances in child development and behavior* (Vol. 2, pp. 19-58). New York: Academic Press.
- Conway, B. A., Halliday, D. M., Farmer, S. F., Shahani, U., Maas, P., Weir, A. I., & Rosenberg, J. R. (1995). Synchronization between motor cortex and spinal motoneuronal pool

- during the performance of a maintained motor task in man. *Journal of Physiology*, 489, 917-924.
- De Jong, R. (1993). Multiple bottlenecks in overlapping task performance. *Journal of Experimental Psychology: Human Perception and Performance*, 19, 965-980.
- De Jong, R., & Sweet, J. B. (1994). Preparatory strategies in overlapping-task performance. *Perception & Psychophysics*, 55, 142-151.
- Desimone, R., & Ungerleider, L. G. (1989). Neural mechanisms of visual processing in monkeys. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (Vol. 2, pp. 267-299). New York: Elsevier.
- Di Pellegrino, G., Fadiga, L., Fogassi, V., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental Brain Research*, 91, 176-180.
- Donders, F. C. (1868/1969). On the speed of mental processes. *Acta Psychologica*, 30, 412-431.
- Eckhorn, R., Frien, A., Bauer, R., Woelbern, T., & Kehr, H. (1993). High frequency (60-90 Hz) oscillations in primary visual cortex of awake monkey. *Neuroreport*, 4, 243-246.
- Engel, A. K., König, P., Kreiter, A. K., & Singer, W. (1991). Interhemispheric synchronization of oscillatory neuronal responses in cat visual cortex. *Science*, 252, 1177-1179.
- Erdelyi, M. H. (1974). A new look at the new look: Perceptual defense and vigilance. *Psychological Review*, 81, 1-25.
- Festinger, L., Burnham, C., Ono, H., & Bamber, D. (1967). Efference and the conscious experience of perception. *Journal of Experimental Psychology Monograph*, 74, 1-36.
- Festinger, L., White, C. W., & Allyn, M. R. (1968). Eye movements and decrement in the Mueller-Lyer illusion. *Perception & Psychophysics*, 3, 376-382.
- Fitts, P. M., & Deininger, M. I. (1954). S-R compatibility: Correspondence among paired elements within stimulus and response codes. *Journal of Experimental Psychology*, 48, 483-492.
- Fitts, P. M., & Seeger, C. M. (1953). S-R compatibility: Spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology*, 46, 199-210.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1990). Action recognition in the premotor cortex. *Brain*, 119, 593-609.
- Gibson, J. J. (1977). *The ecological approach to visual perception*. Boston: Houghton Mifflin.
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends-in-Neurosciences*, 15, 20-25.
- Gray, C. M., Engel, A. K., Koenig, P., & Singer, W. (1992). Synchronization of oscillatory neuronal responses in cat striate cortex: Temporal properties. *Visual Neuroscience*, 8, 337-347.
- Greenwald, A. G. (1970). Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. *Psychological Review*, 77, 73-99.
- Greenwald, A. G., & Shulman, H. (1973). On doing two things at once: II. Elimination of the psychological refractory period effect. *Journal of Experimental Psychology*, 101, 70-76.
- Hall, G. (1991). *Perceptual learning and associative learning*. Oxford: Carendon Press.
- Hochhaus, L., & Johnston, J. C. (1996). Perceptual repetition blindness effects. *Journal of Experimental Psychology: Human Perception and Performance*, 22(2), 355-366.
- Hoffmann, J. (1993). *Vorhersage und Erkenntnis. Die Funktion von Antizipationen in der menschlichen Verhaltenssteuerung* [Prediction and knowledge. The function of anticipation for human action control]. Göttingen (Germany): Hogrefe.
- Hommel, B. (1997). Toward an action concept model of stimulus-response compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues on stimulus-response compatibility* (pp. 281-320). Amsterdam: Elsevier.
- Hommel, B. (1998a). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, 5, 183-216.

- Hommel, B. (1998b). Perceiving one's own action - and what it leads to. In J. S. Jordan (Ed.), *Systems theories and a priori aspects of perception* (pp. 143-179). Amsterdam: Elsevier.
- Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (1999). *The theory of event coding (TEC): A framework for perception and action*. Max Planck Institute for Psychological Research, Munich, Report No. 3/1998 (submitted for publication).
- Ittelson, W. H., & Ames, A. J. (1968). *The Ames demonstration in perception*. New York: Hafner Publishing.
- James, W. (1890). *The principles of psychology*. New York: Holt.
- Jeannerod, M. (1997). *The cognitive neuroscience of action*. Lyon: Blackwell Publishers.
- Jordan, S. (1999). Cognition and spatial perception: Representation construction or autocatalytic control? In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events*. Amsterdam: Elsevier (this volume).
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.
- Kahneman, D., Beatty, J., & Pollack, I. (1967). Perceptual deficit during a mental task. *Science*, *157*, 218-219.
- Kanwisher, N. G. (1987). Repetition blindness: Type recognition without token individuation. *Cognition*, *27*, 117-143.
- Kanwisher, N. G. (1991). Repetition blindness and illusory conjunctions: Errors in binding visual types with visual tokens. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 404-421.
- Keele, S. W., Cohen, A., & Ivry, R. (1990). Motor programs: Concepts and issues. In M. Jeannerod (Ed.), *Motor representation and control. Attention and Performance XIII* (pp. 77-111). Hillsdale, NJ: Erlbaum.
- Koenderink, J. J. (1990). The brain a geometry engine. Special Issue: Domains of mental functioning: Attempts at a synthesis. *Psychological Research*, *52*, 122-127.
- Kohler, I. (1962). Experiments with goggles. *Scientific American*, *206*, 63-72.
- 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, H. (1852). *Medicinische Psychologie oder Physiologie der Seele* [Medical psychology or the physiology of the mind]. Leipzig: Weidmann.
- Massaro, D. W. (1990). An information-processing analysis of perception and action. In O. Neumann & W. Prinz (Eds.), *Relationships between perception and action: Current approaches* (pp. 133-166). Berlin: Springer.
- McGinnies, E. (1949). Emotionality and perceptual defense. *Psychological Review*, *56*, 244-251.
- Meltzoff, A. N., Kuhl, P. K., & Moore, M. K. (1991). Perception, representation, and the control of action in newborns and young infants: Towards a new synthesis. In M. J. Weiss & P. R. Zelazo (Eds.), *Newborn attention: Biological constraints and the influence of experience* (pp. 377-411). Noorwood, NJ: Ablex Press.
- Miller, N. E., & Dollard, J. (1941). *Social learning and imitation*. New Haven: Yale University Press.
- Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.
- Müller, H. J., & Elliott, M. A. (1999). 40-Hz synchronicity priming of Kanizsa-figure detection demonstrated by a novel psychophysical paradigm. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events*. Amsterdam: Elsevier (this volume).
- Müsseler, J. (1994). Position-dependent and position-independent attention shifts: Evidence against the spotlight and premotor assumption of visual focussing. *Psychological Research*, *56*, 251-260.

- Müsseler, J. (1995). *Wahrnehmung und Handlungsplanung. Effekte kompatibler und inkompatibler Reize bei der Initiierung und Ausführung von Reaktionssequenzen* [Perception and action planning. Effects of compatible and incompatible stimuli during initializing and performing of reaction sequences]. Aachen: Shaker.
- Müsseler, J., & Hommel, B. (1997a). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception & Performance*, 23, 861-872.
- Müsseler, J., & Hommel, B. (1997b). Detecting and identifying response-compatible stimuli. *Psychonomic Bulletin & Review*, 4, 125-129.
- Müsseler, J., & Prinz, W. (1996). Action planning during the presentation of stimulus sequences: Effects of compatible and incompatible stimuli. *Psychological Research*, 59, 48-63.
- Müsseler, J., Prinz, W., & Aschersleben, G. (1996). Die Steuerung von Handlungen [Action control]. In G. Roth & W. Prinz (Eds.), *Kopf-Arbeit. Gehirnfunktionen und kognitive Leistungen* [The working brain: Brain functions and cognitive performance] (pp. 309-357). Heidelberg: Spektrum der Wissenschaft.
- Müsseler, J., Steininger, S., & Wühr, P. (1999a). *Can actions actually affect perceptual processing?* (submitted for publication).
- Müsseler, J., Van der Heijden, A. H. C., Mahmud, S. H., Deubel, H., & Ertsey, S. (in press). Relative mislocalizations of briefly presented stimuli in the retinal periphery. *Perception and Psychophysics*.
- Müsseler, J., Wühr, P., & Prinz, W. (1999b). *Varying the response code in the blindness to response-compatible stimuli* (submitted for publication).
- Nelson, J. I., Salin, P. A., Munk, M. H. J., Arzi, M., & Bullier, J. (1992). Spatial and temporal coherence in cortico-cortical connections: A cross-correlation study in areas 17 and 18 in the cat. *Visual Neuroscience*, 9, 21-37.
- Neumann, O. (1987). Beyond capacity: A functional view of attention. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 361-394). Hillsdale, NJ: Erlbaum.
- Neumann, O. (1990). Direct parameter specification and the concept of perception. *Psychological Research*, 52, 207-215.
- Neumann, O. (1996). Theories of attention. In O. Neumann & A. F. Sanders (Eds.), *Handbook of perception and action* (Vol. 3, pp. 299-446). London: Academic Press.
- Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M. Moscovitch (Eds.), *Attention and Performance XV* (pp. 123-150). Cambridge, MA: MIT Press.
- Pashler, H. (1989). Dissociations and dependencies between speed and accuracy: Evidence for a two-component theory of divided attention in simple tasks. *Cognitive Psychology*, 21, 469-514.
- Pashler, H. (1994a). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, 116, 220-244.
- Pashler, H. (1994b). Graded capacity-sharing in dual-task interference. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 330-342.
- Posner, M. I. (1982). Cumulative development of attentional theory. *American Psychologist*, 37, 168-179.
- Postman, L. (1955). Association theory and perceptual learning. *Psychological Review*, 62, 438-446.
- 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.
- Prinz, W., Aschersleben, G., Hommel, B., & Vogt, S. (1995). Handlungen als Ereignisse [Actions as events]. In D. Dörner & E. van der Meer (Eds.), *Das Gedächtnis: Probleme -*

- Trends - Perspektiven* [The memory: problems - trends - perspectives] (pp. 129-168). Göttingen, Germany: Hogrefe.
- Polyshyn, Z. (in press). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*.
- Redding, G. M., & Wallace, B. (1997). *Adaptive spatial alignment*. Mahwah, NJ: Lawrence Erlbaum.
- Riehle, A., Gruen, S., Diesmann, M., & Aertsen, A. (1997). Spike synchronization and rate modulation differentially involved in motor cortical function. *Science*, 278, 1950-1953.
- Rizzolatti, G., & Craighero, L. (1998). Spatial attention: Mechanisms and theories. In M. Sabourin, F. Craik, & M. Robert (Eds.), *Advances in psychological science* (Vol. 2: Biological and cognitive aspects, pp. 171-198). Hove, UK: Psychology Press.
- Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. Special Issue: Selective visual attention. *Neuropsychologia*, 25, 31-40.
- Roelfsema, P. R., Engel, A. K., Koenig, P., & Singer, W. (1997). Visuomotor integration is associated with zero time-lag synchronization among cortical areas. *Nature*, 385, 157-161.
- Ruthruff, E., Miller, J., & Lachmann, T. (1995). Does mental rotation require central mechanisms? *Journal of Experimental Psychology: Human Perception and Performance*, 21, 552-570.
- Sakata, H., Taira, M., Murata, A., & Mine, S. (1995). Neural mechanisms of visual guidance of hand action in the parietal cortex of the monkey. *Cerebral Cortex*, 5, 429-438.
- Sanders, A. F. (1971). *Psychologie der Informationsverarbeitung*. Bern: Huber.
- Sanders, A. F. (1983). Towards a model of stress and human performance. *Acta Psychologica*, 53, 61-97.
- Sanders, A. F. (1998). *Elements of Human Performance. Reaction processes and attention in human skills*. Mahwah, NJ: Lawrence Erlbaum.
- Scheerer, E. (1984). Motor theories of cognitive structures: A historical review. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 77-98). Berlin: Springer.
- 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.
- Singer, W., & Gray, C. M. (1995). Visual feature integration and the temporal correlation hypothesis. *Annual Review of Neuroscience*, 18, 555-586.
- Singer, W., Engel, A. K., Kreiter, A. K., Munk, M. H. J., Neuenschwander, S., & Roelfsema, P. R. (1997). Neuronal assemblies: necessity, signature and detectability. *Trends in Cognitive Sciences*, 1, 252-261.
- Slotnick, R. S. (1969). Adaptation to curvature distortion. *Journal of Experimental Psychology*, 81, 441-448.
- Smith, M. C. (1967). Theories of the psychological refractory period. *Psychological Bulletin*, 80, 161-191.
- Steininger, S. (1999). *Handeln und Wahrnehmen. Eine experimentelle Analyse einer Wahrnehmungsbeeinträchtigung bei simultan ausgeführten Handlungen* [Acting and perceiving. An experimental analysis of a perceptual impairment during the simultaneous execution of actions]. Aachen (Germany): Shaker.
- Stoet, G. (1998). *The role of feature integration in action planning*. Unpublished doctoral thesis, Ludwig-Maximilians University, Munich.
- Stoet, G., & Hommel, B. (in press). Action planning and the temporal binding of response codes. *Journal of Experimental Psychology: Human Perception and Performance*.
- Taira, M., Mine, S., Georgopoulos, A. P., Murata, A., & Sakata, H. (1990). Parietal cortex neurons of the monkey related to the visual guidance of hand movement. *Experimental Brain Research*, 83, 29-36.

- Theios, J. (1975). The components of response-latency in simple human information processing tasks. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and Performance V* (pp. 418-440). New York: Academic Press.
- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12, 97-136.
- Umiltá, C., Riggio, L., Dascola, I., & Rizzolatti, G. (1991). Differential effects of central and peripheral cues on the reorienting of spatial attention. *European Journal of Cognitive Psychology*, 3, 247-267.
- Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549-586). Cambridge, MA: MIT Press.
- Van der Heijden, A. H. C. (1992). *Selective attention in vision*. London: Routledge.
- Van der Heijden, A. H. C., Müsseler, J., & Bridgeman, B. (1999). On the perception of position. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events*. Amsterdam: Elsevier (this volume).
- Van der Heijden, A. H. C., Van der Geest, J. N., De Leeuw, F., Krikke, K., & Müsseler, J. (in press). The perception of position of a single small bar. *Psychological Research*.
- Welch, R. B. (1978). *Perceptual modification. Adapting to altered sensory environments*. New York: Academic Press.
- Welch, R. B. (1986). Adaptation of space perception. In K. R. Boff, L. Kaufman, & J. R. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 1: Sensory processes and perception, pp. 24.21-24.45). New York: Wiley.
- Welford, A. T. (1952). The "psychological refractory period" and the timing of high-speed performance - a review and a theory. *British Journal of Psychology*, 43, 2-19.
- Welford, A. T. (1980). The single-channel hypothesis. In A. T. Welford (Ed.), *Reaction times* (pp. 215-252). London: Academic Press.
- Wohlschläger, A. (1999). *Visual motion priming by invisible hand movements*. (submitted for publication).
- Wohlschläger, A., & Wohlschläger, A. (1998). Mental and manual rotation. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 397-412.
- Wolff, P. (1987). Perceptual learning by saccades: A cognitive approach. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 249-271). Hillsdale, NJ: Erlbaum.
- Wolff, P. (1999). Space perception and the intention of action. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.), *Cognitive contributions to the perception of spatial and temporal events*. Amsterdam: Elsevier (this volume).
- Wühr, P., & Müsseler, J. (1999). *Time course of the blindness to response-compatible stimuli*. (submitted for publication).
- Yarbus, A. L. (1967). *Eye movements and vision*. New York: Plenum Press.
- Ziebler, M. (1998). Response-effect learning as a major component of implicit serial learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24, 962-978.