THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2006, 59 (10), 1785–1804

Psychology Press
Taylor & Francis Group

Priming and binding in and across perception and action: A correlational analysis of the internal structure of event files

Lorenza S. Colzato, Matthijs J. Warrens, and Bernhard Hommel
Leiden University, Leiden, The Netherlands

Individual performance was compared across three different tasks that tap into the binding of stimulus features in perception, the binding of action features in action planning, and the emergence of stimulus–response bindings ("event files"). Within a task correlations between the size of binding effects were found within visual perception (e.g., the strength of shape–location binding correlated positively with the strength of shape–colour binding) but not between perception and action planning, suggesting different, domain-specific binding mechanisms. To some degree, binding strength was predicted by priming effects of the respective features, especially if these features varied on a dimension that matched the current attentional set.

From object to event files

Perceiving a visual (but not only a visual) object involves registering, coding, and processing its sensory features in numerous cortical areas (e.g., Cowey, 1985), and yet what we perceive is a single, coherent event and not a bundle of attributes. This has been taken to suggest that there must be some kind of feature-binding mechanism that allows our brain to integrate the features belonging to the same event (see Treisman, 1996, for an overview). According to Kahneman, Treisman, and Gibbs (1992), attending to a visual object establishes what they call an "object file", an integrated episodic trace containing information about the relationships between object features and their locations, possibly enriched by object-related knowledge from long-term memory. Indeed, a number of studies have provided evidence for the claim that perceiving a visual object involves creating an episodic assembly of object-related feature codes (Gordon & Irwin, 1996; Henderson, 1994; Henderson & Anes, 1994; Hommel, 1998), even though the original approach seems to have overestimated the importance of location for constructing and retrieving such object files (Hommel, 2002; Hommel & Colzato, 2004; Leslie & Kaldy, 2001; Leslie, Xu, Tremoulet, & Scholl, 1998; Pratt & Hommel, 2003).

Although the problem of integration in distributed representational systems has been discussed almost exclusively for the case of visual perception, the fact that the human cortex seems to represent almost all information in a distributed fashion suggests that "binding problems" exist and are apparently resolved in many representational

---

Correspondence should be addressed to Lorenza Colzato, Leiden University, Department of Psychology, Cognitive Psychology Unit, Postbus 9555, 2300 RB Leiden, The Netherlands. E-mail: colzato@fsw.leidenuniv.nl

http://www.psypress.com/qjep
DOI:10.1080/17470210500438304

and processing domains (Singer, 1994; Stoet & Hommel, 1999; Treisman, 1996; Wickens, Hyland, & Anson, 1994). In fact, a number of recent studies (for overviews, see Hommel, 2004) provide evidence of feature binding in action planning (Müsseler & Hommel, 1997; Stoet & Hommel, 1999, 2002) and across perception and action (Hommel, 1998; Hommel & Colzato, 2004). For instance, Stoet and Hommel (1999) showed that planning a speeded left–right keypressing action is delayed if it shares location-related features with (i.e., is carried out with an effector on the same side of the body as) another, already-planned action held in memory. That is, planning an action might involve the integration or binding of those action features that specify the intended action, so that the integrated feature codes are temporarily not (or not that easily) available for the planning and control of other actions (Hommel, Müsseler, Aschersleben, & Prinz, 2001a, 2001b).

Hommel and colleagues (Hommel, 1998; Hommel & Colzato, 2004; Hommel, Proctor, & Vu, 2004) analysed the combined effects of repeating versus alternating stimulus features and the response. The results showed that the repetition of stimulus features did not only interact with other stimulus feature effects but also interacted with response repetition. With respect to stimulus–stimulus binding, repeating the shape of the stimulus produced better performance than alternation if the colour or the location of the stimulus was also repeated, but worse performance than alternation if colour or location alternated. This suggests that seeing an object results in the binding of its features; once bound together, these features can no longer be separately addressed, so that perceiving a new combination of the same features requires a time-consuming rebinding process and/or the resolution of the conflict induced by the previous binding. With respect to stimulus–response binding, repeating a stimulus feature (shape or position) facilitated performance only if the response was also repeated, otherwise stimulus repetition produced a cost. This implies that stimulus features are getting bound to the response that they accompany, so that presenting the same stimulus feature again reactivates the associated response—thus creating a conflict in the case of a response alternation.

We can conclude that feature-binding processes are not restricted to object perception, but cross borders between stimulus and response feature domains. This implies that the object file concept introduced by Kahneman et al. (1992) is more general than anticipated, which led Hommel (1998) to suggest replacing it by the more universal concept of an "event file". According to this idea, all the features belonging to an event, whether perceived, produced, or internally generated, might be integrated into episodic memory traces (cf. Logan, 1988). The question is, what do such traces look like? The perhaps most obvious possibility is that all the information that a given event provides is lumped into one single master file, which would facilitate information exchange within a file. And yet there is evidence that the structure of event files is more complex, more like a loosely connected network.

First, the studies looking into sequential effects of stimulus–response feature conjunctions provide ample evidence of binary interactions (e.g., Shape × Location, Shape × Response, Location × Response), which imply binary feature bindings, but hardly any higher order interaction involving three stimulus and/or response features or more (Hommel, 1998; Hommel, Alonso, & Fuentes, 2003; Hommel & Colzato, 2004). However, such higher order interactions would be expected if all feature codes were integrated into the same file.

Second, interactions between stimulus features (e.g., shape and location) are affected by drugs that modulate the muscarinic-cholinergic system (e.g., caffeine, an agonist, and alcohol, an antagonist), whereas stimulus–response bindings are unaffected by such drugs (Colzato, Erasmus, & Hommel, 2004; Colzato, Fagioli, Erasmus, & Hommel, 2005). The observed link between visual binding and cholinergic activity is consistent with the assumption that the integration of visual features is related to neural synchronization in the gamma frequency band (Engel & Singer, 2001; Keil, Müller, Ray, Gruber, & Elbert, 1999), which is driven by the muscarinic-cholinergic system (Rodriguez, Kallenbach, Singer, & Munk, 2000, 2001, 2004). If so, however, the observation that stimulus–response binding is not equally affected implies that these bindings are created by another neural mechanism, which presumably operates in the beta band (Kopell, Ermentrout, Whittington, & Traub, 2000; see Roelfsema, Engel, Koenig, & Singer, 1997).

Third, the binding of perceptual features seems to be more automatic and to produce more stable traces than the binding of action features. For instance, the response-related costs of feature overlap between action plans that Stoet and Hommel (1999) observed were tightly linked to the planning process and disappeared a few hundred milliseconds after the planned action was carried out (Experiment 3). In contrast, stimulus-related overlap costs, as well as stimulus–response bindings, are largely unaffected by attentional manipulations, and they last at least several seconds (Hommel & Colzato, 2004), if not minutes (Waszak, Hommel, & Allport, 2003).

To summarize, feature integration seems to take place in and across perception and action, creating multimodal episodic links between the codes that represent the features of the perceptual event and/or action plan at hand. However, a number of preliminary observations suggest that these integration processes do not create one single master file but, rather, a loosely connected associative network.

Purpose of the study

The present study was motivated by two questions, one concerned with the way event files are generated and the other with the internal structure of event files and the way different subcomponents of an event file might be interrelated. To understand how we tackled the latter question, assume that we had evidence for the existence of a master event file—that is, let us assume that the codes of all available features of a given event were integrated into one coherent short-term memory structure. Let us further assume that people differ in the strength of feature integration, which suggests that there is a continuum ranging from "strong binders", who create very strong temporary associations between the features they integrate, to "weak binders", who create only weak associations. If so, we would expect interindividual variability in the sizes of binding effects—that is, of effects that are likely to reflect feature binding in and across perception and action. If all bindings would be created by the same binding mechanism, strong binders should show large binding effects whatever features are to be integrated, while weak binders should consistently show small effects. That is, the sizes of binding effects from different integration-requiring tasks should correlate positively: Small (or large) binding effects in one task should go with small (or large) binding effects in the other. However, this should only be observed if all features are integrated by the same mechanism—which in view of the available evidence is unlikely. Therefore, correlations between binding effects should occur only between those effects that were produced, or at least affected, by the same mechanism. In other words, positive correlations between binding effects point to a common integration mechanism while the absence of correlations suggests different mechanisms.

Every participant ran through three tasks, which are assumed to reflect feature integration processes in perception, across perception and action, and in action planning, so that we were able to calculate individual estimates for all task-specific binding effects. On the one extreme all these measures might correlate, suggesting one single master event file, or, on the other extreme, no two measures might correlate, which would point to numerous different integration mechanisms. Our expectations lay in between: Some measures are more likely to correlate, such as those related to different features of the same stimulus, while those related to different domains were more likely to be uncorrelated. In particular, we expected that (significant) effects reflecting the integration of stimulus features (e.g., of shape and location) would correlate with other (significant) stimulus-integration effects but not with effects indicating stimulus–response integration or the integration of response features (Colzato et al., 2004, 2005).

Our other research question refers to the process of event-file construction. Even though event files are apparently created automatically—that is, irrespective of whether they are useful or necessary or not (Hommel & Colzato, 2004)—their structure is often affected by the task goal. In particular, stimulus features that vary on a task-relevant dimension are more likely to be integrated (i.e., produce stronger and more reliable interaction effects) than stimulus features varying on an irrelevant dimension (Hommel, 1998). Interestingly, there is some evidence that feature priming effects—that is, main effects of repeating versus alternating a stimulus feature—follow the same pattern in being stronger for task-relevant than for task-irrelevant feature dimensions (Hommel, 1998; Hommel & Colzato, 2004). This commonality might indicate the criterion underlying feature integration: Codes of features defined on dimensions that are primed by the task context (i.e., objective or subjective task relevance, or salience) might receive a stronger activation than codes of features defined on unprimed dimensions (cf. Hommel et al.'s, 2001a, 2001b, intentional weighting principle). If feature codes are integrated only if they pass a particular activation threshold (Hommel, 2003, 2004), this would mean that codes related to context-primed dimensions are more likely to be integrated than other codes—just as the available findings suggest. Simple feature repetition or priming effects may thus reflect the degree of context-induced dimensional priming (i.e., more strongly primed codes leave more stable or more slowly decaying traces). If so, and if the degree of context-induced priming varies between subjects, priming effects and integration effects may correlate in such a way that pronounced priming effects of two given features are associated with a pronounced integration effect—that is, with a strong interaction involving these two features.

Participants had to carry out three tasks that all produce effects that can be assumed to reflect feature integration processes. The first was the "object-file task" (or stimulus–stimulus, "S–S" task, as we call it here) modelled after Hommel and Colzato (2004), which is sensitive to sequential effects of conjunctions of stimulus features. This task measures after-effects of binding different features of the visual stimulus (here: shape, location, and colour). It involves a prime stimulus (S1) followed by another stimulus (S2) that signals a speeded binary-choice response (R2). The standard outcome is cross-over interactions with repetition/alternation of different stimulus features (Hommel, 1998; Hommel & Colzato, 2004).

The second was the "event-file task" (or stimulus–response, "S–R" task) used by Hommel and Colzato (2004). In addition to tapping into stimulus–stimulus integration (a partial replication of the S–S task), this task presumably taps into after-effects of binding stimulus features with the response. It involves a prime stimulus (S1) that triggers a precued prime response (R1), followed by another stimulus S2 that signals a speeded binary-choice response (R2). Apart from S–S interactions as described for the S–S task, the standard outcome in the S–R task is cross-over interactions between response repetition and the repetition of task-relevant stimulus features (Hommel, 1998; Hommel & Colzato, 2004).

Finally, our third task (response–response, "R–R" task) was modelled after McDevitt and Fournier's (2001) adaptation of Stoet and Hommel's (1999) "action-file" paradigm, a task that arguably measures side- and after-effects of binding action-related features. It involves preparing a cued response (RA), making a speeded response (RB) to a following stimulus (SB), and carrying out the prepared prime response (RA). Standard outcomes are slower RTs on RB if it feature-overlaps with RA (presumably indicating feature integration) and faster RTs on RA if it feature-overlaps with RB (presumably indicating feature priming; Stoet & Hommel, 1999).

To summarize, we were interested in two types of correlational pattern: correlations between the sizes of different binding effects, which we take to point at a common integration mechanism, and correlations between priming effects (main effects of feature repetition) and binding effects involving the respective feature(s), which we take to point to the way codes are integrated.

Method

Participants

A total of 48 students of the Leiden University took part for pay in three sessions, 16 each beginning with the S−S session, the S−R session, and the R−R session, respectively (see below). Of these participants, 4 failed to complete all three tasks, and their data were therefore excluded from further analysis (1 participant beginning with the S−S session, 2 participants with the S−R session, and 1 with the R−R session). All participants reported having normal or corrected-to-normal vision. They were not familiar with the purpose of the experiment.

Apparatus and stimuli

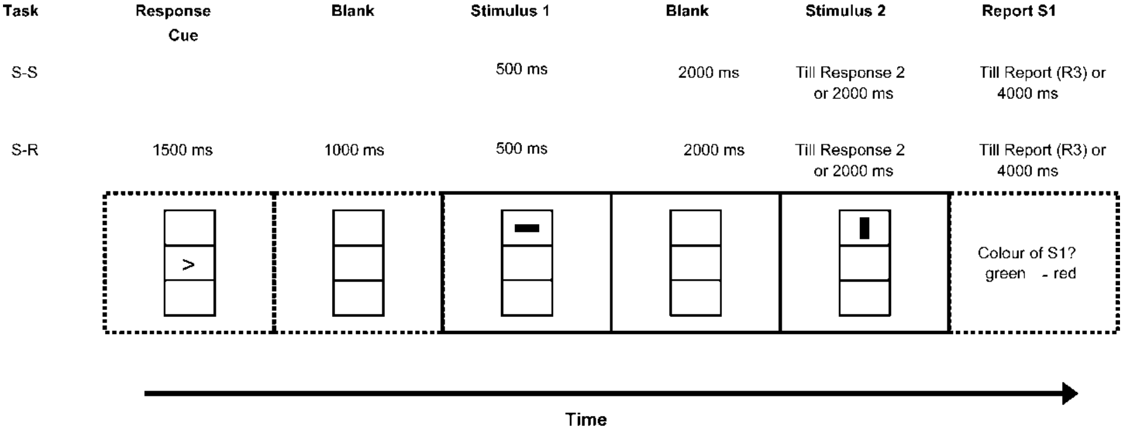
The experiment was controlled by a Targa Pentium III computer, attached to a Targa TM 1769-A 17″ monitor.

In S−S and S−R sessions, which were modelled after Hommel and Colzato (2004), participants faced three grey rectangular outlines, vertically arranged, as illustrated in Figure 1. From a viewing distance of about 60 cm, each of these frames measured 2.6° × 3.1°. A thin vertical line (0.1° × 0.6°) and a some what thicker horizontal line (0.3° × 0.1°) served as S1 and S2 alternatives, which were presented in red or green in the top or bottom frame. Response cues (in the S−R session only) were presented in the middle grey frame (see Figure 1), with a left- or right-pointing grey arrow indicating a left and right keypress, respectively. Responses to S1 (in the S−R session only) and to S2 were made by pressing the left or right shift-key of the computer keyboard with the corresponding index finger.

In the R−R session modelled after McDevitt and Fournier (2001) and Stoet and Hommel (1999), illustrated in Figure 2, a white cross on a black background that appeared at the centre of the monitor served as the first fixation mark. Stimulus A (SA) consisted of a white arrowhead appearing above the cross and an asterisk appearing above or below the arrowhead. From a viewing distance of about 60 cm, each character constituting SA (i.e., each asterisk and the arrowhead), measured about 0.3° in width and 0.4° in height. A white cross was used again as second fixation mark, which also appeared at screen centre. Below the cross appeared, then, the symbol # or & to signal Stimulus B (SB).

Procedure and design

S−S task. In the S−S session participants carried out two responses (R2 and R3) per trial. First, they made a binary-choice reaction to the second of two successive stimuli. Half of the participants responded to the vertical and the horizontal line by pressing the left and right key, respectively,



Task	Response Cue	Blank	Stimulus 1	Blank	Stimulus 2	Report S1
S-S			500 ms	2000 ms	Till Response 2 or 2000 ms	Till Report (R3) or 4000 ms
S-R	1500 ms	1000 ms	500 ms	2000 ms	Till Response 2 or 2000 ms	Till Report (R3) or 4000 ms

Figure 1. *Overview of the display and the timing of events in the stimulus–stimulus (S–S) task and the stimulus–response (S–R) task.*

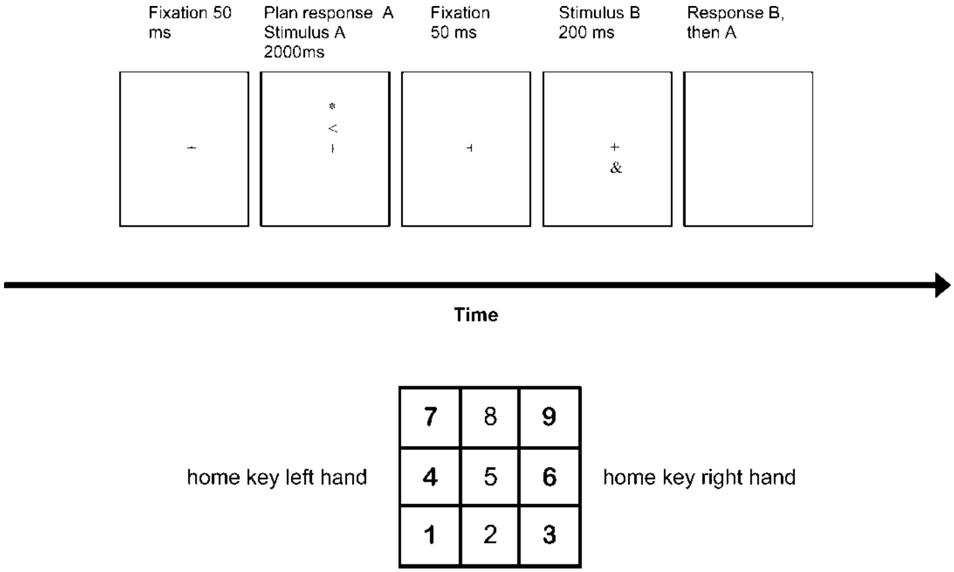


Figure 2. *Overview of the display and the timing of events in the response–response (R–R) task and display of the numbers of the computer keys used as response keys.*

while the other half received the opposite mapping. After each binary-choice reaction to S2, participants were probed for their memory of a feature of S1 (= R3)—a manipulation that encourages the processing of all features of S1 and that produces pronounced and stable effects (Hommel & Colzato, 2004). Participants were presented with one of three questions, asking for the shape, colour, or location of S1 (e.g., "What was the colour of Stimulus 1?", in Dutch). Two words indicating the two response alternatives ("horizontal–vertical", "red–green", or "top–bottom", in Dutch) were presented below the question, with their relative position indicating the mapping of alternatives onto the left and right shift key. The six combinations of the three stimulus dimensions and two alternative-key mappings were presented in pseudorandom sequence but equally often within one session. The sequence of events is shown in the upper row of Figure 1. The intertrial interval of 2,000 ms was followed by a 500-ms appearance of S1. The duration of the next, blank, interval was 2,000 ms. Then S2 appeared and stayed until the response was given or 2,000 ms had passed. If the response was incorrect auditory feedback was presented. This sequence of events was then followed by the memory-probe question, which stayed until the response was given or 4,000 ms had passed. The S–S session comprised 256 trials, composed of a factorial combination of the two shapes (vertical vs. horizontal line), colours (red vs. green), and locations (top vs. bottom) of S2 and the repetition versus alternation of shape, colour, and location (2 × 2 × 2 × 2 × 2 × 2 × 4 replications). Participants were allowed to take a short break during each session.

S–R task. The procedure in the S–R session was as that in the S–S session, with the following exceptions. Participants carried out three responses per trial. R1 was a simple reaction with the left or right key, as indicated by the response cue. It had to be carried out as soon as S1 appeared, independent of its shape, colour, or location. Participants were informed that there would be no systematic relationship between S1 and R1, or between S1 and S2, and they were encouraged to respond to the onset of S1. As in the S–S session, R2 was a binary-choice reaction to the shape of S2, and R3 required the identification of a randomly selected feature of S1. The sequence of events in each trial is shown in the lower row of Figure 1. Next to the intertrial of 2,000 ms a response cue signalled R1 for 1,500 ms, followed by a blank interval of 1,000 ms. Then S1 appeared for 500 ms, followed by a further blank interval of 2,000 ms. If R1 was incorrect or not given within 500 ms the trial started again. After the stimulus onset asynchrony, S2 appeared and stayed until R2 was given or 2,000 ms had passed. The session comprised 384 trials, composed of a factorial combination of the two shapes (vertical vs. horizontal line), colours (red vs. green), and locations (top vs. bottom) of S2, the repetition versus alternation of shape, colour, and location, and the response ($2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 3$ replications = 384).

R−R task. In the R−R session, the intertrial interval of 1,500 ms was followed by the sequence of events shown in Figure 2. Participants had to perform two tasks in each trial, Task A and Task B, and the second task was embedded in the first task. Stimulus A always appeared before Stimulus B, but the corresponding response had to be executed only after the response to Stimulus B was performed (ABBA design).This implied that the participants were forced to memorize Response A while Task B was performed. As shown in Figure 2, Numbers 1, 4 (home key), and 7 of the computer keyboard served as response keys for the left hand while Numbers 3, 6 (home key), and 9 served as response keys for the right hand.

Task A was signalled by a left- or right-pointing arrowhead, accompanied by the symbol "*" above or below it. Arrowhead direction indicated whether Response A was to be performed with the index finger of the left or right hand. The asterisk indicated the direction of the response. The movement always started with pressing the home key with the hand specified by the arrowhead. When the asterisk appeared above, participants pressed the numeric key above the home key and then pressed again the home key. For example, if the arrowhead pointed to the right, and the asterisk was above, participants had to use the index finger of the right hand by pressing 6 (home key), then 9 (numeric key above the home key), and then again 6 (back to the home key). If the arrowhead pointed to the left participants had to use the index finger of the left hand by pressing 4 (home key), then 7 (numeric key above the home key), and then again 4 (back to the home key). When the asterisk appeared below, participants pressed the numeric key below the home key and then pressed again the home key. For example, if the arrowhead pointed to the right, and the asterisk was below, participants had to use the index finger of the right hand by pressing 6 (home key), then 3 (numeric key below the home key), and then again 6 (back to the home key). If the arrowhead pointed to the left participants had to use the index finger of the left hand by pressing 4 (home key), then 1 (numeric key below the home key), and then again 4 (back to the home key). Response B was signalled by presentation of the symbol # or &, which required a binary-choice reaction to the shape of the symbol by pressing one of the home keys.

Figure 2 shows that after a 50-ms fixation cross, Stimulus A was presented with the fixation mark for 2 s. Following a 50-ms fixation cross, Stimulus B appeared with it for 200 ms. Stimulus B was to be responded to immediately by performing Response B, followed by the already-planned Response A.

There were eight conditions resulting from the orthogonal variation of three within-participant factors with two levels each: side of RA (left or right), side of RB (left or right), and direction of first movement of RA (back or forth). Participants worked through a practice block of 40 trials (8 conditions × 5 replications) and an experimental block of 256 trials (8 conditions × 32 replications). The possible mappings of RB (binary-choice reaction to the shape of the symbol # or &) were counterbalanced across participants.

We used a randomized cross-over design with counterbalancing of the order of sessions; that is, one third of the participants began with the S−S session, one third with the S−R session, and one third with the R−R session.

Results and discussion

Analytical procedures

To facilitate access to the rather complex data pattern we sort, present, and discuss the outcomes according to their theoretical implications. First, we present the data separately for each task, with particular emphasis on *priming effects* (main effects of the repetition or alternation of a single stimulus feature or the response) and *binding effects* (interactions between effects of repeating or alternating one stimulus feature and the effect of repeating or alternating another stimulus feature or the response). Second, we present the correlations between the individually computed sizes of priming and integration reaction time (RT) effects from all three tasks.[1] Table 6 summarizes most of the relevant findings: priming and binary binding RT effects (significant effects underlined) and their correlations (significant effects marked by asterisks).

Of the data from S–S and S–R sessions trials with missing or anticipatory responses (1.2% and 1.6%, respectively) were excluded from the analysis (R1 was always correct). We also excluded trials in which the memory-probe response was incorrect. From the remaining data, mean RTs and proportions of errors (PEs) for R2 (i.e., the response to S2) were further analysed. From S–S data, means and error rates were computed as a function of the three possible relationships between the two stimuli in each trial—that is, repetition versus alternation of stimulus shape, colour, or location (see Table 1 for means). Analyses of variance (ANOVAs) were performed by using a three-way design for repeated measures. From S–R data, means and error rates were computed as a function of the four possible relationships between the two responses (R1 and R2) and the two stimuli in each trial—that is, repetition versus alternation of response, stimulus shape, colour, or location (see Table 3 for means). ANOVAs were performed by using a four-way design for repeated measures.

Table 1. *S–S task: Mean reaction times*[a] *and percentages of errors for responses to Stimulus 2, as a function of the feature match between Stimulus 1 and Stimulus 2*

Repeated	RT_{R2}	PE_{R2}
Neither	560	3.00
C	572	3.10
L	598	3.19
S	610	3.58
CL	605	3.77
SL	616	3.97
SC	597	4.10
SLC	606	3.49

Note: S–S task = stimulus–stimulus task. RT_{R2} = reaction time for response to Stimulus 2. PE_{R2} = percentage of error for response to Stimulus 2. C = colour. L = location. S = shape.
[a] In ms.

In the data from the R–R session, RTs refer to error-free trials only. For Response B, the first to-be-emitted reaction, RT was measured from the onset of Stimulus B to the pressing of the home key. For Response A, the second reaction, interresponse times (IRT) were measured from the release of the key for Response B, hence the first release of the home key, to the second release of the home key. Error rates for Response A refer to all incorrect responses following a correct Response B. All measures were analysed with ANOVAs for repeated measures and the significance criterion was set to $p < .05$.

---

[1] *Priming effects* were calculated as the difference between the RT for repeating a particular feature and the RT for alternating this feature. That is, if feature X was repeated and alternated, the corresponding priming effect P_X would be $P_X = RT_{X/alt} - RT_{X/rep}$. Accordingly, a positive value means that the participant reacted faster to repetitions than to alternations, whereas a negative value means the opposite. *Binding effects* were calculated as the difference between the RTs for partial repetitions (feature X repeated and feature Y alternated, or vice versa) and the RTs for complete repetitions and "complete" alternations. That is, if features X and Y repeated and alternated, their binding effect BP_{XY} would be $BP_{XY} = (RT_{X/alt,Y/rep} + RT_{X/rep,Y/alt})/2 - (RT_{X/rep,Y/rep} + RT_{X/alt,Y/alt})/2$. Binding effects thus correspond to the two-way interaction term of the respective features; a value close to zero means that the repetition effects of the two given features do not interact; a value greater than zero indicates a "binding-type" interaction of the sort described in the text.

S–S task

Tables 1 and 2 provide an overview of the means and ANOVA outcomes for RTs and PEs obtained for R2. In the RTs analysis of R2 we found two main effects: one involving shape and the other location. For both stimulus features, repetition produces a cost. In the case of shape, this may be due to a strategic expectation bias towards stimulus (or response) alternation (Kornblum, 1973; Soetens, Boer, & Hueting, 1985). The benefit of location alternation reflects inhibition of return (IOR), the common observation that attending to an irrelevant stimulus impairs later responses to relevant stimuli appearing in the same location (Posner & Cohen, 1984).

We obtained two interactions between stimulus feature repetition effects: Shape, the most relevant stimulus feature, interacted with location and with colour. The pattern of these interactions is shown in Figure 3: Taking into account the location main effect, we can see that performance was better if both of the respective features repeated or if they both alternated than if one repeated while the other did not.

The PE analyses did not yield significant effects.

Discussion. We were able to replicate the main findings of Hommel (1998) and Hommel and Colzato (2004): The impact of repeating a stimulus feature depended on whether or not other stimulus features repeated as well. That is, if only one but not the other feature overlaps (partial match), reactivating the code of the matching feature may spread activation to the code that it has just been integrated with, thus impairing its integration with the actual feature. We take these results to indicate the integration of feature codes in visual perception. Note that these integration effects were accompanied by significant priming (i.e., main) effects for shape and location, which were both negative.

Table 2. *Results of analysis of variance on mean reaction time of correct responses and percentage of errors for S–S task*

		RT_{R2}		PE_{R2}	
Effect	*df*	*MSE*	*F*	*MSE*	*F*
C	1, 43	1,025.75	0.08	10.94	0.23
L	1, 43	1,582.66	25.65**	25.82	0.10
S	1, 43	1,994.33	24.25**	14.40	1.54
C × L	1, 43	1,070.86	0.03	14.98	0.11
S × L	1, 43	1,056.05	17.30**	11.17	0.41
S × C	1, 43	1,436.69	6.82*	12.18	0.20
S × L × C	1, 43	888.20	0.39	11.35	0.68

Note: S–S task = stimulus–stimulus task. RT$_{R2}$ = reaction time for response to Stimulus 2. PE$_{R2}$ = percentage of error for response to Stimulus 2. C = colour. L = location. S = shape. *$p < .05$; ** $p < .01$.

Table 3. *S–R task: Mean reaction times*[a] *and percentages of errors for responses to Stimulus 2, as a function of the match between Response 1 and Response 2 and the feature match between Stimulus 1 and Stimulus 2*

	Repeated		*Alternated*	
Response	RT_{R2}	PE_{R2}	RT_{R2}	PE_{R2}
Neither	591	9.75	519	1.42
C	582	7.95	520	2.46
L	590	6.62	557	2.65
S	578	6.63	578	3.69
CL	585	8.61	566	5.21
SL	560	2.74	599	8.61
SC	558	3.41	575	4.83
SLC	543	1.13	600	13.82

Note: S–R task = stimulus–response task. RT$_{R2}$ = reaction time for response to Stimulus 2. PE$_{R2}$ = percentage of error for response to Stimulus 2. C = colour. L = location. S = shape.
[a] In ms.

S–R task

Tables 3 and 4 provide an overview of the means and ANOVA outcomes for RTs and PEs obtained for R2. As in the S–S task we found a main (priming) effect for shape and location. There was also a main effect of the response. All three effects were due to better performance if the respective feature alternated than if it was repeated.

Shape and location produced a two-way interaction of the same sort as that in the S–S task, whereas the corresponding interaction of shape and colour missed the significance criterion, $p <$ .08. In addition, response repetition interacted

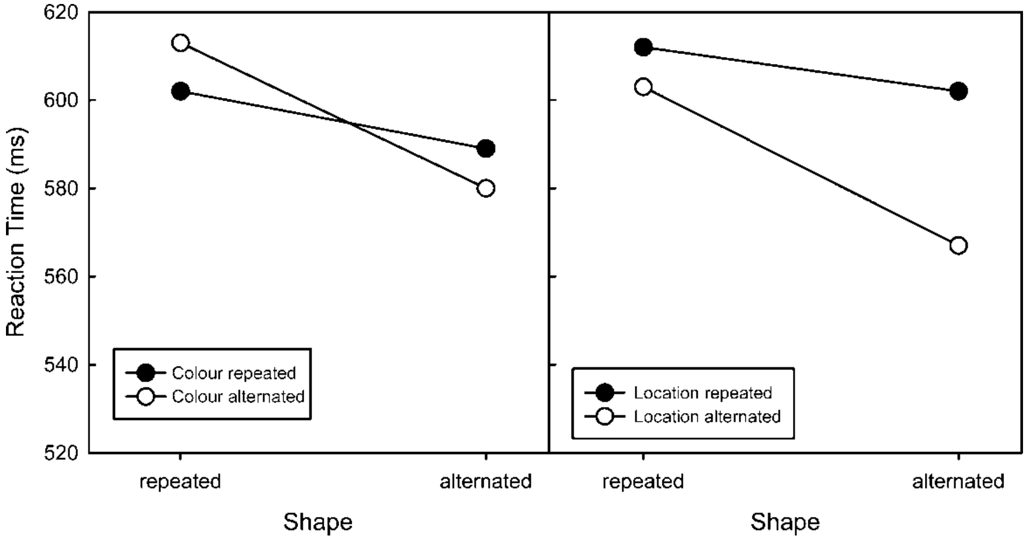


Figure 3. *Reaction times in the stimulus–stimulus (S–S) task, as a function of the repetition versus alternation of stimulus shape and stimulus colour (left panel) and of stimulus shape and stimulus location (right panel).*

Table 4. *Results of analysis of variance on mean reaction time of correct responses and percentage of errors for S–R task*

		RT_{R2}		PE_{R2}	
Effect	*df*	*MSE*	*F*	*MSE*	*F*
C	1, 43	1,330.08	3.69	14.10	5.49*
L	1, 43	1,950.56	14.49**	33.60	7.05*
S	1, 43	2,086.57	8.39**	28.71	0.04
R	1, 43	1,703.54	8.52**	44.86	1.06
C × L	1, 43	828.99	1.00	13.02	25.49**
S × L	1, 43	1,079.10	13.28**	27.22	3.95
S × C	1, 43	987.78	3.20	16.07	0.88
S × L × C	1, 43	1,049.06	0.13	21.84	0.02
C × R	1, 43	1,067.59	8.63**	33.78	17.30**
L × R	1, 43	1,017.26	69.80**	49.05	39.40**
S × R	1, 43	2,284.95	106.81**	93.17	43.18**
C × L × R	1, 43	1,451.77	0.04	20.74	0.01
S × L × R	1, 43	748.34	0.01	25.30	20.20**
S × C × R	1, 43	804.11	0.54	40.19	4.13*
S × L × C × R	1, 43	1,203.28	0.05	18.59	3.32

Note: S–R task = stimulus–response task. RT_{R2} = reaction time for response to Stimulus 2. PE_{R2} = percentage of error for response to Stimulus 2. C = colour. L = location. S = shape. R = response.
$^{*}p < .05$; $^{**}p < .01$.

with the repetition of all three stimulus features. Taking into account the significant negative priming effects, we can see in Figure 4 that performance was better if both response and respective stimulus feature repeated or alternated than if one repeated while the other did not.

The errors followed a similar pattern: Apart from main effects of location and colour, significant interactions were obtained between location and colour, and response repetition interacted with each of the three stimulus features. In addition, we found response being involved in two higher order interactions with shape and colour and with shape and location. Separate ANOVAs showed that colour and shape interacted significantly if the response repeated, $p < .018$, but not if it alternated, $p < .272$, whereas shape and location interacted if the response alternated, $p < .001$, but not if it was repeated, $p < .07$.

Discussion. Again, we replicated the main findings of Hommel (1998) and of Hommel and Colzato (2004): The impact of repeating a stimulus feature depended on whether or not other stimulus

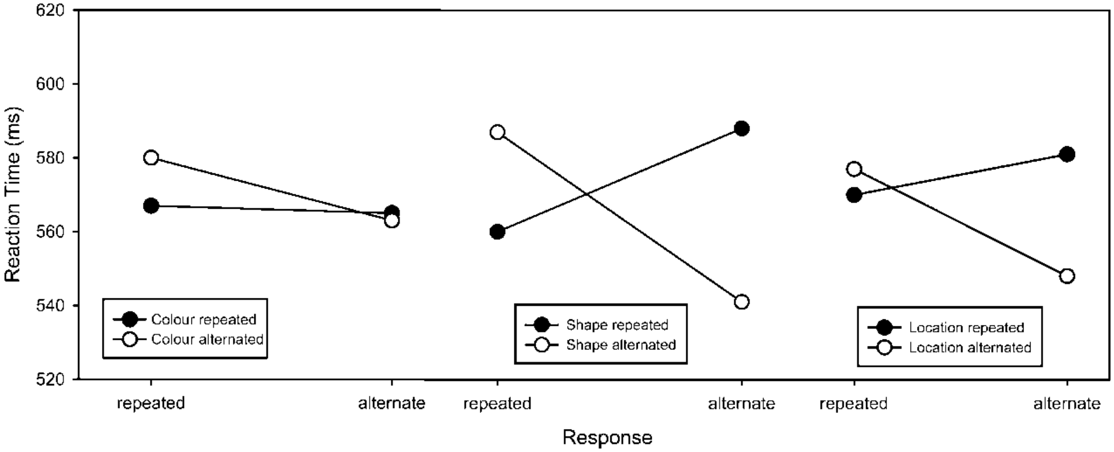


Figure 4. *Reaction times in the stimulus–response (S–R) task, as a function of the repetition versus alternation of response and stimulus colour (left panel), of response and stimulus shape (middle panel), and of response and stimulus location (right panel).*

features or the response repeated as well, suggesting that stimulus and response features were integrated. Interestingly, most integration-related effects were restricted to binary interactions, a common observation in integration studies. Again, the integration effects were accompanied by significant priming (i.e., main) effects for shape and location, as well as for the response, and again all priming effects were negative.

R–R task

Table 5 provides an overview of the RTs, IRTs, and PEs. The RT analysis for RB yielded a significant effect of overlap, $F(1, 43) = 16.50$, $p < .001$, indicating that the latency of RB was longer with RB–RA feature overlap than with no overlap (612 vs. 587 ms). Likewise, overlap yielded more errors than did nonoverlap (4.9% vs. 3.1%), $F(1, 43) = 15.45$, $p < .001$. The IRTs for RA were numerically faster for overlap than for nonoverlap (277 vs. 282 ms) but this effect did not reach significance.

Table 5. *R–R task: Mean reaction times*[a]*, interresponse times*[a]*, and percentage of errors as a function of feature overlap between Response A and Response B*

	Response B	*Response A*	
	RT	*IRT*	*PE*
Overlap	612	277	4.88
No overlap	587	282	3.09

Note: R–R task = response–response task. RT = reaction time. IRT = interresponse time. PE = percentage of errors.
[a]In ms.

Discussion. According to Stoet and Hommel (1999, 2002), integrated action-feature codes should be less available for other planning activities as long as the current plan is not executed or abandoned. The results indeed confirm that feature overlap between a planned and a to-be-performed action negatively affects the latter, whereas a previous, already executed, action plan primes a following, feature-overlapping action (although this latter effect was unreliable here). We take these results to indicate the integration of feature codes in action planning.

Correlations

Having replicated all theoretically relevant effects in the three tasks, we computed Pearson correlation coefficients to indicate the relationships between the individually calculated priming-effect and binding-effect sizes, see Table 6. Considering that the numbers of variables and correlations are high relative to the number of

Table 6. *Correlations among the priming and integration effects for the three tasks*

				S–S task						*S–R task*										*R–R task*
				Priming			*Integration*			*Priming*				*Integration*						*Priming*
Task	*Effect category*		*Split-half reliability*	*C*	*L*	*S*	*C × L*	*S × L*	*S × C*	*C*	*L*	*S*	*R*	*C × L*	*S × L*	*S × C*	*C × R*	*L × R*	*S × R*	R_A
S–S	Priming	C	.26																	
		L	.47**	.10																
		S	.58**	.06	.32*															
	Integration	C × L	.08	−.23	−.28	.20														
		S × L	.34*	.05	.13	.42**	−.02													
		S × C	.32*	.26	.14	.44**	−.04	.32*												
S–R	Priming	C	.09	.15	−.10	−.08	−.00	.14	.18											
		L	.45**	.20	.42**	−.01	−.23	−.05	−.15	−.08										
		S	.48**	.22	.20	.45**	.08	.44**	.20	.25	.17									
		R	.17	−.08	.23	.04	.07	−.12	−.01	−.09	.23	.16								
	Integration	C × L	.30	.11	.13	−.02	−.01	−.01	−.12	.08	.30*	.20	.12							
		S × L	.35*	−.02	.22	.16	−.13	.08	.16	−.12	.53**	.13	.31*	.42**						
		S × C	.36*	−.14	−.19	−.13	−.07	−.17	−.02	.19	−.20	−.03	.23	.31*	.09					
		C × R	.14	.40**	−.23	−.17	−.08	.02	.05	.23	.06	.09	−.01	−.05	−.17	.02				
		L × R	.45**	.06	−.13	.06	.09	.13	.27	.16	.04	.06	−.15	.06	−.24	−.10	.09			
		S × R	.44**	.04	−.02	.21	.08	.03	−.13	.04	−.25	.13	−.16	.10	−.19	−.20	.15	.21		
R–R	Priming	R_A	.53**	.04	−.14	.09	.01	.27	−.06	.06	.11	−.04	.10	−.12	.04	−.02	.06	.15	−.21	
	Integration	R_B	.42**	−.13	.03	.15	−.03	−.03	−.01	−.30	.03	.17	.10	−.05	.10	−.12	−.10	.13	.05	.22

Note: Reliable main effects and two-way interactions are underlined. S–S = stimulus–stimulus. S–R = stimulus–response. R–R = response–response. C = colour. L = location. S = shape. R = response.

*$p < .05$; **$p < .01$.

participants, we provide two types of information that allow the reader to estimate the reliability of our measures and the related correlations. First, we flag the passed significance criterion, thereby distinguishing between the alpha levels of $p < .05$, and $p < .01$, with the latter yielding only one or two significant correlations by chance. Second, we report the split-half reliability for all correlated measures, computed by correlating the measures derived from odd trials (i.e., Trials 1, 3, 5, . . .) with the measures derived from even trials (Trials 2, 4, 6, . . .), see Table 6.

Reliability of priming and binding effects. Most measures were reliable with only two types of exception: First, the response-repetition main effect was not reliable, even though the response variable was involved in reliable interaction effects. Given that the response main effect did not yield any reliable correlation with another measure, the interpretation of the results will be unaffected by this unreliability. Second, almost all measures involving colour, the variable with the least direct task relevance, were unreliable. The only exceptions are the shape–colour binding effects in the S–S task and S–R task.

Priming × Priming effects. These correlations follow a consistent pattern that shows three characteristics. First, colour and response repetition measures are unreliable, and their (insignificant) effects do not correlate with any other repetition effect, not even with corresponding effects in other tasks. Second, shape and location repetition effects correlate across experiments with their equivalents—that is, the relative sizes of shape repetition and location repetition effects in the S–S task correspond to those in the S–R task.

Binding × Binding effects. There were only three reliable correlations, and all three relate within-task bindings to each other. In the S–S task, the two significant binding effects (shape–location and shape–colour) are correlated. In the S–R task, colour–location binding is correlated with the other two stimulus binding effects; however, these two correlations must be treated with caution because the colour–location measure was unreliable, and its effect did not reach significance.

We checked why the correlation obtained for the S–S task (shape–location and shape–colour) did not replicate. Previous findings have shown that, in tasks where colour is irrelevant for the S2–R2 decision, the integration of shape and colour is weak and often disappears with practice (Colzato, Raffone, & Hommel, in press). Given that the S–R task was much longer, and thus allowed for much more practice than the S–S task, it may be that the correlation in the S–R was present in the early trials but disappeared over time. Indeed, when we computed the correlations between shape–location binding and shape–colour binding separately for the first and the second half of the S–R task, we found the correlation to be high in the first half, $r^2 = .39, p < .01$, but absent in the second half, $r^2 = .06, p > .05$.

Notably, binding effects in the S–S task did not correlate with binding effects in the S–R task, and not a single stimulus binding effect correlated with any of the stimulus–response binding effects.

Priming × Binding effects. These effects fall into four clusters: First, the shape repetition effect was correlated with both bindings involving shape in the S–S task but not in the S–R task. Second, the location repetition effect was correlated with location–shape binding in the S–R task but not in the S–S task. Third, the shape–location binding in the S–S task correlated with the shape repetition effect in the S–R task.

Finally, the colour repetition effect in the S–S task correlated with the colour–response binding in the S–R task—note that the correlation between the latter and the colour repetition effect in the S–R task was also relatively high (.23) but that all of these colour-related correlations were associated with unreliable measures and unreliable statistical effects.

GENERAL DISCUSSION

Our study sought for correlations between measures of feature-priming and feature-binding effects within and across three different but related tasks. In particular, we looked for two types of correlation: those between the sizes of different measures of bindings—which might point to a common integration mechanism—and those between priming effects on the one hand and binding effects on the other—which might reflect that the degree to which a feature that is contextually primed predicts the likelihood that it is integrated. Considering the correlative nature of our study, the large correlation matrix, and the limited number of participants, we emphasize that our conclusions are necessarily tentative, but we think that we can draw some preliminary conclusions.

How many mechanisms?

With regard to correlations between different binding measures the outcome is clear-cut: There is converging evidence that the processes responsible for binding different features of a given stimulus within a task are related. Binding effects of the S–S task do not, however, correlate with binding effects of the S–R task. It therefore seems that, to some degree, feature binding is not general but task specific. The only difference between the S–S and S–R tasks is the simple reaction (R1) that has to be carried out in the latter task. How might that produce task-specific feature binding?

First, the need to carry out a response to S1 can be assumed to increase task difficulty. However, recent manipulations of task difficulty by adding or not adding a memory task (Hommel & Colzato, 2004) or by introducing additional response-selection requirements (Hommel, 2005) do not suggest that feature integration might suffer from task difficulty–which, for instance, rules out the idea that a more difficult task may occupy attentional capacity needed to bind features.

Second, the presence of a response to a stimulus induces various bindings between stimulus and response features, which then provide a kind of cognitive context in which stimulus processing takes place. In other words, even though the *creation* of stimulus–response bindings may proceed independently from the creation of stimulus–stimulus bindings (as suggested by our data pattern), the fact that the stimulus feature with which another stimulus feature becomes bound is also associated with a response may change the *quality* of the stimulus–stimulus binding. This idea fits well with the suppositions of Cohen and Servan-Schreiber (1992) about the close relationship between selective attention and the internal representation of context and about the influence of context on the selection of the appropriate response.

Third, it is reasonable to assume that the presence or absence of R1 affected the attentional set of the participants. In the S–S task, participants do not have anything to do before the appearance of S2, which suggests that the attentional set is optimized to process the relevant feature of S2—shape. To the degree that this set is optimized and maintained—a factor with respect to which people are known to differ (Duncan, Emslie, Williams, Johnson, & Freer, 1996; Miyake et al., 2000)—processing stimulus shape will be facilitated and, thus, produce a stronger (positive) priming effect. The stronger the priming the more activated the respective shape code must be, which increases the likelihood to become integrated with other sufficiently activated feature codes. In contrast, in the S–R task people are not able to prepare for S2 processing before having detected S1 and having carried out the prepared R1. Accordingly, their attentional set should be related to the dimension that is relevant for this part of the task, which given the use of spatial responses must be location (see Hommel, 1996, for evidence that prepared responses are under spatial control until executed). If so, it will be (more) the processing of location but not (or less) of shape of S1 that is facilitated, and the integration of location- but not shape-related bindings that is supported. Even though the obvious presence of top-down expectation effects makes the pure estimation of priming effects difficult, this scenario is consistent with the relationship between priming and integration effects discussed below. For present purposes the central point is that the S–S task and the S–R task are likely to differ with respect to the attentional set under which S1 was processed, which introduces another source of interindividual variability, variability that works against the correlations of integration effects across tasks. Within tasks, the (hypothesized) attentional set has a systematic, organizing effect: Whereas only the two shape-related binding effects correlate in the S–S task (i.e., under a strong shape set), the S–R task (i.e., a strong location set) shows the strongest correlation between the two location-related binding effects.

In contrast to these within-object correlations there was no evidence of any correlation crossing borders between perception and action. Given the equivocal status of null effects this lack of evidence should not be taken as a strong proof that such cross-border relations do not exist. And yet, the absence of such effects in the presence of strong within-object correlations is consistent with the hypothesis that within-object bindings are created by a different mechanism from that for bindings between stimulus and response features.

Converging support for this hypothesis comes from the already-mentioned drug studies of Colzato and colleagues (2004, 2005), which employed a version of the present S–R task. Starting from the assumption that feature binding is mediated by neural synchronization, which in the visual cortex seems to be driven by the muscarinic-cholinergic system (Munk, 2003; Rodriguez et al., 2000, 2001, 2004), Colzato et al. found that within-object bindings were significantly decreased by alcohol, a muscarinic-cholinergic antagonist, significantly increased by caffeine, a muscarinic-cholinergic agonist, and unaffected by nicotine, which only affects the nicotinic-cholinergic system. Most interestingly, none of these manipulations had any impact on bindings of stimulus and response features. Thus, if we assume that visual–visual binding is mediated by cholinergically driven neural synchronization in the gamma frequency band (Engel & Singer, 2001; Keil et al., 1999), stimulus–response bindings seem to be created in a different fashion—either in terms of the driving system or in terms of the synchronization frequency used. Indeed, there are a number of indications that longer range bindings are associated more with the beta frequency band (Gross et al., 2004; Kopell et al., 2000; Roelfsema et al., 1997).

Priming and integration

Our second question was whether the degree to which a feature is contextually primed predicts the likelihood that it is integrated. If so, we would expect reliable correlations between priming effects and integration effects. The first thing to note is that all reliable correlations between priming and integration effects were positive whereas all the reliable priming effects we obtained were negative (alternation was faster than repetition). The observation of negative priming effects that we found as such is not uncommon, especially with interresponse times as long as the 2 seconds used in the S–S and S–R tasks (Kornblum, 1973; Soetens et al., 1985). They are likely to reflect the gambler's fallacy—the expectation that events are more likely to alternate than to repeat.[2,3]

The finding of a positive correlation with integration effects (e.g., the shape–location and shape–colour interactions in the S–S task), means that integration was more pronounced the

---

[2] In view of the outcome pattern, one may also consider that negative priming (for overviews, see Fox, 1995; May, Kane, & Hasher, 1995; Tipper, 2001) may have played a role here. However, given that S1 was not to be "selected against" any other stimulus, and no particular feature of S1 was to be "selected" anyway, it is difficult to see why any S1 feature should have been inhibited so to produce a repetition cost.

[3] At this point the reader may wonder why nonsignificant experimental effects in ANOVAs can contribute to significant correlations with other variables. Note that with an ANOVA, mean values of conditions are compared given a certain amount of variance around the means. By calculating a correlation two mean values are removed from the analysis, and the degree of similarity of the two variances is determined. Thus, the effects are not necessarily related.

smaller the bias towards alternation. Positive repetition effects—which reflect the speed-up of processing by left-over traces that we assume to support integration—and negative repetition effects have been argued to indicate antagonistic processes (Soetens et al., 1985). If we assume that positive and negative effects combine in an additive fashion and that negative effects (i.e., expectations) were more or less constant across tasks and conditions, we can infer that less negative net effects reflect more positive priming than do more negative net effects. Accordingly, our findings show that individual variability in the more automatic, positive component of the repetition effect is a rather reliable predictor of at least some integration effects. This outcome fits nicely with our hypothesis that the degree to which a feature is contextually primed predicts the likelihood that it is integrated.

An interesting observation is the double dissociation of the impact of shape and location priming on integration: The shape repetition effect predicted (statistically) shape-related bindings in the S−S task only, whereas the location repetition effect predicted location-related bindings in the S−R task only. This is exactly what one would expect from the attentional set scenario developed above—that is, if S1 was processed under a shape-related attentional set in the S−S task but under a location-related attentional set in the S−R task.

It is an interesting question why other stimulus−response bindings were not as well predicted by the respective stimulus-priming effects—that is, shape−response binding by shape repetition or location−response binding by location repetition. Lack of variability cannot account for this difference, as repetition effect sizes varied considerably for both stimulus shape (ranges from −91 to +102 ms and from −74 to +40 in the S−S and the S−R task, respectively) and location (from −82 to +68 ms and from −81 to +37 ms). However, apart from the unclear role of counteracting expectations it might be that the task requirements put so much more emphasis on shape (relevant S2 dimension) and location (relevant response dimension) that these dimensions were primed to a degree that individual variability no longer mattered. That is, shape and location codes might have been sufficiently activated for integration even in "weak primers". Clearly, this issue needs to be investigated more closely.

Theoretical implications

In sum, the present study provides tentative but converging evidence that feature integration is a general phenomenon, which, however, is accomplished by domain-specific mechanisms. In particular, binding effects within the same domain—visual feature integration in our case—tend to correlate with each other, suggesting that people differ in the degree to which they bind visual features and/or with respect to the "stickiness" that these bindings exhibit over time. To some degree, the strength of a binding can be predicted based on the degree to which the respective features are activated—as indicated by priming effects. The most reliable predictors in this respect seem to be features varying on a dimension that matches the currently implemented attentional set.

Figure 5 summarizes the major conclusions in form of a highly idealized and simplified cartoon model. There are three stimulus dimensions coding for the two shapes, two locations, and two colours varied in the S−S and S−R tasks of this study, and a response dimension coding for the left and right response.[4] A given stimulus is coded on all three dimensions by activating the respective feature code. However, the increase in activation depends on the degree of top-down

---

[4] Especially the response representation is drastically simplified. Responses are represented in terms of the features of their sensory effects (Hommel, 1997, 2003), so that each response is actually represented by a network of feature codes referring to the response's location, effector, direction, speed, and so on. However, as the two response alternatives employed in the S−S and S−R tasks of the present study differed on a single dimension only (relative location, confounded with effector), this simplification does not affect our main argument.

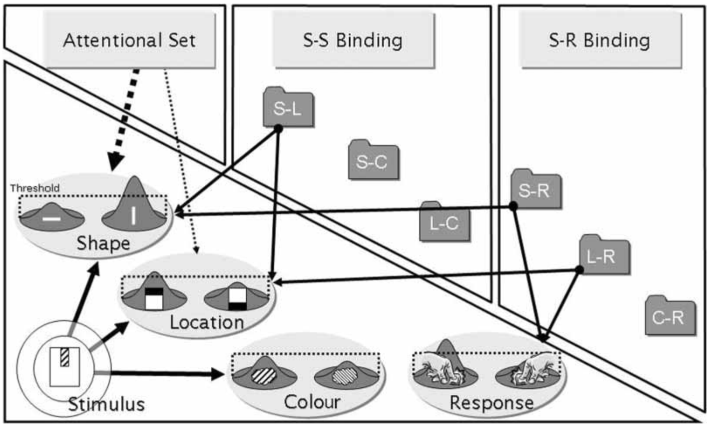


Figure 5. *Cartoon model of the interaction between attentional set and feature integration. In the example, the stimulus is coded in terms of shape, location, and colour, and is accompanied by a left response. The attentional set provides strong support for shape processing and a little support for location processing, thereby excluding colour information from the integration process.*

dimensional priming (Hommel et al., 2001a). Dimensions that are task relevant receive top-down support from the current attentional set (Hommel, 2004), so that stimuli coded on that dimension are more likely to exceed the current coding threshold (see dotted horizontal lines) and, thus, have a stronger impact on response selection (Bundesen, 1990). In the example, it is assumed that the attentional set strongly supports shape coding (as we assumed for S1 processing in the S–S task) and, due to the task relevance of response location, provides some support for location coding. As a consequence, shape and location codes pass the threshold and are integrated. There are several ways of how integration may be accomplished (see Hommel, 2004); here we assume that the codes are synchronized, which again allows for the creation of pointers to the respective feature codes (i.e., event files).

As said before, this is an idealized picture, which can only be an approximation of individual binding performance. For one, it is likely that people vary, both intra- and interindividually, in the degree of support of shape and location coding. There are reasons to assume that the distribution of attention to the different dimensions varies with increasing experience. For instance, unpractised participants tend to distribute attention more evenly between task-relevant and task-irrelevant stimulus features than do more practised participants, who focus more on relevant information (Colzato et al., in press). It is also likely that people differ with respect to the stimulus dimensions and modalities that they prefer to attend—a characteristic that neurolinguistic-programming (NLP) therapists attempt to exploit (Allen, 1982; Beale, 1980; Cody, 1983). Finally, some stimulus features may be more salient in a particular context than others, which may also affect the amount of activation that they produce. However, to the degree that the task requirements suggest one particular attentional set, as in the present S–S and S–R tasks, stimulus features matching that attentional set do seem to have a higher probability of being coded and integrated.

Consistent with previous findings, the present study found numerous hints to binary feature bindings but no evidence of higher order integration—which is why Figure 5 contains binary files only. On the one hand, this means that integration does not consist of a single process that lumps together all the available information but, rather, of numerous local processes that presumably run off in parallel. On the other hand, we pointed out that some of these local processes seem to be equally affected by experimental factors, such as cholinergic drugs (which affect S–S binding processes). This suggests that the local integration processes within particular brain areas operate independently but are nevertheless driven by the same neurotransmitter system. Recent observations from neuroscientific studies are consistent with this account. If we assume that feature binding in the visual cortex is associated with neural synchronization in the gamma frequency band (Engel & Singer, 2001; Keil et al., 1999) and consider that gamma activity in the visual cortex is driven by the muscarinic-cholinergic system (Rodriguez et al., 2004), it makes sense to believe that visual feature integration relies on cholinergic support. However, what is supported does not seem to be a single operation but, rather, numerous local gamma oscillations spread throughout the whole visual cortex (Lachaux et al., 2000). Clearly, more research is needed to find out which processing characteristics (neuromodulators, preferred synchronization frequency, etc.) apply to S–R and R–R integration and how these characteristics affect binding performance and behaviour. But what the present findings show already is that integration is much less of a unitary act than originally believed.

Original manuscript received 9 December 2004
Accepted revision received 4 October 2005

REFERENCES

Allen, K. L. (1982). An investigation of the effectiveness of neurolinguistic programming procedures in treating snake phobics (Doctoral dissertation, University of Missouri at Kansas City, 1982). *Dissertation Abstracts International, 43*(3), 861-B. (UMI No. AAC8216956)

Beale, R. P. (1980). The testing of a model for the representation of consciousness (Doctoral dissertation, The Fielding Institute, 1980). *Dissertation Abstracts International, 41*(9), 3565-B. (UMI No. 8106799)

Bundesen, C. (1990). A theory of visual attention. *Psychological Review, 97*, 523–547.

Cody, S. G. (1983). The stability and impact of the primary representational system in neurolinguistic programming: A critical examination (Doctoral dissertation, University of Connecticut, 1983). *Dissertation Abstracts International, 44*(4), 1232-B. (UMI No. AAC8319187)

Cohen, J. D., & Servan-Schreiber, D. (1992). Context, cortex and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review*, *99*, 45–77.

Colzato, L. S., Erasmus, V., & Hommel, B. (2004). Moderate alcohol consumption impairs feature binding in visual perception but not across perception and action. *Neuroscience Letters*, *360*, 103–105.

Colzato, L. S., Fagioli, S., Erasmus, V., & Hommel B. (2005). Caffeine, but not nicotine enhances visual feature binding. *European Journal of Neuroscience, 21*, 591–595.

Colzato, L. S., Raffone, A., & Hommel, B. (in press). What do we learn from binding features? Evidence for multilevel feature integration. *Journal of Experimental Psychology: Human Perception and Performance.*

Cowey, A. (1985). Aspects of cortical organization related to selective attention and selective impairments of visual perception: A tutorial review. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 41–62). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Duncan, J., Emslie, H., Williams, P., Johnson, R., & Freer, C. (1996). Intelligence and the frontal lobe: The organization of goal-directed behavior. *Cognitive Psychology, 30*, 257–303.

Engel, A. K., & Singer, W. (2001). Temporal binding and the neural correlates of sensory awareness. *Trends in Cognitive Science, 5*, 16–25.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review*, *2*, 145–173.

Gordon, R. D., & Irwin, D. E. (1996). What's in an object file? Evidence from priming studies. *Perception & Psychophysics*, *58*, 1260–1277.

Gross, J., Schmitz, F., Schnitzler, I., Kessler, K., Shapiro, K., Hommel, B., et al. (2004). Long-range neural synchrony predicts temporal limitations of visual attention in humans. *Proceedings of the National Academy of Sciences USA*, *101*, 13050–13055.

Henderson, J. M. (1994). Two representational systems in dynamic visual identification. *Journal of Experimental Psychology: General*, *123*, 410–426.

Henderson, J. M., & Anes, M. D. (1994). Roles of object-file review and type priming in visual identification within and across eye-fixations. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 826–839.

Hommel, B. (1996). S–R compatibility effects without response uncertainty. *Quarterly Journal of Experimental Psychology, 49A*, 546–571.

Hommel, B. (1997). Toward an action-concept model of stimulus-response compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus-response compatibility* (pp. 281–320). Amsterdam: North-Holland.

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus response episodes. *Visual Cognition, 5*, 183–216.

Hommel, B. (2002). Responding to object files: Automatic integration of spatial information revealed by stimulus–response compatibility effects. *Quarterly Journal of Experimental Psychology, 55A*, 567–580.

Hommel, B. (2003). *Feature integration across perception and action: Event files affect response choice*. Manuscript submitted for publication.

Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in Cognitive Sciences, 8*, 494–500.

Hommel, B., Alonso, D., & Fuentes, L. J. (2003). Acquisition and generalization of action effects. *Visual Cognition, 10*, 965–986.

Hommel, B., & Colzato, L. S. (2004). Visual attention and the temporal dynamics of feature integration. *Visual Cognition, 11*, 483–521.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001a). Codes and their vicissitudes. *Behavioral and Brain Sciences, 24*, 910–937.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001b). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849–878.

Hommel, B., Proctor, R. W., & Vu, K.-P. L. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research, 68*, 1–17.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24*, 175–219.

Keil, A., Müller, M. M., Ray, W. J., Gruber, T., & Elbert, T. (1999). Human gamma band activity and perception of a Gestalt. *Journal of Neuroscience, 19*, 7152–7161.

Kopell, N., Ermentrout, G. B., Whittington, M. A., & Traub, R. D. (2000). Gamma rhythms and beta rhythms have different synchronization properties. *Proceedings of the National Academy of Sciences USA, 97*, 1867–1872.

Kornblum, S. (1973). Sequential effects in choice RT: A tutorial review. In S. Kornblum (Ed.), *Attention & performance IV* (pp. 259–288). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Lachaux, J.-P., Rodriguez, E., Martinerie, J., Adam, C., Hasboun, D., & Varela, F. J. (2000). A quantitative study of gamma-band activity in human intracranial recordings triggered by visual stimuli. *European Journal of Neuroscience, 12*, 2608–2622.

Leslie, A. M., & Kaldy, Z. (2001). Indexing objects in infant working memory. *Journal of Experimental Child Psychology, 78*, 61–74.

Leslie, A. M., Xu, F., Tremoulet, P. D., & Scholl, B. J. (1998). Indexing and the object concept: Developing "what" and "where" systems. *Trends in Cognitive Sciences, 2*, 10–18.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95*, 492–527.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118*, 35–54.

McDevitt, J., & Fournier, L. (2001). Withholding a planned action delays execution of partially compatible actions. *Abstracts of the Psychonomic Society*, *6*, 16.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Munk, M. H. J. (2003). The principle of controlling neuronal dynamics in neocortex: Rapid reorganization and consolidation of neuronal assemblies. In R. H. Kluwe, G. Lüer, & F. Rösler (Eds.), *Principles of learning and memory* (pp. 187–205). Basel: Birkhäuser Verlag.

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

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X* (pp. 531–556). Hove, UK: Lawrence Erlbaum Associates Ltd.

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

Rodriguez, R., Kallenbach, U., Singer, W., & Munk, M. H. (2000). Effects of cholinergic stimulation on gamma oscillations during visual responses in cat visual cortex. *European Journal of Neuroscience Supplement, 12*, 221.15.

Rodriguez, R., Kallenbach, U., Singer, W., & Munk, M. H. (2001). Reduction of gamma-oscillatory responses after scopolamine application in cat visual cortex. *Abstract Society of Neuroscience, 27*, 123.3.

Rodriguez, R., Kallenbach, U., Singer, W., & Munk, M. H. (2004). Short- and long-term effects of cholinergic modulation on gamma oscillations and response synchronization in the visual cortex. *Journal of Neuroscience, 24*(46), 10369–10379.

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.

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

Soetens, E., Boer, L. C., & Hueting, J. E. (1985). Expectancy or automatic facilitation? Separating sequential effects in two-choice reaction time. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 598–616.

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

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

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology, 54A*, 321–343.

Treisman, A. (1996). The binding problem. *Current Opinion in Neurobiology, 6*, 171–178.

Waszak, F., Hommel, B., & Allport, A. (2003). Task-switching and long-term priming: Role of episodic stimulus-task bindings in task-shift costs. *Cognitive Psychology, 46*, 361–413.

Wickens, J., Hyland, B., & Anson, G. (1994). Cortical cell assemblies: A possible mechanism for motor programs. *Journal of Motor Behavior, 26*, 66–82.