

26 Interaction between feature binding in perception and action

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Abstract. To explain how coherent representations can be formed of information that is distributed throughout the brain, binding mechanisms have been hypothesized that temporarily hold together or bind such distributed information. Evidence of temporary feature binding has been reported from tasks requiring perceptual integration and action planning, and there is some evidence that action planning affects perception. The present study provides further evidence that binding-related effects cross borders between perceptual and motor domains by demonstrating that perceptual integration affects action planning. Results from 3 psychophysical experiments suggest that if a particular perceptual feature is bound into an object representation, it is less accessible for concurrent action planning. Furthermore, our results support the idea that the formation of object representations goes through two phases: feature activation and feature integration. Feature sharing between perception and action is beneficial during the feature activation, but leads to mutual interferences in feature integration. Wider implications of these findings are discussed, especially with regard to feature binding as a general mechanism of cognitive representation as well as the relationship between perception and action.

Psychologists and neuroscientists have long studied how representations of perceptual and action events are organized and how these representations are related to neuronal activity. It is known that elementary features of perceptual and action representations are represented by specific neuronal populations. For example, features of visual objects have been found to be coded in various feature maps distributed across the brain (DeYoe and Van Essen 1988; Ungerleider and Haxby 1994), and neurons coding specific motor features, such as the direction of reaching movements, have been identified (Georgopoulos 1990). Therefore, it is likely that representations of objects and action plans are based on distributed neuronal populations, each coding different aspects or features of the representation (Singer 1994). One of the unanswered questions associated with this hypothesis about the structure of representations refers to the binding problem: if objects are represented by the activity of distributed sets of neurons, how is the relationship between these neurons coded (von der Malsburg 1981, 1995)? This problem is nicely illustrated by Rosenblatt's (1961) example of a perceptron, a simple neural network consisting of just four neurons (Fig. 26.1(a)). Neuron 1 responds to the presence of a triangle and neuron 2 to the presence of a square. Neuron 3 responds to all objects in the upper visual field and neuron 4 to all objects in the lower visual field. If this system has to detect a square in the upper visual field, an output neuron would have to detect the simultaneous activity in neuron 2 and 3 (Fig. 26.1(a)). But now suppose that there is a triangle in the upper and a square in the lower visual field: The output neuron would falsely respond (Fig. 26.1(b)). In other words, the perceptron can only handle one object at a time. The example shows that representing the presence or absence of features alone is not sufficient to represent multiple objects simultaneously.

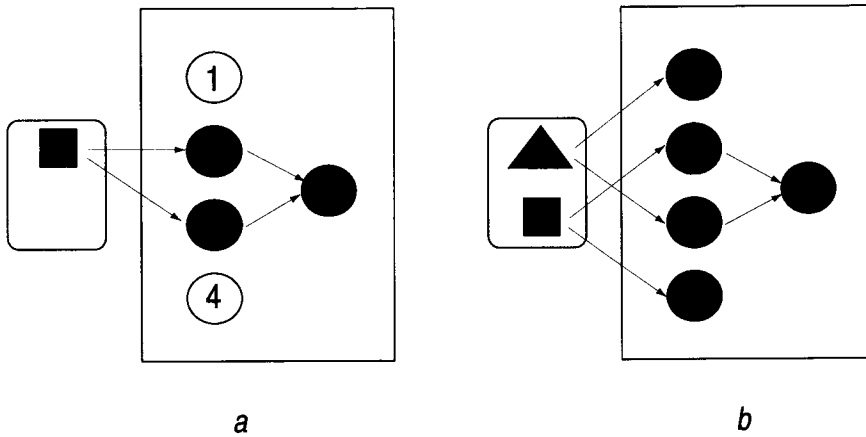


Fig. 26.1 (a): Correct detection of a square in the upper visual field. (b): Perceptron cannot handle the coactivation of two objects.

In order to represent multiple objects, the brain needs to code which features belong together and which do not. However, this simple binding scheme becomes problematic if some features belong to several objects at the same time, as is illustrated in Fig. 26.2. In the model of Fig. 26.2(a), a red circle and a green square are represented at the same time. While the active neurons (filled circles) code the features that are present in the environment, the bindings represent which features belong together. Although this model offers a solution to the perceptron problem (illustrated in Fig. 26.1), the model cannot represent multiple objects that share a feature (Fig. 26.2(b)): the presence of a red and a green circle result in one blurred object. This is because the shared feature connects the two objects, and there is no way of distinguishing the two objects when the same types of bindings are used for the different objects. A solution is presented in Fig. 26.2(c), where different types of bindings are used for the different objects. The shared feature is connected to each object with a different type of binding.

Altogether, the binding problem is best characterized by the question of how distributed sets of features can represent multiple objects without confusing the features of the individual objects. A solution of the binding problem requires three conditions to be satisfied. First of all, it should allow features to interact with each other. Second, feature interactions must be flexible, because feature relationships in the environment change quickly. Third, it should allow features to participate in different representations at the same time.

Although the binding problem has been investigated mainly in visual perception, there are also some studies on action planning (Engel, Roelfsema, Fries, Brecht, and Singer 1997; Stoet and Hommel 1999). The reason to consider a binding problem in the motor domain is that action plans are likely to be based on sets of distributed action features (Stoet and Hommel 1999) so that, as in perception, the simultaneous representation of multiple actions requires a mechanism for coding which motor features belong together. Suppose that you plan a LEFT FOOT and a RIGHT HAND movement. If the action plans involve the features LEFT, RIGHT, HAND, FOOT, then binding is required to prevent feature confusion that would lead to a LEFT HAND and a RIGHT FOOT movement.

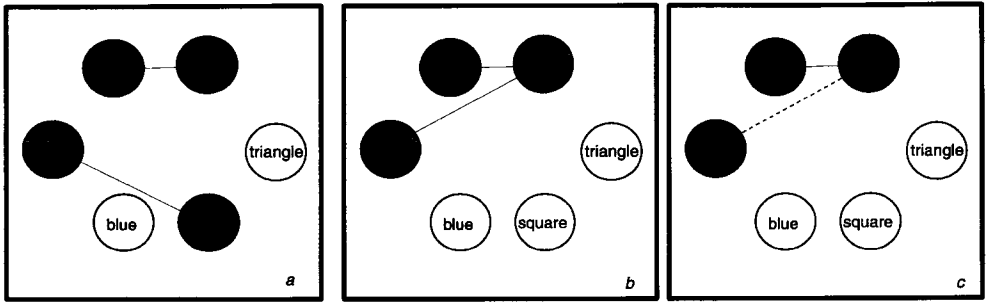


Fig. 26.2 (a): Two sets of active feature neurons representing a red circle and a green square. Inactive neurons (open circles) do not participate in representations. (b): Representation of a red circle and a green circle is not possible without loss of information if bindings are not distinguishable. (c): Representation of a red circle and a green circle is possible because the two sets of features are distinguished by different types of binding.

The solutions of the binding problem proposed until now are controversial and hotly debated in neuroscience (for an impression of the debate, see *Neuron*, Vol. 24, Sept. 1999). Yet psychophysical research has contributed to a better understanding of the binding problem independent of implementation questions on the neurophysiological level. Psychophysical experiments have studied behavior under conditions where feature binding is necessary. For example, in visual search tasks, people have been shown to perform much better if the target is defined in terms of a single feature rather than a feature conjunction, suggesting that in the latter case some time-consuming feature integration needs to take place (Treisman 1996). Likewise, when being only briefly presented with more than one object, people tend to produce illusory conjunctions, hence to combine features the wrong way (Treisman and Gelade 1980).

Other psychophysical experiments have explored interactions between features bound to different representations. For example, Stoet and Hommel (1999) investigated how a previously prepared action plan (A) residing in memory for later execution influences the preparation of another action plan (B). They found that if plan B shares an action feature with the already prepared plan A, planning takes more time. According to Stoet and Hommel, this is because an already bound feature is, in a sense, occupied and thus less easily available for other action plans until the planned action is carried out.

Recent findings of Müsseler and colleagues even suggest that integrating features in action planning has an impact on perceptual integration. In particular, Müsseler and Hommel (1997a,b) showed that identifying or detecting an arrow pointing to the left or right is more *difficult* if a spatially *compatible* response is made at the same time. Wühr and Müsseler (1997) observed that this kind of ‘blindness’ to response-compatible stimuli sets in as early as two seconds before the manual response is actually emitted, revealing that it is not the execution, but the planning of a feature-overlapping action that hampers perception.

Along the lines of Stoet and Hommel’s (1999) feature-occupation account, the observation of Müsseler and colleagues might indicate that the binding of a, in that case spatial, feature code to an action plan makes it less available for representing a visual object (cf. Müsseler and Wühr, this

volume, Chapter 25). In other words, the effects of feature-occupation might cross borders between perception and action planning. Such an interpretation fits nicely with the general idea that perceptual events and action plans are coded within the same representational domain (Prinz 1997), so that feature codes are shared by perception and action planning (Hommel, Müsseler, Aschersleben, and Prinz, *in press*; Müsseler and Hommel 1997a). If so, we should also be able to find effects going in the opposite direction from Müsseler and colleagues' action-effect blindness. That is, we should be able to demonstrate that coding a perceptual event including a particular feature X should impair the planning of an unrelated action sharing this feature. This is what we did in three experiments, in which we asked human subjects to perform a left- or right-hand action some time after being presented with a stimulus appearing on the same or the other side.

26.1 Paradigm and rationale

We adapted Stoet and Hommel's (1999) ABBA paradigm so as to allow us to investigate possible interactions between perception and action planning. Participants performed two tasks (A and B) on each trial, with task B embedded in Task A (see Fig. 26.3). In the basic version, Task A required memorization of a visually presented object (Stimulus A). Task B was a speeded choice reaction task in which a left or right index finger movement (Response B) was signaled by the identity of a centrally presented letter (Stimulus B). After completion of Task B, a series of forced-choice questions about the features of Stimulus A were answered (Response A). Thus, participants had to hold a representation of Stimulus A in mind while performing Task B.

These modifications of Stoet and Hommel's (1999) original design enabled us to study the influence of an already constructed and maintained stimulus representation (Stimulus A) on the formation of an action plan (Action Plan B). If the already constructed representation A has a given feature code bound to it, and if this very code needs to be integrated into plan B as well, creating the plan should be more difficult than in situations without feature overlap. That is, feature overlap between Stimulus A and Response B should impair the formation of Response B's action plan and delay its initiation. For a concrete example, assume Stimulus A is a red square appearing on the left side. Upon presentation, the corresponding codes RED, SQUARE, and LEFT are integrated into a coherent representation. If Response B is then a right-hand movement, the RIGHT code needs to be integrated into action plan B, which does not conflict with maintaining the representation of Stimulus A. However, in case of a left-hand response, the required LEFT feature would already be bound to the representation of Stimulus A, and it would therefore be difficult to access.

The prediction that feature overlap between a stimulus and response impairs the response seems at odds with established stimulus-response compatibility research that reports faster and more accurate responses to stimuli sharing features with the responses (see Hommel and Prinz 1997, for an overview). For example, in the Simon task (Simon 1990) people respond to a nonspatial stimulus that is presented at different locations. Even though the stimulus location has no task relevance, responses are faster if stimulus and response locations correspond. However, as we will discuss in Experiment 3 in more detail, there are important differences between the Simon task and the paradigm of the present study, the most important being the temporal delay between the critical stimulus and response. In the Simon task people react to the stimulus that carries the irrelevant location feature, so that the processes concerned with forming the stimulus representation and the action plan overlap in time (Hommel 1993a). In contrast, the ABBA paradigm separates the critical stimulus and response (and, thus, the underlying processes) by having the subjects perform response B to

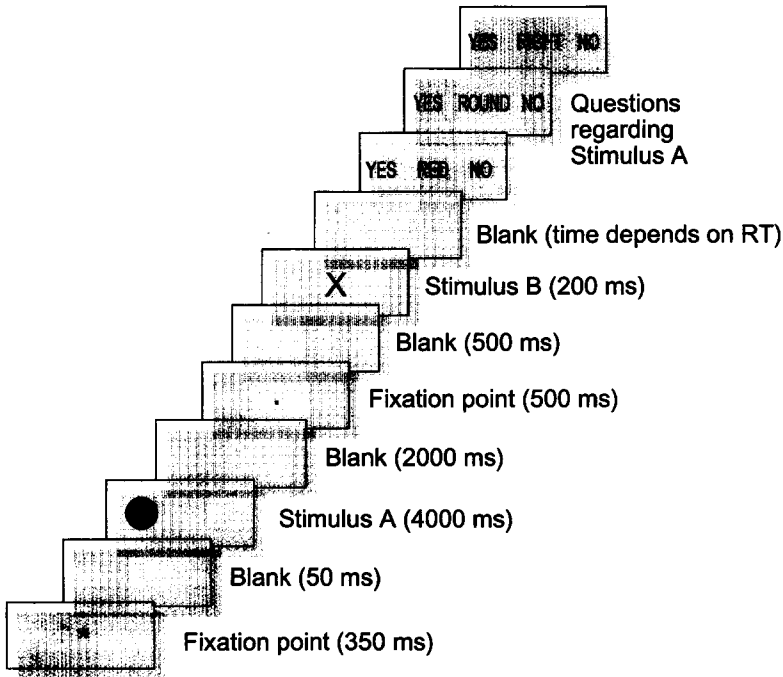


Fig. 26.3 Sequence of events in the experimental procedure of Experiment 1. The printed colors in the figure are different from the real colors in the paradigm. The background color of the screen was always black. Stimulus A is either red or green, round or rectangular, and left or right on the screen. Stimulus A has to be memorized for recall at the end of the trial. Stimulus B is an white 'X' or an 'H', instructing to perform a left- or a right-hand task immediately. After Response B questions concerning the previously memorized Stimulus A have to be answered.

stimulus B, which is presented some time after stimulus A has been processed. Accordingly, planning response B is unlikely to be affected by processes having to do either with coding stimulus A (the process presumably causing the Simon effect; see Hommel 1993b) or with integrating or consolidating it (a process that might cause nonspecific capacity limitations; see Jolicoeur, Tombu, Oriet, and Stevanovsky, this volume, Chapter 28). Hence, if we obtain an effect of Stimulus A on planning Response B even if the two are separated in time, this must be due to some outcome or products of coding and integration processes—such as the hypothesized feature bindings.

26.2 Experiment 1

In our first experiment, we tested whether planning Response B is impaired (i.e. takes more time) if it shares a spatial feature with Stimulus A, in which case the respective feature code (LEFT or RIGHT) should be already integrated into the representation of Stimulus A. Hence, we expected that spatial feature overlap between Stimulus A and Response B (i.e. both left or both right) would result in a slower Response B than when there is no spatial feature overlap.

26.2.1 Method

On each trial, participants experienced the following sequence of events (Fig. 26.3). A white fixation asterisk appeared on the black screen, followed by a blank and Stimulus A. Stimulus A varied randomly in position (left or right), shape (circle or square), and color (red or green). Participants were asked to memorize the features of Stimulus A for later recall. Then, after another blank screen, a fixation dot was presented, followed by a blank screen and a brief presentation of Stimulus B (the centrally presented letter H or X). This stimulus signaled a speeded manual response, which consisted in lifting the left or right index finger from the touch-sensitive metal plate on which it rested. If Response B was correct, the questions concerning the features of Stimulus A followed. For each of the three feature dimensions (presented in random order), one of the two possible features (randomly determined) was presented at the center, and participants were to make an unspeeded present-absent ('yes' or 'no') decision by lifting their left or right index finger. The mapping of decisions ('yes' or 'no') to fingers (which was also indicated in each display) was constant for a given participant but balanced across participants. Importantly, however, the random variation of the judged feature values did not allow subjects to translate information about Stimulus A into responses in advance of the final question phase. In case of an incorrect answer no further questions were presented.

Twelve adult volunteers participated for pay in a single session of about 15 min. They worked through a practice block of eight trials and an experimental block of 80 error-free trials (2 locations of Stimulus A \times 2 locations of Response B \times 20 replications). Trials with incorrect responses, response omissions (RT > 1000 ms for Response B or RT > 5000 for Response A), or anticipations (RT < 100 ms) were repeated at some random position in the remainder of the block. Participants were informed about their general performance after every 10 error-free trials, and in the end they received a small bonus depending on their mean performance.

26.2.2 Results and discussion

Mean RTs and percentages of errors (PEs) for Responses B and A were analyzed as a function of feature overlap (LEFT-LEFT or RIGHT-RIGHT) versus no overlap (LEFT-RIGHT or RIGHT-LEFT) between Stimulus A and Response B (see Table 26.1). The significance criterion was set to $p < 0.05$.

RTs of Response B were significantly longer in the overlap than in the no-overlap condition, $F(1, 11) = 6.35$, $p < 0.05$, providing first support for the hypothesis that constructing a perceptual object representation occupies the codes of the object features, so that these codes are temporarily less available for the construction of other, in this case action-related, representations. Apparently, memorizing Stimulus A led to the integration of the spatial code referring to A's location (e.g. LEFT) so that later integration of the same code into the action plan of Response B was difficult and RT increased. In contrast, the RTs of Response A were long and not different in the overlap and no-overlap conditions, presumably reflecting the nonspeeded nature of this response.

26.3 Experiment 2

Experiment 1 provided first evidence for the assumption that integrating a feature in representing a stimulus event occupies the respective spatial code, and that this occupation impairs the planning of a feature-overlapping action. However, one might argue that requiring subjects to memorize

Table 26.1 Mean reaction times (RTs) and proportion of errors (PEs) for Expts. 1–3 as a function of feature overlap between stimulus A and response B. Standard deviations are given in parentheses

	<i>Response B</i>		<i>Response A</i>	
	RT	PE	RT	PE
Experiment 1				
Overlap	482 (78)	2.0 (1.4)	816 (137)	8.4 (4.1)
No overlap	469 (89)	2.5 (2.2)	814 (144)	5.3 (6.6)
Experiment 2				
Overlap	430 (51)	3.0 (2.7)		
No overlap	420 (51)	2.5 (1.8)		
Experiment 3 (long preview)				
Overlap	384 (75)	4.0 (2.1)	1888 (522)	5.1 (7.1)
No overlap	374 (65)	4.0 (3.4)	1998 (574)	5.4 (3.4)
Experiment 3 (short preview)				
Overlap	359 (35)	3.0 (3.5)	1749 (213)	1.0 (1.0)
No overlap	376 (35)	6.0 (5.6)	1832 (294)	1.5 (1.9)

a stimulus for later report brings in all sorts of possible strategies, such as recoding the stimulus into a more abstract format, or imagery techniques. If so, it may be that these strategies were responsible for the obtained result pattern, rather than the assumed feature-integration processes. To rule that out, we sought for a modification of our design which, on the one hand, would require participants to at least briefly attend to Stimulus A, so that feature integration could take place but, on the other hand, would not require memorizing the stimulus and thereby introduce possible recoding strategies. Accordingly, we modified the task of Experiment 1 by having Stimulus A and its features no longer be memorized, so that there was no memory test and no Response A. However, Stimulus A served as a Go-signal for Task B. In particular, participants were to react to Stimulus B only when Stimulus A appeared; its features had no behavioral relevance. In 12 randomly intermixed catch trials Stimulus A was omitted, in which case participants were to refrain from responding to Stimulus B. Participants were urged to attend to the Go-signal by informing them that they would be excluded from the

experiment in case of more than two responses in the catch trials. Ten naive adult volunteers participated for pay.

26.3.1 Results and discussion

Similar to Experiment 1, RTs for Response B were significantly slower in the overlap than in the no-overlap condition, $F(1,9)=7.64$, $p < 0.05$. This suggests that the binding of a feature to a perceptual representation makes it less available for subsequent binding into an action plan. This effect cannot be attributed to memory rehearsal or other possible strategies, because no feature of Stimulus A was to be memorized or was otherwise relevant to the task. This is consistent with the claim of Kahneman, Treisman, and Gibbs (1992), that attentively perceiving a stimulus is a sufficient condition for feature binding to occur. Here it is demonstrated that this spontaneous binding affects not only perception but action planning as well.

26.4 Experiment 3

As already admitted, the finding that feature overlap between one event and another yields a *negative* effect might seem puzzling at first sight. No doubt, the much more common findings are *positive* effects of feature overlap, as documented by numerous reports from research on S–R compatibility (for overviews, see Hommel and Prinz 1997). Given that, the observation that feature overlap produces interference seems to stand in contradiction to a whole wealth of well-established effects and phenomena.

In order to address this apparent contradiction, Stoet and Hommel (1999) assumed that the temporal delay between the two events may play a critical role, an idea they tested by varying this delay in their version of the ABBA design. In particular, participants were cued to prepare Action A, but to withhold it until the end of the trial. In between preparation and execution of Action A, subjects were asked to prepare and execute a second Action B. If the temporal delay between Stimulus A and Stimulus B was long (presumably allowing for full integration of plan A) the already reported negative effects of feature overlap were obtained. Hence, if subjects had prepared and memorized a *left-hand* Action A, they were slower initiating a *left-hand* than a *right-hand* Action B. However, if Stimulus B appeared soon (100 ms) after Stimulus A—so that planning Action A could not be completed before at least starting to plan Action B—positive effects on B were obtained, that is, feature overlap sped up initiating B. These and other findings (see Hommel 1998b) suggested a two-phase model of action planning. In the first phase, the individual features of an action plan are activated. During this phase, the features are primed and they facilitate processes using the same features. In the second phase, the activated action features are integrated into an action plan and are from then on less available for other representational processes.

Although the original two-phase model refers to action planning, the observed commonalities between perceptual integration and action planning suggest that it might also apply to feature integration in perception (Hommel *et al.*, in press). Indeed, there is evidence that codes of perceptual features get activated before effects indicative of feature binding can be observed (Hommel, submitted). If so, the key variable to explain the apparent contradiction between the standard positive effects of feature overlap and the present observation of negative effects would be time or, more precisely, the interval between the presentation of Stimulus A and the planning of Action B. If this interval is short, action planning would be more likely to fall into the first phase of perceptual

integration, so that feature overlap between stimulus and action should facilitate. This seems to characterize the situation in standard compatibility experiments, where the action follows the stimulus immediately. However, as soon as feature-integration processes begin (i.e. after about 250–500 ms; see Hommel, submitted) feature codes are still activated but now bound to a particular event representation. This should make it more difficult to use these codes to create other representations; benefits turn into impairments. In short, effects of stimulus–response feature overlap should be positive with short, but negative with long intervals between object presentation and response planning.

This prediction was tested in Experiment 3 by comparing two conditions (see Fig. 26.4). In a long-preview condition, Experiment 1 was replicated by presenting Stimulus A for a time long enough to allow the integration of object features needed for later recall. In a short-preview condition, the basic task was the same, but there were two major modifications. First, Stimulus A preceded Stimulus B only briefly, so that the feature codes representing Stimulus A were likely to be activated but unlikely to be fully integrated before the planning of Response B started. Second, Stimulus A remained on the display until Response B was performed, so that memorizing Stimulus A before planning Response B was unnecessary. According to the distinction between activation and integration, short preview should produce positive effects of feature overlap between Stimulus A and Response B, whereas long preview should yield negative effects, similar to Experiments 1 and 2.

26.4.1 Method

The method was similar to Experiment 1, except for the following modifications. Stimulus A was always followed by a $15^\circ \times 3^\circ$ mask consisting of 76×12 randomly ordered red and green

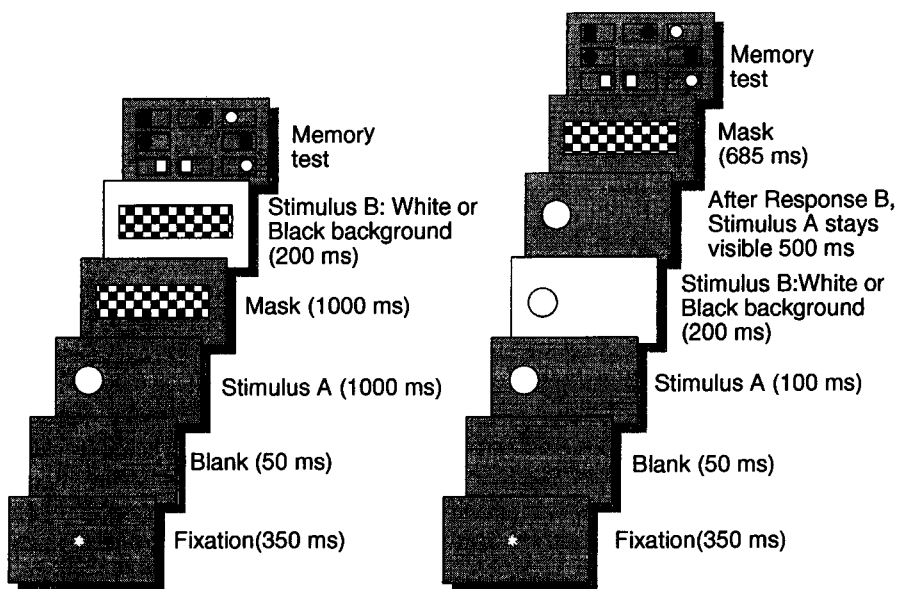


Fig. 26.4 Sequence of events in the experimental procedure of Experiment 3.

rectangles. Stimulus B consisted of a change in the brightness of the screen background from gray to black or to white. There were two separate sessions, one with long preview of Stimulus A and one with short preview (Fig. 26.3). In the long-preview session, a yellow fixation asterisk was followed by a blank and Stimulus A. Then the stimulus was masked and, after a further interval, Stimulus B was presented by changing the background color. After completion of Response B, the whole screen turned gray and the memory test began (i.e. Response A). It consisted of the presentation of eight randomly ordered rectangles, each containing one of the objects (i.e. combinations of location, shape, and color) used as Stimulus A. Participants indicated their decision by pressing the corresponding key (1–9, excluding the central 5) of the numeric keyboard of the PC. Although RTs were measured for Response B, the memory test was not under time pressure. In the short-preview session, Stimulus A preceded Stimulus B by only 100 ms but stayed visible up to 685 ms after Response B had been completed. Then it was masked and the memory test began. Twelve new adult volunteers participated for pay in both the short and long preview sessions, which took about 15 min each.

26.4.2 Results and discussion

For Response B, significant interactions of feature overlap and preview were obtained in both RTs, $F(1, 11)=78.56$, $p<0.001$, and PEs, $F(1, 11)=7.72$, $p<0.05$. Separate analyses showed that, as expected, RTs were negatively affected by feature overlap with long preview, $F(1, 11)=5.10$, $p<0.05$, but positively affected with short preview, $F(1, 11)=18.68$, $p<0.001$ (see Table 26.1). The PE effect is due to the fact that feature overlap had no effect with long preview (this replicating the previous findings), but a positive effect with short preview, $F(1, 11)=8.21$, $p<0.05$. This result pattern supports the prediction that briefly after a stimulus is presented, its features are activated, but not yet bound.¹ After some time, the features get integrated and are more difficult to bind to other, feature-overlapping events.

Interestingly, in the memory test (Response A), RTs were faster with feature overlap than without, $F(1, 11)=9.12$, $p<0.05$, and accuracy was greater in the short- than the long-preview condition, $F(1, 11)=6.44$, $p<0.05$. This is in accordance with the activation–integration model and with a similar observation of Stoet and Hommel (1999). At the moment that Response A is prepared and executed, none of its codes are integrated in another task, since the plan for the other action, Response B is no longer maintained. That is, after Response B is executed the bindings between the codes of its representation are disintegrated. Nevertheless, the codes still have a rest activity that is carried over to the preparation of Response A.

26.5 General discussion

In all three of our experiments we found evidence that action planning is affected by perceptual feature integration. In particular, we were able to demonstrate that responses are initiated more slowly if the response location corresponds to the location of a previously memorized (Exp. 1 and 3) or merely perceived (Exp. 2) object. Furthermore, Experiment 3 provided preliminary evidence that this effect depends on the time available to integrate the features of that object—suggesting that feature binding is a temporally extended, time demanding process that can be distinguished from the mere activation of feature codes. Taken together, these findings are in agreement with the two-phase

activation-integration model, proposed by Stoet and Hommel (1999) and extended here to include perceptual integration. Figure 26.5 summarizes how this model accounts for the processes taking place in the overlap (Fig. 26.5 (a) to (f)) and no overlap (Fig. 26.5 (g) to (l)) conditions we investigated. Our findings have several implications, two of which we would like to emphasize.

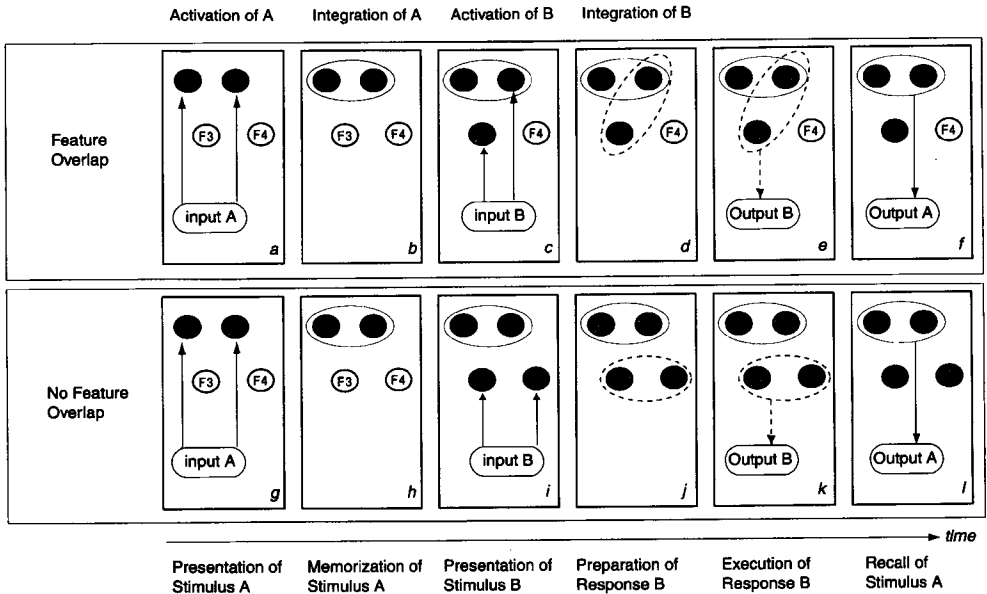


Fig. 26.5 Explanation of the results in terms of the action and integration model of feature integration. (a) and (g): Stimulus presentation causes activation of the feature codes that correspond to the feature codes of the stimulus (activated features are illustrated as filled circles). (b) and (h): The memorization process as in Exps. 1 and 3, or the attention in Exp. 2 cause the temporal integration of the activated features. (c) and (i): The presentation of Stimulus B causes activation in associated motor features. For simplicity, it is assumed that Stimulus B automatically activates the properties of the motor plan associated with Stimulus B. Note that in (c) one of the features already belongs to the integrated set of features representing Stimulus A, whereas in (i) none of the features of A and B overlap. (d) and (j) represent the process of integration. In the feature overlap trial feature F2 must be integrated in two different representations, whereas in (j) none of the features is shared by different representations. It is exactly this phase of processing where the disadvantage of feature overlap comes into play: integration of features that are already in use for other representations is more difficult than integration of features that are free. (e) and (k) show that the execution of Response B is based on the representation of the action. The model assumes no differences between the two execution processes. (f) and (l) show that the recall process of Stimulus A is based on the representation of Stimulus A. Note that the integration of B no longer exists. The model assumes that the temporal binding of Plan B was discarded after execution of B. The model assumes that after the disintegration of Plan B, the activity of its codes dissipates gradually. This causes a positive effect on the recall of Stimulus A in case of overlap.

26.5.1 *Binding and bindings*

Negative effects of feature overlap between Stimulus A and Action B on initiating the latter were obtained only if Stimulus A appeared two or more seconds before Action B was signaled, but not if Stimulus A and B were presented in close succession. This suggests that, inasmuch as the negative overlap effect is related to feature binding, it is unlikely to reflect direct interference between ongoing binding processes. Rather, it seems to indicate an after-effect of one binding process (via the binding it produced) on another binding process, a kind of prospective interference. In other words, our results seem to be due to the impact of an already existing binding (a cognitive *structure*) on current binding (a cognitive *process*).

The main characteristics of our effect (its specificity and temporal range) distinguish it from another interference effect that stimulus processing can exert on action planning. As Jolicœur and colleagues (e.g. Jolicœur, Dell'Acqua, and Crebolder 2000; Jolicœur *et al.*, this volume, Chapter 28) have repeatedly shown, storing a stimulus for later report interferes with selecting a response at the same time and up to some hundred milliseconds later. Jolicœur and Dell'Acqua (1998) have argued that later report of a stimulus requires a process that they call short-term consolidation, a process that they assume interferes with selecting a response. In elaborating on these ideas, Jolicœur *et al.* (this volume, Chapter 28) suggest that response selection may involve response-code consolidation, a process similar to the short-term consolidation of stimulus information.

We are sympathetic to this view and think that it is very close to the perspective that we propose here. Nevertheless, it is important to consider that Jolicœur *et al.* focus on the *direct interference* between two integration or consolidation processes, not on the *products* of these processes. Accordingly, the effects they deal with are most pronounced if stimulus and response processing overlap in time but disappear with delays of one or more seconds—the exact opposite of what we observed. Moreover, the interference demonstrated by Jolicœur and colleagues is nonspecific in the sense that stimulus processing interfered with response selection independent of any feature overlap, whereas feature overlap played a crucial role in our findings.

The picture that emerges from these result patterns might be sketched like this: integrating the features of a perceived or planned event might draw upon a strictly resource-limited mechanism that allows integration of only one event at a time—a characteristic that may be responsible for costs in both the consolidation of stimulus information (Jolicœur and Dell'Acqua 1998) and delays of action planning in multiple-task performance (Hommel 1998b). The outcome of such an integration or binding process is a coherent cognitive structure comprising codes of the features of the respective event. If one or more of these codes are shared with another, later integrated event, this integration process is prolonged and/or its use is complicated through cross-talk from the involuntarily connected structure.

26.5.2 *Perception and action*

Our findings add to an increasing number of phenomena in perception and action that indicate the existence of temporary feature bindings. The similarity between these phenomena and their characteristics suggest a general principle of how events are represented in perception and action, namely through cognitive structures formed by temporarily integrating codes representing the features of the to-be-represented event (Hommel *et al.*, in press). But apart from mere similarity of processes, our findings also suggest at least some sharing of representational codes.

Minimally, the observation that feature overlap between a stimulus and a logically unrelated action affects performance on the latter seems to suggest that codes of this feature are shared, that is, accessed and used by both perceptual processing and action planning. However, even though converging evidence for this conclusion comes from Müsseler and Hommel (1997a,b) and related studies, there is a possible objection. Assume that what get integrated are not low-level perceptual features of stimuli but more abstract, high-level semantic codes, which then interact with the semantic representation of the to-be-planned action. This would imply that our binding story may hold but there would be no need to claim interactions between perceptual and action-related feature codes. Instead, what interacts may be codes of the same, abstract kind. If so, the observation of code sharing would be somewhat less surprising.

Although our present data do not allow us to rule out this idea, some recent data of Hommel and Müsseler (2001) make us doubt that it is applicable. Hommel and Müsseler employed the design developed by Müsseler and Hommel (1997a) but varied the 'format' of both the to-be-planned action and the to-be-identified stimulus. That is, they asked subjects to plan either a left- or right-hand keypress or the verbal utterance 'left' or 'right' (or, to be precise, the German equivalents) and presented then either left- or right-pointing arrows or the words 'left' or 'right'. If subjects were presented with arrows while maintaining the plan to perform a keypressing action, action-compatible arrows were less accurately identified than incompatible arrows, which replicates the findings of Müsseler and Hommel (1997a). As a left-pointing arrow and the word 'left', or a right-pointing arrow and the word 'right', have the same meaning, their semantic representations should be equivalent or even identical, so that a semantic-coding view would predict comparable effects of action planning on arrows and words. However, word identification was not affected by planning keypresses at all. In contrast, planning verbal utterances impaired the identification of compatible words, while arrow identification remained unaffected. Obviously, a merely semantic relationship between a planned action and a processed stimulus is insufficient to produce interactions between their codes; what seems necessary is similarity between more low-level perceptual and action-related codes, just as our feature-binding approach suggests. If so, there is considerable reason to think that our findings reflect a true interaction between perception and action planning.

If these considerations are correct, we are left with the insight that the codes that seem to be shared are specific and abstract at the same time. They are specific inasmuch as they code real locations of stimulus events or actions, not just spatial meaning. But they are also abstract in being able to code both perceptual events and action plans. Although this sounds self-contradictory it need not be. If we assume that actions are cognitively coded and planned in terms of their perceivable effects (Elsner and Hommel, in press; Hommel 1996; Hommel *et al.*, in press; Müsseler and Hommel 1997a), the only difference between the codes involved in perceiving an event and in planning an action is that the former may or may not have resulted from one's own movements and that the latter is still in the process of being produced. The quality of the codes themselves does not need to differ; in either case they make up internal structures the activity of which is correlated with the intended or real presence or absence of a particular event characterized through the possession of particular features. In other words, feature codes may code features irrespective of whether these belong to registered input or intended output. If so, feature codes would always be *specific* with respect to the features it codes but would be *abstract* with respect to the origin of the coded event.

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Note

1. Although our findings suggest a critical role of timing, we should mention that some aspects of our design do not allow us to exclude possible contributions from another factor. In order to roughly equate the durations of Stimulus A in the two preview conditions, and to discourage subjects from memorizing that stimulus under short preview, we left Stimulus A on the screen while subjects were working on Task B. As this was not the case under long preview, it might be that the presence of Stimulus A somehow contributed to the different results under short and long preview. Although we find it difficult to imagine what such a contribution may look like, future research may provide us with a more differentiated picture.

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