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Event Files: Evidence for Automatic Integration of Stimulus–Response Episodes

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One of the main functions that visual attention serves in perception and action is feature binding; that is, integrating all information that belongs to an object. The outcome of this integration has been called "object file", a hypothetical memory structure coding episodic combinations of stimulus features. Action-oriented approaches to attention, however, suggest that such a purely perceptual or perceptually derived structure may be incomplete: If attention subserves action control, object files may include action-related information as well. That is, feature binding may not be restricted to stimulus features but also include features of the responses made to the respective stimulus. In three experiments, subjects performed simple, already prepared left- or right-key responses (R1) to the mere presence of "Go" signals (S1) that varied randomly in form, colour and location. Shortly after the prepared response, a binary choice reaction (R2) to the form or colour of a second stimulus (S2) was made. The results show that benefits due to stimulus-feature repetitions (S1–S2) interact: Form repetition only facilitates performance if colour is also repeated, and repeating the relevant stimulus feature (form or colour) only facilitates performance if stimulus location is repeated. This can be taken as evidence for object-file formation. But there was also evidence for bindings between stimulus and response features: Repetition benefits associated with both the relevant stimulus feature and stimulus location depended on response repetition. This suggests that object files represent only one component of more complex "event files" that link information about stimulus and response aspects of an experienced episode.

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INTRODUCTION

When we look around, we see objects and events, made up of particular combinations of particular features, located in particular positions in space. How does the cognitive system deal with the information delivered by vision and the other senses? As we now know, visual information is registered in various features maps distributed throughout the visual cortex (e.g. Cowey, 1985; DeYoe & Van Essen, 1988), not speaking of the information propagated directly to the colliculus superior, to the frontal eye fields, and so forth. How do the systems involved in perception "know" which feature belongs to which object? According to which rules and principles are codes of these features related to each other?

There are several answers to this question and most have a great deal to do with location. As a first approximation, Treisman (1988; Treisman & Gelade, 1980) suggested that visuospatial attention serves to integrate the information belonging to one object. Visual attention is assumed to work like a spotlight with an adjustable size that can be directed to certain locations on, and moved across, a so-called "master map of locations". This location map, which, according to Treisman (1993), might be fed by the dorsal "where" path suggested by Ungerleider and Mishkin (1982), is connected to all (or at least many of) the other, also spatially organised, representational maps, which code simple features, such as form, colour and orientation, and thus could represent a stage in Ungerleider and Mishkin's ventral "what" path. Focusing attention onto a master-map location results in the integration of all features registered in the corresponding locations of the connected representational maps. Based on the assumption that corresponding map locations represent features from the same location in the visual world, and given that features belonging to the same object usually occupy the same environmental location, such an integration mechanism could well serve to integrate object-specific information. If all we needed to know about our visual environment was whether or not registered features belong to a common object, this integration-by-attending-to-location mechanism would be all that we needed.

But what do we need to know about features and objects? Many of the possible answers to this question have to do with orientation and anticipation: If we know that two or more features belong to the same object, we can discriminate between several objects sharing certain features; or expect the presence of one feature of an object when seeing another; or anticipate what will happen to one by observing another; or experience object constancy despite changes over time in some of the features. Yet, none of these functions could be served by a merely temporary integration through attending: As soon as the attentional spotlight moves to the next location, all the work would be lost again. Thus, what we also need is some kind of memory that preserves the outcome of feature integration over time.

Object Files

Kahneman and Treisman (1984; Kahneman, Treisman, & Gibbs, 1992; Treisman, 1993) have suggested a mechanism that may serve the function of preserving the products of feature-integration processes. Building upon Treisman's feature-integration theory, they assume that the result of the integration process, possibly enriched by long-term knowledge, is temporarily stored in what they call an “object file”. Object files thus contain (or represent), among other things, knowledge about feature conjunctions that specify the corresponding object, together with information about the current object location. Once formed, object files do not allow for cross-referencing of object-specific features, but keep track of objects in spite of changes in their location or in some of their features over time: If the changes are small enough or only refer to relative location, new visual events (i.e. changes in features or feature values in a particular location) do not require the formation of a new file, just an update of the old file. While forming a new file may correspond to the experience of a novel object, file updating could correspond to the experience of object reappearance, hence underlying perceived object constancy and continuity.

There are at least two types of experimental evidence to support the object-file approach—the effect of “negative priming” and the “reviewing effect”. Negative priming was first reported by Allport, Tipper and Chmiel (1985; for reviews, see Fox, 1995; May, Kane, & Hasher, 1995). Allport et al. had their subjects work through lists or sequences of superimposed pairs of letters or pictures. One member of each pair was the to-be-named target, printed in a particular target colour (e.g. red), while the other member served as a distractor printed in a different colour (e.g. green). Importantly, the trials on which the current target matched the preceding distractor were associated with slower reaction times (RTs) than trials without such a match. One interpretation offered by Allport et al. (1985) and recently revived by Park and Kanwisher (1994) comes close to the object-file concept. It holds that, in a given trial, the features of target and distractor are integrated (i.e. linked cross-domains) automatically and separately. If, in the next trial, the available features combine in the same fashion, integration is easier or faster for these than for new combinations, which require the formation of new cross-domain links. Obviously, this is the same idea underlying the object-file concept, only that integration here is assumed to precede rather than to follow attentional orienting (Allport et al., 1985).

Further evidence for the existence of object files has been reported by Kahneman et al. (1992). They presented their subjects with a sequence of two displays, a multi-letter preview or prime display, which did not require any response, and a single-letter probe display, which required naming the letter. In some trials, the letter that eventually appeared in the probe display was already part of the prime display. If this was the case, the responses were sometimes, but not always, faster than when the probe letter did not match any one of the prime letters. However, this preview effect was also much larger when the matching prime letter appeared in the same (relative or absolute) location as the probe letter. The authors interpreted this finding as evidence that prime-letter identities and locations were integrated into letter-specific object files. If the particular identity-location conjunction of the probe letter matched one of the object files formed during the preview, integration was faster or even superfluous. This produced an “object-specific preview benefit”, which Kahneman et al. contrast with the much weaker “non-specific preview benefit” that occurred if prime and probe matched as to identity, but not location. Object-specific preview benefits have also been reported by Henderson (1994; Henderson & Anes, 1994), although in this studies considerable non-specific benefits were also found.

Non-specific and specific preview effects have different theoretical implications. Non-specific effects are usually attributed to the priming of “type” representations; that is, stored descriptions of object features in (semantic?) long-term memory. Only one code or representation is assumed to exist for every feature in the world, so that, if a feature is shared by more than one object in the field, the activation of a code does not unambiguously identify its source. Object-specific effects, in contrast, as observed in negative-priming and preview tasks, imply that encountering a visual event does not only result in the priming of object types, but also in separate episodic bindings of the features belonging to the objects perceived (i.e. object files). If the same object appears again and, thus, the particular feature conjunction is repeated, the corresponding object file is retrieved, or revived, and updated. If, in contrast, a novel object appears, the object-specific features are integrated and information about their conjunction is stored in a newly created object file. Importantly for the present study, the latter case should be associated with slower processing times than the former.

Event Files

A number of studies have demonstrated binding effects (i.e. effects of feature-conjunction repetitions versus non-repetitions) in a variety of tasks with different kinds of stimuli and responses. For instance, evidence for the binding of visual stimulus features has been reported for form and colour (Allport et al., 1985), form and location (Kahneman et al., 1992) and colour and location (Tipper, Weaver, & Houghton, 1994), independent of whether or not the prime stimulus or stimuli must be “selected-against” alternative stimuli (Park & Kanwisher, 1994). However, until now, binding effects have only been sought between (visual) stimulus features, not between stimulus and response features.

Considering that the object-file concept was originally invoked to account for the integration of distributed sensory information, this is hardly surprising; yet, there are some indications that object files are not purely perceptual or object-related structures, but include action-related information as well.

First, Treisman (1992) reported experiments in which subjects learned to perform certain tasks with, or mental operations on, a number of nonsense patterns. Although performance improved with practice, there was little transfer to other tasks using the same patterns. As Treisman argued, this may indicate that repeated experience with new objects—and, thus, repeated formation of object files for these objects—leads to the integration of task- or response-related information, so that the files or traces of the overlearned patterns can no longer be used if the responses change.

Second, Danzinger and Robertson (1994) conducted a series of negative-priming experiments using a variant of Allport and co-workers' (1985) dual-letter design. Subjects were presented with pairs of letters—one of two possible target letters together with one of two possible distractors—and were asked to respond manually to the identity of the target. Performance was better if the colour or the location of the target (both irrelevant stimulus features) was repeated rather than alternated, but this repetition benefit was mainly restricted to cases where target identity was also repeated—hence, there was evidence for the integration of stimulus features, as expected from an object-file perspective. In a further experiment, two target letters were assigned to each response key, so that the effects of identity repetition and of response repetition could be separated. Although the relevant statistical tests are not reported, the results suggest that response alternation reduced the beneficial effect of stimulus-feature repetition. Again, this may indicate that stimulus and response features were integrated into a common episodic structure.

Based on these observations, it may be that, somewhat paradoxically, there is more in an object file than information about an object. In fact, if object files were really the basis of our episodic long-term memory, it would make sense not only to link codes of sensory features common to an object, but also to store what this feature conjunction is useful for, what action this object affords. If so, the original object-file concept may in fact be too narrow and may need to be merged with, or even replaced by, the concept of an "event file"; that is, an episodic memory trace linking codes of features belonging to an action-relevant object with codes of features characterising the corresponding action.

Such an event-file concept stresses the possibly action-related function of stimulus-feature integration and, thus, fits well with the action-oriented approach to visual attention proposed by Allport (1987), Neumann (1990) and Van der Heijden (1992). Allport (1987) pointed out that traces of episodic object-action couplings may serve to guide action on subsequent occasions. In the same vein, Logan (1988) proposed that instances of stimulus–response combinations may be stored over time, and Henderson (1996) considered this possibility, in particular for spatial information from stimulus- and response-related maps. Until now, however, all we have is casual observations, while systematic investigations of possible event-file-formation processes are lacking. The present study was aimed to tap into these hypothetical processes to demonstrate the existence of event files and to unravel their structure.

If event files really do exist, they may take one of at least three kinds of structure. An obvious possibility is that action-related information is just another ingredient of object files, so that event files could be viewed as extended, informationally enriched object files. If so, stimulus location should be crucial in addressing the corresponding episodic structure, just as proposed originally by Kahneman et al. (1992). They assumed that location information provides the “label” that is attached to an object file, whereas information about other stimulus features—and maybe about the response as well—forms the file's “contents”. This suggests that integrated response information can be accessed only if some spatial continuity of the stimulus is given; hence, response-repetition effects unfold only, or more strongly, if stimulus location is also repeated. In other words, an “extended-object-file hypothesis” predicts that effects of response repetition and of stimulus-location repetition interact in an underadditive fashion (i.e. especially good performance if both response and stimulus location is repeated).

A second possibility is that everything is integrated into a single, uniform event file. On the one hand, it is true that the results of Henderson (1994), Henderson and Anes (1994) and Kahneman et al. (1992) provide substantial support for the assumption that codes of stimulus form and location are bound together. On the other hand, these features were the only two investigated (apart from a combination of form and colour in study 6 of Kahneman et al.), so that we do not know what will happen if more features are involved, especially response-related ones. Possibly, all available stimulus and response features become interconnected, so that the emerging event file can be accessed via every feature involved, not just in the case of spatial stimulus continuity. If so, repeating a particular stimulus or response feature should produce beneficial effects only, or at least to a greater extent, if other features are repeated as well. In other words, a “uniform-event-file hypothesis” would predict a higher-order interaction of all feature-repetition effects involved, regardless of whether the feature belongs to the stimulus or to the response.

Third, event files may have a more differentiated structure. It may be that object files—whether they have a spatial “label” or not—are only part of a more complex, perhaps highly structured event file comprising both object- and action-related information. Some stimulus-feature codes may be strongly associated with codes representing stimulus location, whereas others are associated with response-related codes. Or the same code may be part of several, different episodic linkages, perhaps depending on its role or importance in the task at hand. Consequently, there may be a set of different, co-existing interactions between the effects of stimulus- and response-feature repetitions in a particular task that do not need to be further modified by a higher-order interaction. *A priori*, such a "structured-event-file hypothesis" does not allow for positive predictions of the same precision as the extended-object-file hypothesis or the uniform-event-file hypothesis; it is clear, however, that both interactions between stimulus-feature repetitions and between stimulus and response-feature repetitions should be involved.

The Task

The task used to investigate the existence and structure of event files was based on Kahneman and co-workers' (1992) preview design. The basic experimental ideal was to extend the prime–probe design of Kahneman et al. (1992) in a way that allows for a temporal coupling between the prime and a systematically varied response. To achieve an orthogonal manipulation of prime stimulus and prime-related response, however, the response should only accompany, but not depend on, the features of the prime. That is, the identity of the response should be signalled by a stimulus other than the prime.

Figure 1 shows the task resulting from these considerations. Each trial started with the presentation of a response cue, indicating which response (R1) was to be made to the prime (S1). Between the response cue and presentation of S1, ample time was given to prepare the response. Although the form, colour and location of the prime varied, subjects were only to respond to the *presence* of the (temporally predictable) prime, independently of its features. In this way,

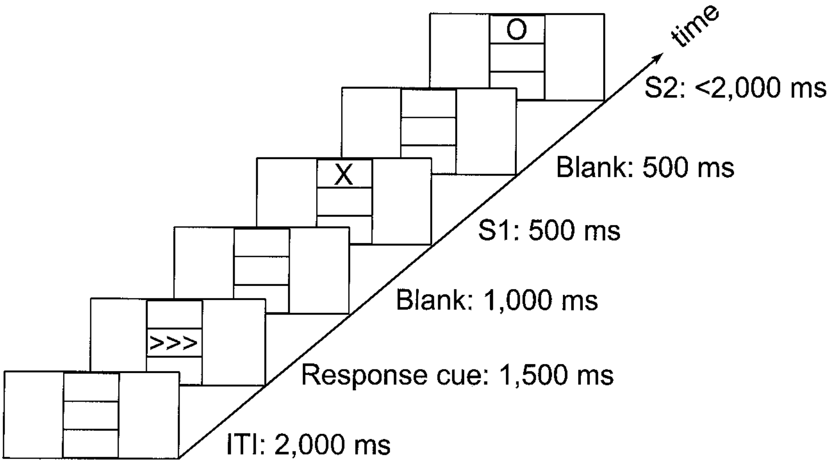

FIG. 1. Schematic illustration of the displays and the timing of events in Experiments 1–3.

any possible combination of S1 and R1 features could be realised. One second after prime presentation, the probe (S2) appeared. The probe always varied on the same dimensions as the prime, so that S1 and S2 could match or mismatch as to form, location or colour. The response to the probe (R2) was not known in advance, but was signalled by one of the S2 features (form in Experiments 1 and 3, colour in Experiment 2). That is, while R1 was a simple reaction to the presence of S1, R2 was a binary-choice reaction to the task-relevant feature of S2.

This task has several relevant characteristics. Importantly, S1 and R1 overlap in time, or at least occur in close temporal proximity, so that the preconditions for integrating stimulus and response information into a single event file are given: Temporally, S1 and R1 belong to the same event. However, the relationship between S1 and R1 features is completely arbitrary; that is, in no way task relevant or informative. Moreover, S1 is not only temporally predictable, it is also the only stimulus that appears, so that it must not be "selected-against" a distractor or alternative stimulus. That is, no single feature of S1 is to be coded or even identified to perform properly—only its presence matters. If, under such circumstances, S1 and R1 features were integrated, this would suggest a high degree of autonomy and automaticity of event integration.

EXPERIMENTS 1A AND 1B

Experiment 1 was conducted as a first test of whether response-related information is really integrated together with stimulus-related information into a common memory structure. Of the three stimulus dimensions—form, colour and location—only form was relevant to the task (i.e. to the second response); only one response dimension, location, was also task-relevant. Each stimulus dimension could take one of two values, so that form, colour and location could be repeated or alternated from S1 to S2. The same was true for the response dimension: Response location could be repeated or alternated from R1 to R2. In Experiment 1A, a third response condition was added, where no R1 was required. This single-response condition was considered to be a neutral condition for comparisons, which in the case of response repetition–alternation effects may help to decide whether repetition was beneficial or alternation was detrimental for performance.

Experiment 1 can be expected to produce three types of results that differ widely in their theoretical implications. The most obvious outcome would be main effects of repeating or alternating stimulus or response features. As already discussed, effects of this kind do not indicate the integration of feature information, but can be regarded as non-specific[1] (i.e. object- or event-unspecific) effects that may result from the priming of type representations in long-term memory.

A second outcome that was expected refers to the effects of repeating versus alternating the features for S1 and S2. The available evidence strongly suggests that different stimulus features of the same object are integrated into an object file, so that it should matter whether the particular stimulus-feature conjunction in S1 is or is not repeated. More precisely, repeating a stimulus feature should be beneficial only, or to a larger extent, if other stimulus features are also repeated. Consequently, the effects of stimulus-feature repetition were expected to interact: While repeating the particular conjunction of features from S1 to S2 should facilitate R2, repeating only some of the features should produce less benefit or none at all.

However, it is an open question whether interactions are to be found among all stimulus features, as the original object-file concept would suggest. On the one hand, previous studies have shown that form, colour and location can all participate in object-file formation, so that contributions from all of the present stimulus dimensions are possible. On the other hand, in most previous experiments, the respective dimension was relevant to the task, while only form is relevant there. Thus, the question is whether irrelevant stimulus dimensions are also integrated. As far as location is concerned, the answer seems to be yes. In the study of Kahneman et al. (1992), for instance, subjects were only asked to name a single letter in the probe display after having seen the prime—yet, naming was especially fast if both letter identity *and* relative location were repeated. Together with the very similar results of Henderson (1994: Henderson & Anes, 1994), this suggests that stimulus location information is combined with the relevant stimulus feature even if location is irrelevant to the task, just as Kahneman and co-workers' (1992) "location-label" assumption implies. Therefore, integration of form, the relevant stimulus feature and stimulus location was expected in the present experiment, and hence an interaction between form repetition and location repetition.

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[1] Strictly speaking, the main effects of (stimulus-) feature repetition reported here, and summarized in part in Fig. 5, do not correspond exactly to—and thus cannot be compared directly with—the non-specific preview effects reported by Kahneman et al. (1992) or Henderson (1994). In the present study, each stimulus-feature repetition effect is computed across several response conditions (two to four, depending on the experiment) and several other stimulus-repetition or alternation conditions. In contrast, Kahneman et al. and Henderson only compared conditions where the target letter did not match the two or more (not responded-to) preview letters with conditions where it matched one of them in identity but not location. However, despite these differences in computational details, main effects of feature repetition do represent preview effects that are not object- or event-specific, and thus should measure the same thing (e.g. priming of feature- or dimension-specific nodes) as non-specific preview effects.

But what about non-spatial irrelevant features? According to the approach of Kahneman and Treisman (1984; Treisman, 1988), all features that belong to an object are integrated into an object file, independent of their task relevance. This would suggest that colour and form would be integrated as well as colour and location, corresponding to interactions between colour repetition and form repetition and between colour repetition and location repetition, or even a three-way interaction, as implied by the "location-label" assumption. However, the task relevance of non-spatial stimulus dimensions has been shown to affect the role of the respective feature in negative priming (Milliken, Tipper, & Weaver, 1994; Tipper et al., 1994). If at least some part of the negative priming phenomenon is due to the formation of object files (Allport et al., 1985; Park & Kanwisher, 1994), this would suggest that task relevance may also affect performance in the present experiment. Accordingly, it may be that location, but not colour, repetition effects interact with the effect of form repetition, much as the structured-event-file account implies.

A third type of expected outcome refers to the interaction between the effect of response (R1–R2) repetition versus alternation on the one hand and the effects of repeating versus alternating (S1–S2) stimulus features on the other. The basic idea pursued here is that response information may be integrated together with stimulus information into something like an event file. If so, the effect of response repetition should depend on whether or not the respective stimulus features are also repeated and vice versa. More precisely, while repeating the particular conjunction of stimulus (S1) and response (R1) features should facilitate the second response (R2), a partial repetition should produce no (at least not that much) better performance than a complete non-repetition. One may even expect partial repetitions to produce worse performance than non-repetitions: If, for instance, the combination of stimulus feature S_A and response R_X is followed by the combination of S_A and R_Y (i.e. another response), re-viewing S_A may activate the associated (by now incorrect) response R_X, thus yielding a response conflict that would not be present if S_A and R_Y had been preceded by S_B and R_X. *A priori* it is not clear whether all of the three stimulus features participate in the event-file formation. If, according to the uniform-event-file hypothesis, integration is fully non-selective, only a four-way interaction should be obtained, hence performance should be best if everything is repeated (or everything is alternated). Yet, it may also be that response information is associated with the relevant stimulus feature only (i.e. form) or with stimulus location, which is known to be a likely ingredient of object files. Accordingly, lower-order interactions involving the R1–R2 relationship were to be expected.

In the original design of the experiment, reported here as Experiment 1A, the letters X and O where used to manipulate stimulus form, as in many previous studies. However, as form was the task-relevant stimulus feature, this choice may lead to a possible confounding. Although X and O clearly differ in form, they represent familiar and nameable stimulus configurations for the subjects investigated and thus may be processed in a somewhat different way, or on a different level, than the colour or location of the stimulus. Thus, if different outcomes were obtained for form on the one hand and colour or location on the other—and this turns out to be the case—it would be difficult to tell whether this asymmetry is due to some peculiarity of form processing (or processing the task-relevant stimulus feature) or a result of using familiar symbols as stimuli. To rule out the latter possibility, a control experiment (Experiment 1B) was run with a limited number of conditions (excluding the single-response condition), where horizontal and vertical lines were used as stimuli. If possible asymmetric findings in Experiment 1A could be replicated in 1B, we would be sure that they are not due to the use of familiar symbols as relevant stimuli.

Method

Subjects. Eight paid volunteers (5 females and 3 males, aged 21–35 years) took part in Experiment 1A and another eight (7 females and 1 male, aged 23–35 years) in Experiment 1B. All reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus and Stimuli. Both experiments were controlled by a Hewlett Packard Vectra QS20 computer, attached to an Eizo 9080i monitor via an Eizo MD-B11 graphics adaptor. From a viewing distance of about 60 cm, the subjects faced three 1.2° × 1.2° grey square outlines, vertically arranged (see Fig. 1). The stimuli were presented in red or green in the top or bottom frame. The form of the stimuli was different in the two experiments. The upper-case letters O and X (0.3° × 0.4°) were used in Experiment 1A, while a thin vertical line (0.07° × 0.6°) and a somewhat thicker horizontal line (0.3° × 0.11°) were used in Experiment 1B. The middle box, positioned at the centre of the screen, was used for response (R1) cue presentation only. The response cues were rows of three white left- or right-pointing arrows, or hyphens, indicating a left, a right or no response (R1), respectively. Responses were made by pressing the left or right of two microswitches mounted on a board with the index or middle finger of the right hand, respectively.

Procedure and Design. In a given trial, subjects made one or two responses. If required, the first response (R1) was always a simple reaction. The type of response (i.e. left or right keypress) was indicated by the response cue, which was to be carried out as soon as the first stimulus (S1) appeared. Subjects were told that there would be no systematic relationship between S1 and R1, so that they should perform the precued response at S1 onset, disregarding the form, colour and location of S1. The second response (R2)—or first, if R1 was not required—was always a binary-choice reaction to the second stimulus (S2).

The critical stimulus feature was S2 form: Half of the subjects responded to an O (Experiment 1A) or a vertical line (Experiment 1B) by pressing the left key, and to an X (Experiment 1A) or a horizontal line (Experiment 1B) by pressing the right key; the other half received the opposite mapping. Subjects were told that colour or location of S2 would be unimportant and uninformative, and hence should be ignored.

The sequence of events in each trial is illustrated in Fig. 1. After an inter-trial interval of 2000 msec, R1 was signalled by the response cue for 1500 msec, followed by a blank interval of 1000 msec. Then S1 appeared for 500 msec, followed by a further blank interval of 500 msec. If R1 was incorrect or missing, a new trial was started. Otherwise, S2 was presented and remained on until the end of the trial. The program waited until R2 was given but no longer than 2000 msec. If R1 or R2 was incorrect or missing, auditory error feedback was provided, and the trial was recorded and repeated at some random position in the remainder of the block.

In Experiment 1A, a session consisted of three blocks of 192 randomly ordered trials each, one for practice only and two experimental blocks. A short break was allowed after the first two blocks. Each block was composed of a factorial combination of S2 form (O *vs* X, corresponding to left *vs* right R2), colour (red *vs* green) and location (top *vs* bottom box), the possible relationships between S1 and S2 (i.e. repetition *vs* alternation) regarding form, colour and location, and the three possible relationships between R1 and R2 (repetition, alternation, or single response).

In Experiment 1B, a session consisted of two experimental blocks of 128 trials each, preceded by 40 randomly drawn practice trials. Each block was composed as in Experiment 1A, except that the single-response condition was dropped. That is, R2 was always preceded by a (same or different) R1.

Results

In Experiment 1A, R1 responses were missing, incorrect or anticipated (RT<100 msec) in 1.4, 1.5 and 2.0% of the trials, respectively. In Experiment 1B, the corresponding rates were 1.0, 1.0 and 0.4%. Correct R1 responses were given within 342 msec (Experiment 1A) and 376 msec (Experiment 1B) on average. R1 data were not analysed further.

Trials with missing R2 responses (Experiment 1A, 0.03%; Experiment 1B, 0.05%), or anticipations (Experiment 1A, 2.3%; Experiment 1B 0.5%), were also excluded from analysis. For the remaining data, mean RTs and proportions of errors (PEs) were calculated for each experiment as a function of the four possible relationships between the stimuli and the responses of the two subtasks; that is, according to whether the form, colour or location of S1 and S2 was repeated or alternated, and whether R2 was preceded by a same, a different or no response (See Table 1 and 2 for means). Analyses of variance (ANOVA) were performed by using a four-way design for repeated measures.

TABLE 1
Means of Mean Reaction Times (RT; in msec) and Percentages of Errors (PE) for R2 in Experiment 1A as a Function of the Relationship Between S1 and S2 and Between R1 and R2 (R2 Repeated, Alternated or Single)

	Response					
	Repeated		*Alternated*		*Single*	
Stimulus Feature Repeated	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Neither	514	7.6	431	2.1	464	0.7
L(ocation)	510	7.3	479	0.7	495	2.2
F(orm)	488	2.9	477	1.4	516	2.2
C(olour)	543	5.5	449	0.0	474	2.1
LF	441	0.7	493	7.1	524	2.0
LC	524	1.5	488	3.2	517	1.4
FC	481	3.9	471	4.7	495	2.1
LFC	432	0.0	504	10.0	526	4.1

Reaction Times. There were only two significant main effects: One of response relation in Experiment 1A, $F(2,14) = 4.58$, $p < .05$, where responses were faster with response alternation (474 msec) than with repetition (491 msec), and slowest in the single-response condition (501 msec); and one of colour repetition in Experiment 1B, $F(1,7) = 6.09$, $p < .05$, where repeating stimulus colour yielded faster responses than alternating (447 *vs* 460 msec).

More important, however, was whether the benefit of the repetition of stimulus form, colour or location would depend on (and thus interact with) the

TABLE 2
Means of Mean Reaction Times (RT; in msec) and Percentages of Errors (PE) for R2 in Experiment 1B as a Function of the Relationship Between S1 and S2 and Between R1 and R2 (R2 Repeated or Alternated)

	Response			
	Repeated		*Alternated*	
Stimulus Feature Repeated	*RT*	*PE*	*RT*	*PE*
Neither	487	7.6	424	2.2
L(ocation)	468	4.9	442	1.5
F(orm)	466	1.5	485	9.7
C(olour)	485	3.4	408	0.0
LF	414	0.7	492	14.0
LC	477	7.2	447	6.2
FC	434	2.1	454	10.0
LFC	393	2.3	476	12.6

relationship between R1 and R2. If so, a RT benefit would be expected if the two responses were the same but not if they were different. Figure 2 shows, for the two experiments, the relative repetition benefit for each stimulus dimension (i.e. mean RT for alternation of form, colour or location, minus mean RT for repetition) as a function of the relationship between R1 and R2. Clearly, repeating stimulus form or location produced a benefit with response repetition but not with response alternation or single responses, where repetition costs

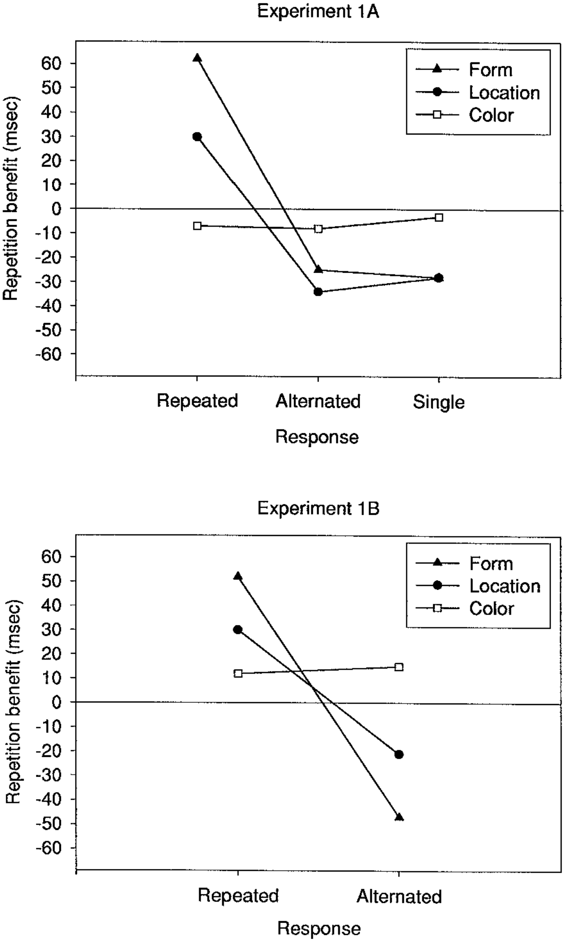

FIG. 2. Stimulus (S1–S2) repetition benefits ($RT_{alternation}$–$RT_{repetition}$) for stimulus form (F), colour (C) and location (L) in Experiments 1A (upper panel) and 1B (lower panel) as a function of response relation (R1–R2 repetition or alternation, or single). $RT_{alternation}$ corresponds to the mean of all conditions involving alternation of the respective stimulus feature (e.g. conditions Neither, L, C and LC, for stimulus form) in the given response condition, while $RT_{repetition}$ corresponds to the mean of all conditions involving repetition of that feature (e.g. conditions F, LF, FC and LFC).

were obtained. This pattern produced a highly significant interaction between response relationship and form repetition in Experiment 1A, $F(2,14) = 22.30$, $p < .001$, and Experiment 1B, $F(1,7) = 58.18$, $p < .001$, and an interaction between response relationship and stimulus-location relation in Experiment 1A, $F(2,14) = 34.98$, $p < .001$, and Experiment 1B, $F(1,7) = 23.04$, $p < .005$. However, there was no interaction of response relationship and colour in either experiment ($F < 1$). A separate ANOVA on alternate- and single-response trials only in Experiment 1A did not reveal any interaction involving response relation, showing that both conditions played a comparable role.

Single comparisons, (t-tests, two-tailed) confirmed that, in Experiment 1A, all response-specific repetition benefits and costs associated with form and location (Fig. 2) were significantly different from zero ($p < .05$), except the location-repetition benefit with response repetition and the form-repetition cost in the single-response condition. However, even these latter effects approached significance ($p < .08$ and $p < .07$, respectively). A similar picture was obtained in Experiment 1B, where all form- and location-related costs and benefits were significant or nearly so, as in the case of location-repetition costs with response alternation ($p < .06$). Colour-related effects were all far from significance, except the repetition benefit with response repetition in Experiment 1B ($p < .07$).

There were two further commonalities between the two experiments: First, form and colour repetition interacted in Experiment 1A, $F(1,7) = 5.71$, $p < .05$, as well as in Experiment 1B, $F(1,7) = 10.10$, $p < .05$. In both cases, this was due to faster responses if form and colour were either both repeated or both alternated (483 and 447 msec for Experiment 1A and 1B, respectively) than if only one, but not the other, was repeated (494 and 459 msec, respectively). Second, there was a very similar interaction between form and location, which was clearly significant in Experiment 1A, $F(1,7) = 11.74$, $p < .05$, but only marginally so in Experiment 1B, $F(1,7) = 3.97$, $p < .09$: Responses were faster if the two stimulus attributes were either both repeated or both alternated (483 and 447 msec for Experiments 1A and 1B, respectively) than if only one, but not the other, attribute was repeated (495 and 459 msec, respectively).

Errors. In Experiment 1A, there were just two significant effects, both mirroring the RT results. An interaction of response relation and stimulus location, $F(2,14) = 5.01$, $p < .05$, showed that repeating stimulus location decreased the error rates with response repetitions (2.4 and 5.0% for location repetition and alternation, respectively), but increased rates with response alternations (5.2 and 2.0%, respectively) and single responses (2.4 and 1.8%, respectively). In the same vein, an interaction of response relation and stimulus form, $F(2.14) = 7.47$, $p < .01$, indicated that repeating form decreased the error rates with response repetitions (1.9 and 5.5% for form repetition and alternation, respectively), but increased rates with response alternations (5.8 and 1.5%, respectively) and single responses (2.6 and 1.6%, respectively). Both interactions disappeared in a separate ANOVA on alternation and single-response trials only, suggesting that response repetition was the crucial condition.

In Experiment 1B, repeated responses produced smaller error rates (3.7%) than response alternations (7.0%), $F(1,7) = 6.67$, $p < .05$, and form repetitions yielded larger rates (6.6%) than form alternations (4.1%), $F(1,7) = 18.54$, $p < .005$. The two variables also interacted, $F(1,7) = 27.59$, $p < .001$, replicating the corresponding pattern in Experiment 1A: Again, repeating stimulus form decreased the error rates with response repetitions (1.6 and 5.8% for form repetition and alternation, respectively), but increased rates with response alternations (11.6 and 2.5%, respectively).

Discussion

The results reveal two theoretically important patterns. First, pure repetition effects of stimulus dimensions are virtually absent; the common pattern is an interaction between form—the task-relevant stimulus feature—and colour on the one hand, and between form and location on the other. These interactions do not seem to result from priming feature-specific type nodes, but rather from re-addressing structures of integrated feature conjunctions. As already mentioned, this finding is not new: Interactions between (relevant) form and (irrelevant) location have been reported by Henderson (1994; Henderson & Anes, 1994) and Kahneman et al. (1992), and colour-related effects have also been found previously (e.g. Allport et el., 1985). However, the present results also show that stimulus features do not seem to be integrated non-selectively, as both the original object-file concept and the uniform-event-file view would have led us to expect. If they were, a three-way interaction should have been observed, implying that only repeating the complete stimulus produced a benefit, while partial repetitions are ineffective. Yet, the results suggest that there is not one global binding of all features, but two different, local bindings, one between the two non-spatial stimulus features and one between the task-relevant stimulus feature and stimulus location. In contrast, there is no evidence for binding of location and colour, the irrelevant non-spatial feature, independently of whether the relevant feature was familiar symbols (Experiment 1A) or simple lines (Experiment 1B).

Second, and even more important in the present context, there are pronounced interactions involving response location. Again, the particular outcome pattern does not suggest a global binding of stimulus and response features, but two different, local bindings, one between the task-relevant feature and response location, and one between the two spatial features stimulus location and response location. There was also some indication of a binding of colour and response location in Experiment 1B, but it was unreliable and clearly on a different scale to the form- and location-related bindings. Therefore, Experiment 1 provides good evidence for the existence of event files integrating stimulus and response information, but on the stimulus side only task-relevant and spatial features seem to be involved.

One interpretation of the binding of stimulus form and response location is in terms of rule verification. Another way of putting this is that it represents a benefit of repeating the valid stimulus–response mapping rule. Consider, for instance, the case when an X (S2) is responded to by pressing a left key (R2). Based on the interaction obtained, this response was faster when it was preceded by a left keypress (R1) to an X (S1) or a right keypress to an O, than when it was preceded by a left keypress to an O or a right keypress to an X. In other words, although the stimulus–response relationship was completely unimportant for R1, R2 was faster if it followed a stimulus–response combination that obeyed the stimulus–response mapping rules valid for R2 than if it followed a mapping-rule "violation". That is, following a mapping rule is easier if it has been "confirmed" by the preceding stimulus–response combination, although this combination did not result from *applying* the mapping rule. This again suggests that rule-governed behaviour (i.e. S2–R2 performance) can be affected by the retrieval of traces of previous combinations of the present stimulus and a response. Logan (1988) has argued that performing a task leads to the formation of such traces. Once formed and stored, a trace or instance will be automatically retrieved whenever the corresponding stimulus or response occurs again. Thus, if the S1–R1 combination X→right key is followed by the S2–R2 combination X→left key, automatic trace retrieval and intentional rule application will yield conflicting outcomes, which again should prolong the initiation of the correct response. Under the plausible assumption that stored traces comprise relevant stimulus and response information only, the present interaction of stimulus-form and response-location repetition is consistent with such an interpretation.

However, it was not only relevant stimulus information that was integrated with response information, but stimulus location too. The presence of this second local response-related interaction points to a strong, intra-domain coupling of spatial stimulus and response codes. Such a tight coupling has already been postulated by Henderson (1996) on the basis of results from eye-movement studies. However, Henderson's idea was that spatial stimulus coding facilitates motor action *towards* the stimulus, just as maintained by proponents of the premotor theory or attention (Rizzolatti, Riggio, & Sheliga, 1994), or by theories of stimulus–response compatibility (see Hommel & Prinz, 1997). Yet, the present interaction has nothing to do with stimulus–response *correspondence*, but represents a benefit of (repeating) the spatial *relationship* between stimulus and response.

Interestingly, virtually identical results were obtained for the response-alternation and single-response conditions, which implies that the latter does not represent a truly neutral condition. Obviously, from the perspective of our subjects, omitting R1 was as different from performing a particular R2 as pressing the alternate key. Although this is an interesting observation, we will see in Experiment 2 that it is not always obtained and must thus be treated with caution. In Experiment 3, the role of the single-response condition will be investigated further.

Taken together, the results of Experiment 1 support the assumption that stimulus and response information is not integrated separately but bound together, thus forming a common event file, or several of them. Yet, the indication that colour information is not integrated with information about stimulus or response location suggests that feature binding is selective. Moreover, although the basic result of previous preview studies—interacting effects of stimulus-form repetition and stimulus-location repetition—was successfully replicated, the absence of three- or four-way interactions suggests that the responsible bindings were local, not global. These observations are inconsistent with the original object-file conception of Kahneman and Treisman (1984; Treisman, 1988), or any response-related extension, and with the uniform-event-file hypothesis described in the Introduction. They rather suggest that integration takes place at multiple levels, and is modulated by task relevance, just as implied by a structured-event-file approach.

EXPERIMENT 2

In Experiment 1, information about stimulus form, stimulus location and response location was found to be involved in mutual interactions, whereas colour information only interacted with stimulus form. What is the reason for this negligible part played by the colour dimension? An obvious interpretation points to the importance of task relevance, or behavioural goals, as Tipper et al. (1994) have put it: Because colour was irrelevant to the task, it may have been considered only in object-related bindings proper (i.e. form and colour), but not integrated with response location, the relevant response feature, or stimulus location, a dimension that may be functional in cross-referencing stimulus and response information. Yet, on the basis of Experiment 1 alone, we cannot firmly conclude that task irrelevance was responsible for the limited “binding willingness” of colour—maybe it was the poor saliency of this dimension or some other factor. An obvious way to test the task-relevance interpretation is to exchange the roles of form and colour, as in Experiment 2. If task relevance is really the decisive factor, we would expect the same outcome as in Experiment 1, but with form- and colour-related effects interchanged; hence, interactions between colour and form, colour and stimulus location, colour and response location, and stimulus and response location.

Method

Subjects. Eight paid volunteers (5 females and 3 males, aged 20–36 years) participated. They reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus, Stimuli, Procedure and Design. These were as in Experiment 1A, with the following exceptions: The response-relevant stimulus feature of S2 was colour. Half of the subjects responded to a green-coloured stimulus by pressing the left key and to a red one by pressing the right key, while the other half received the opposite mapping. A sessions consisted of two experimental blocks of 192 trials each (composed as in Experiment 1A), preceded by 40 randomly drawn practice trials.

Results

R1 responses were missing, incorrect or anticipated in 1.3, 0.8 and 1.6% of the trials, respectively. Correct R1 responses were given in 371 msec on average. After excluding missing (0.2%) or anticipated (1.8%) R2 responses, the R2 data were treated as in Experiment 1 (see Table 3 for means).

Reaction Times. Figure 3 shows the repetition benefits for each stimulus dimension as a function of the relationship between R1 and R2. As in Experiment 1, repeating stimulus form or location produced a benefit with response repetitions but not with response alternations, where repetition costs were obtained, or with single responses, which were associated with modest costs only. This time, however, there was also a benefit of colour repetition that

TABLE 3

Means of Mean Reaction Times (RT; in msec) and Percentages of Errors (PE) for R2 in Experiment 2 as a Function of the Relationship Between S1 and S2 and Between R1 and R2 (R2 Repeated, Alternated or Single)

	Response					
	Repeated		*Alternated*		*Single*	
Stimulus Feature Repeated	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Neither	541	11.9	466	0.8	487	0.7
L(ocation)	516	7.5	504	2.3	500	4.6
F(orm)	540	5.7	451	1.5	516	4.2
C(olour)	523	2.1	519	5.7	520	2.8
LF	520	7.6	495	2.9	532	2.9
LC	469	0.7	528	11.0	512	1.5
FC	482	2.3	510	8.2	512	2.9
LFC	447	0.7	530	9.3	532	2.7

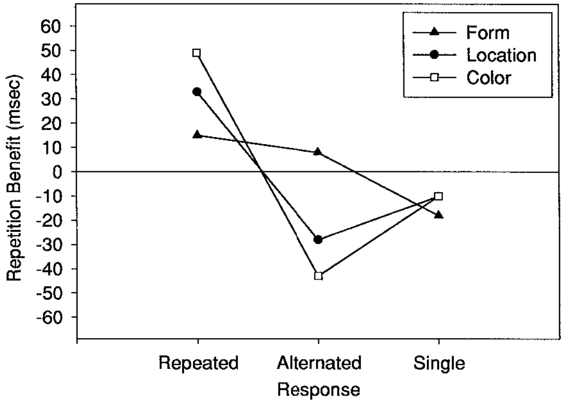

FIG. 3. Stimulus (S1–S2) repetition benefits ($RT_{alternation}–RT_{repetition}$) for stimulus form, colour and location in Experiment 2 as a function of response relation (R1–R2 repetition or alternation, or single).

depended on the inter-response relationship. All three interactions were clearly significant: response by form, $F(2,14) = 6.24$, $p < .05$, response by location, $F(2,14) = 5.40$, $p < .05$, and response by colour, $F(2,14) = 27.43$, $p < .001$. In a separate ANOVA including alternation and single-response trials only, response relation interacted with colour, $F(1,7) = 5.43$, $p < .06$, and with form, $F(1,7) = 6.48$, $p < .05$, but not with stimulus location ($p < .4$). That is, in contrast to Experiment 1, the single-response condition played a more neutral role than the alternation condition.

Single comparisons confirmed that colour and location, but not form, produced significant repetition benefits with response repetition. With response alternation, all three stimulus dimensions produced an effect: The colour cost was significant and the location cost nearly so ($p < .08$), while form yielded a small but significant repetition benefit. In the single-response condition, however, not one effect reached the significance criterion ($.14 < p < .45$).

Apart from a marginally significant interaction between form and colour ($p < .09$ showing the same pattern as in Experiment 1, no further effect reached or approached significance.

Errors. There were only two significant effects on error rates: The main effect of response relation, $F(2,14) = 3.76$, $p < .05$, was a result of error rates being lower with single responses (2.8%) than with response repetitions (4.8%) or alternations (5.2%). The interaction between response relation and stimulus colour, $F(2,14) = 17.45$, $p < .001$, indicated that colour repetition decreased the error rates with response repetitions (1.5 and 8.2% for colour repetition and alternation, respectively), hardly affected them with single responses (2.5 and 3.1%, respectively), but increased them with response alternations (8.5 and 1.8%, respectively). Both effects were also obtained in a separate ANOVA on alternation and single-response trials only, which showed that, in contrast to Experiment 1A, the latter condition was less effective than the former.

Discussion

As expected, exchanging the task relevance of form and colour yielded a partial reversal at least of the results obtained in Experiment 1. In Experiment 1, the response factor interacted most strongly with form, modestly with stimulus location, and not at all with colour. In Experiment 2, this order was completely reversed, with the strongest interaction between response and colour and the weakest between response and form. This dependence of effect-size order on task relevance points to an important role of the latter in the binding of stimulus and response features. Interestingly, however, even the irrelevant form feature produced a reliable interaction with response repetition. This suggests that task relevance only modifies the strengths of stimulus–response bindings, but does not preclude task-irrelevant couplings.

As far as bindings between stimulus features are concerned, the exchange of the roles played by colour and form did not yield an exact reversal of the results. Apart from the marginal form × colour interaction, replicating the corresponding effect in Experiment 1, there were no further interactions between stimulus dimensions. While the absence of the interaction between stimulus location and the now irrelevant form was expected, the absence of an interaction between stimulus location and the now relevant colour was not. Although there is no obvious explanation for this latter outcome, it should be pointed out that the overall pattern suggests a numerical reversal at least in the expected direction (see General Discussion). So, there is reason to assume that the asymmetry between colour- and form-related effects observed in Experimen 1 did not result from any particularities associated with the colour dimension, but was due to the task relevance of form.

EXPERIMENT 3

Experiment 3 was conducted to investigate further the role of the single-response condition used in Experiments 1A and 2. In Experiment 1A, this condition was comparable to the response-alternation condition in interacting in the same way with effects of stimulus-feature repetition. In Experiment 2, however, it rather behaved like the neutral condition it originally was supposed to be. The main aim of the present experiment was to assess whether the non-neutral behaviour of the single condition observed in Experiment 1 was a chance finding, or whether the different outcomes in Experiments 1 and 2 were due to the exchange of form and colour as relevant stimulus dimensions. Therefore, Experiment 3 comprised a replication of Experiment 1, with form as the relevant feature. The critical question was whether the equivalence between alternation and the single condition observed in Experiment 1 could be repeated.

A second aim of Experiment 3 was to investigate the differences between the present findings and those obtained with the preview design used in other studies. With a preview design, significant effects of stimulus-feature repetition (i.e. type priming) are sometimes observed (e.g. Henderson, 1994; Henderson & Anes, 1994) but not always (Kahneman et al., 1992). Although the single-response condition used here is not too different from the typical preview design, there was no indication of any repetition benefit in this condition. On the one hand, investigating and obtaining these effects was not the main objective of the present study, and there are a number of methodological differences, such as the number of previewed stimuli or the timing of preview and probe display, that may well account for the diverging outcomes. On the other hand, however, the observation that the single-response condition in Experiment 1A produced virtually the same results as the alternation condition aroused the suspicion that a different factor may have been responsible —and for a critical assessment of the present task, it seemed crucial to test whether this factor actually played a role.

One possible reason for the absence of non-specific priming with single responses is that not responding to a stimulus may be coded differently if the stimulus is never responded to, compared to when a response also represents a viable alternative. In priming or preview tasks, the prime is never responded to (or, as in the case of prime-signalled saccades, is always responded to, but differently than the probe), so that no decision needs to be made whether or not to respond. In the present design, however, S1 was sometimes responded to and sometimes not, so that such a decision was necessary. Consequently, our subjects may have coded the fact that no response is required explicitly. If so, this no-response code may have been integrated together with stimulus information into an event file just like codes for left- and right-key responses. Consequently, an event file including a no-response code would mismatch with S2 and R2 or the S2–R2 relationship just like event files including alternate responses do, thus leading to comparable performance in the response-alternation and single-response conditions. In contrast, priming or preview designs do not require any response to the prime, so that no response decision is to be made and no no-response code is to be formed, this precluding the integration of this code into an event file. If the event file does not include response information, not even no-response information, its match or mismatch with that in the probe trial cannot depend on the response relationship, hence response-independent type priming is possible.

If these considerations hold, a dependence of stimulus-feature repetition effects in single-response conditions on the response-related task context should be observed. To test for this possibility, Experiment 3 consisted of two sections. In one section (the “mixed” section), Experiment 1A was partially replicated (i.e. without the colour manipulation): S2 form was relevant, stimulus location was irrelevant, and response repetitions, alternations and single-response conditions were presented in random order. The second section (the "blocked" section) consisted of single-response trials only, thus replicating the standard preview experiments. Response decisions associated with S1, the preview part of the trial, were necessary in the mixed section, but not in the blocked section. Consequently, if effects of type priming (i.e. main effects of stimulus-feature repetition) are really dependent on whether or not response decisions are to be made before or during prime presentation, these effects should show up in the blocked section, but not in the single-response trials of the mixed section.

Method

Subjects. Sixteen paid volunteers (8 females and 8 males, aged 19–39 years) participated. They reported having normal or corrected-to-normal vision, and were not familiar with the purpose of the experiment.

Apparatus, Stimuli, Procedure and Design. These were as in Experiment 1A, with the following exceptions: The stimuli (S1 and S2) were always presented in green, hence colour did not vary. The session comprised two sections, the order of which was balanced across subjects. In Section A, the type of R1 varied randomly, just like in the preceding experiments. This section consisted of one practice block and four experimental blocks. Each block was composed of 48 trials, corresponding to the factorial combination of S2 form (O *vs* X) and location (top *vs* bottom), the possible S1–S2 relationships regarding form and location, and the three possible R1–R2 relationships (repetition, alternation or single response). In Section B, only single responses (i.e. R2) were required. The remaining task was in Section A, including the corresponding single-response precues, but subjects were informed that conditions involving R1 responses would never occur in this section. Section B also consisted of one practice block and four experimental blocks, but each block was now composed of 16 trials only, due to the exclusion of response-repetition and response-alternation conditions. Subjects were given the opportunity to rest between the two sections.

Results

R1 responses were missing, incorrect or anticipated in 1.3, 0.8 and 1.6% of the trials, respectively. Correct R1 responses were given in 371 msec on average. After excluding missing (0.2%) or anticipated (1.8%) R2 responses, the R2 data was treated as in Experiment 1 (see Table 4 means). Reaction times and percentages of errors were subjected to 2 × 2 × 4 ANOVAs with S1/S2-form relation, S1/S2-location relation, and R1–R2 relation (repetition, alternation, mixed single, blocked single) as within-subject factors. Control analyses that

TABLE 4
Means of Mean Reaction Times (RT; in msec) and Percentages of Errors (PE) for R2 in Experiment 1A as a Function of the Relationship Between S1 and S2 and Between R1 and R2 (R2 Repeated, Alternated or Single)

	Response							
Stimulus Feature	*Repeated*		*Alternated*		*Single (Random)*		*Single (Blocked)*	
Repeated	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Neither	537	11.1	487	1.8	509	4.8	507	2.8
L(ocation)	535	7.1	508	5.8	521	2.8	534	3.2
F(orm)	490	1.9	509	6.6	525	3.4	511	2.2
LF)	453	0.4	511	12.1	506	4.2	514	0.7

included the order of sections (mixed first *vs* blocked first) as a between-subjects variable did not reveal any interaction of the variable in question; there was only an interaction of order and response relation in RTs, indicating that performance in the blocked single section was better if that section followed rather than preceded the other section.

Reaction Times. Among the repetition main effects, only the form effect approached significance ($p < .052$). Form and stimulus location interacted significantly, $F(1,15) = 5.63$, $p < .05$. Figure 4 shows the relative repetition benefits for each stimulus dimension as a function of the relationship between R1 and R2. As in Experiment 1, repeating stimulus form or location produced

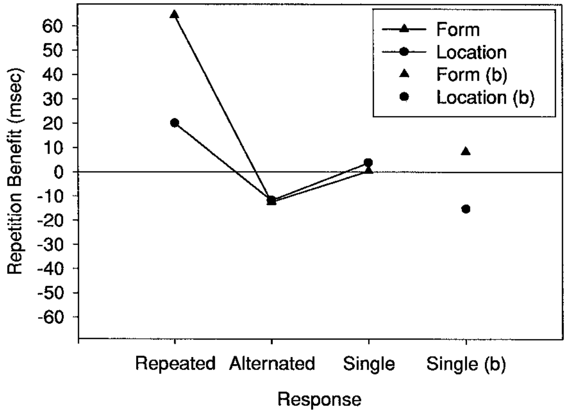

FIG. 4. Stimulus (S1–S2) repetition benefits ($RT_{alternation}-RT_{repetition}$) for stimulus form and location in Experiment 3 as a function of response relation (R1–R2 repetition or alternation, single random, single blocked).

a benefit with response repetition but not with response alternation or without a preceding R1. The corresponding interactions were clearly significant—response × form, $F(3,45) = 13.83$, $p < .001$, and response × location, $F(3,45) = 4.50$, $p < .01$. The fact that both of these interactions disappeared in a separate ANOVA of alternation and single-response trials only (taken from the random section) shows that response repetition was the crucial factor here. Correspondingly, in single comparisons, only the form-repetition benefit and the location-repetition benefit under response repetition were significant or nearly so ($p < .05$ and $p < .08$, respectively). As a specific test of the role of blocked versus random presentation of single-response trials, a separate ANOVA was performed on these trials. Apart from the interaction of form and stimulus-location repetition, no other effect even approached significance.

Errors. There was a main effect of response relation, $F(3,45) = 5.78$, $p < .005$, mainly because fewer errors were made in the single-response conditions (3.8% for mixed and 2.2% for blocked condition) than with response repetitions (5.1%) or alternations (6.6%). The interaction between response relation and stimulus form, $F(3,45) = 15.13$, $p < .001$, was produced by form repetition producing fewer errors then form alternation with response repetitions (1.1 *vs* 9.1%), while the reverse was true for response alternations (9.4 *vs* 3.8%); with single responses, form repetition and alternation yielded much more similar results, whether response relation was mixed (3.8 *vs* 3.8%) or blocked (1.5 *vs* 3.0%). Finally, there was an interaction between response relation and stimulus location, $F(3,45) = 5.75$, $p < .005$, that was of the same type as the form × response interaction: Repetition of stimulus location produced fewer errors than location alternation when the response was also repeated (3.8 *vs* 6.5%), but more errors when the response was alternated (8.8 *vs* 4.2%); again, the different between stimulus-location repetition and alternation was much less pronounced with mixed (3.5 *vs* 4.1%) and blocked (1.2 *vs* 2.5%) single responses. All these effects were also obtained in a separate ANOVA on alternation and single-response trials from the random section only.

Discussion

The main aim of Experiment 3 concerned the relationship between the alternate-response and the single-response conditions. In Experiment 1A, the single-response condition showed interactions with the repetition of stimulus dimensions comparable to those of the alternation condition, whereas in Experiment 2, single responses were not associated with repetition benefits or costs. The results of Experiment 3 do not really clarify matters. On the one hand, the alternate-response and single-response conditions during random presentation interacted similarly with the repetition of stimulus features, thus replicating the findings of Experiment 1A. On the other hand, this was not associated with similar repetition costs, as it was in Experiment 1A, but with an absence of any reliable stimulus–repetition effect in both conditions. Together with the observation that the single-response condition did not produce any perceptible numerical cost or benefit, this suggests that the similarity was more likely due to a floor effect than to some theoretically important special role of form stimuli (relevant in Experiments 1A and 3) compared to colour stimuli (relevant in Experiment 2). Based on the present results all one can say is that the single-response condition does not seem to represent a reliable neutral condition that could serve as a referent for comparing effects of response repetition and response alternation on stimulus-repetition effects. Therefore, the General Discussion focuses mainly on the effects of, and the relationship between, response repetition and alternation.

The second aim of Experiment 3 was to investigate whether dimensional, non-specific priming effects depend on the task context or, more precisely, on whether pure preview trials (i.e. single-response trials) occur in isolation or in the context of trials that require some kind of response decision before or during prime presentation. Although a brief look at Fig. 4 might suggest that something different happened in the blocked and random trials, there was nothing in the results to support this. Moreover, the absence of an interaction involving section order rules out carry-over effects from random to blocked presentation being responsible for the similarity between the two single-response conditions. All this suggests that reliable effects of non-specific, dimensional priming, as reported by Henderson (1994; Henderson & Anes, 1994), cannot be obtained with the particular task used in the present study. One reason for this may be that the prime display always consisted of a single object only, while displays in preview studies usually consist of two or more objects. Possibly, type priming only occurs if feature binding is difficult, hence with several objects. Another reason concerns the temporal lag between prime and probe display, which was very short in the experiments of Henderson (the latency of a saccade), longer in most conditions of Kahneman and co-workers' (1992) study, and consistently very long in the present study. Interestingly, Kahneman et al. obtained the numerically largest non-specific effects for the small (two symbol), static displays with very short preview-probe intervals (100 msec, study 1), and the effect shrank with increasing interval length (see 250 msec condition in study 1 and the longer intervals in study 2). Thus, type priming may be a rather short-lived phenomenon which explains, in view of the 1000 msec intervals used here, why we were unable to find such effects. But most important for assessing the present task, whatever the underlying reason for the lack of dimensional priming was, it seems clear that task context was not responsible.

GENERAL DISCUSSION

The main objective of the present study was to test the hypothesis that response-related information is integrated with stimulus information into event files; that is, episodic memory structures representing both stimulus and response aspects of events. All four experiments reported here provide evidence in favour of this hypothesis, allowing some conclusions to be drawn as to how event files may be internally structured. However, before I discuss the relevant findings and their implications in detail, I will first address two further outcome patterns that are more related to previous studies of object-file formation in perception.

The first interesting outcome concerns dimensional or type priming; that is, the object-unspecific effects of repeating versus alternating particular stimulus features. Figure 5 provides an overview of such repetition effects in Experiments 1A, 1B, 2 and 3. Effects were not only rare, but also very unsystematic. This suggests that the absence of repetition main effects cannot be attributed to the small size of the effects or the limited power of the present experiments to detect them. A reasonable explanation for their absence would be the rather long interval between S1 and S2, during which the activation of primed type nodes may have decayed. As already pointed out, such an interpretation would fit with the unreliable priming effects of Kanheman et al. (1992), who often used rather long intervals, and the large effects reported by Henderson (1994; Henderson & Anes, 1994), who used very short intervals only. In fact, preliminary results from pilot work in our laboratory suggest that non-specific effects decay over time.

The second interesting outcome concerns conjunction priming or object-file formation, as indicated by interactions between stimulus-feature repetition effects. The upper panel of Fig. 6 gives an overview of the degree of interaction for each of the two or three stimulus-feature combinations (see figure legend for computational details). There are two very systematic patterns. One is that stimulus location always interacts with the relevant stimulus feature, be it form, as in Experiments 1A, 1B and 3, or colour, as in Experiment 2. That is, repeating the relevant stimulus feature produces a benefit only if stimulus location is also repeated; if not, alternation tends to yield better performance (the latter being the case for Experiments 1B and 2). The observed benefit associated with conjunction repetitions replicates the results from preview studies and is consistent with the idea that location information is used to address and select object files for retrieval or updating (Kahneman et al., 1992; Treisman, 1988). Another pattern is that, independent of task relevance, the two non-spatial stimulus features, form and colour, always interact. That is, performance is better if form and colour are repeated—or, as in Experiments 1A and 2, if both alternate—compared to when only one alternates while the other is repeated. From an object-file approach, this result is unexpected. True, it does fit the general idea that perceiving a particular feature combination leads to the

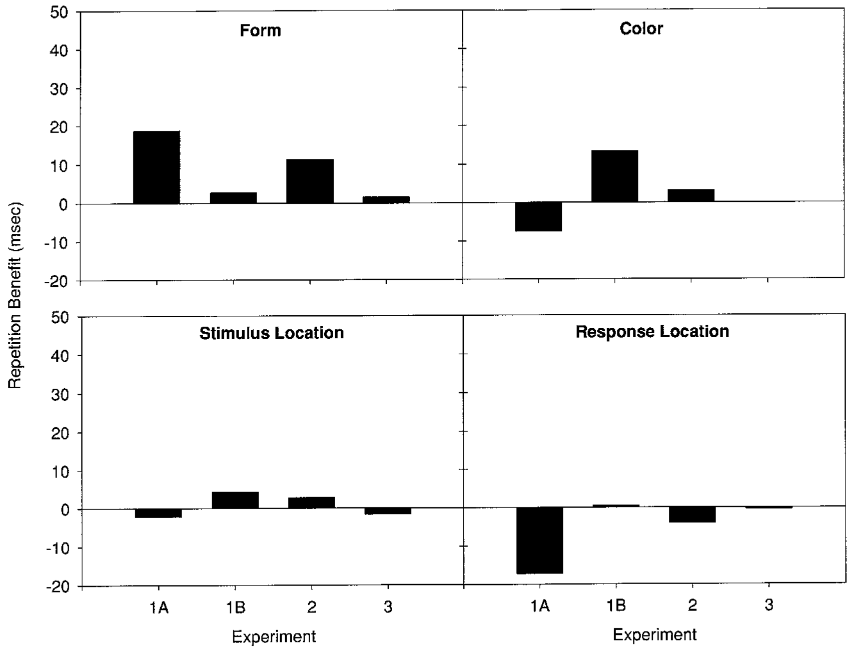

FIG. 5. Repetition benefits ($RT_{alternation}-RT_{repetition}$) for stimulus form (F), colour (C) and location (L), and response location in Experiments 1–3. For stimulus features, $RT_{alternation}$ corresponds to the mean of all conditions involving alternation of the respective feature (e.g. conditions Neither, L, C and LC, collapsed across response repetition and response alternation, for stimulus form), while $RT_{repetition}$ corresponds to the mean of all conditions involving repetition of that feature (e.g. conditions, F, LF, FC and LFC). Analogously, for response location, $RT_{alternation}$ corresponds to the mean of all conditions involving response alternation (collapsed across all stimulus repetition or alternation conditions), while $RT_{repetition}$ corresponds to the mean of all conditions involving response repetition. For optimal comparability between experiments, all computations are based on response–repetition and response–alternation conditions only, while single-response conditions were not considered.

formation of an object file: The features are not (or not only) registered independently, but integrated into a common episodic memory structure. If the same combination is then perceived again, it is not necessary to create a new file, but just update the old file. However, if object files are really addressed by location, the benefit of repeating a form-colour combination should depend on whether location is also repeated; yet there was no three-way interaction of form-, colour-, and location-repetition in any experiment in this study.

Although the absence of type priming and the presence of two different stimulus-feature bindings are of some theoretical interest, the main focus of this study is on the binding between stimulus and response features. The lower panel of Fig. 6 gives a summary of the degree of interaction observed between response type (only repetition and alternation conditions considered) and each

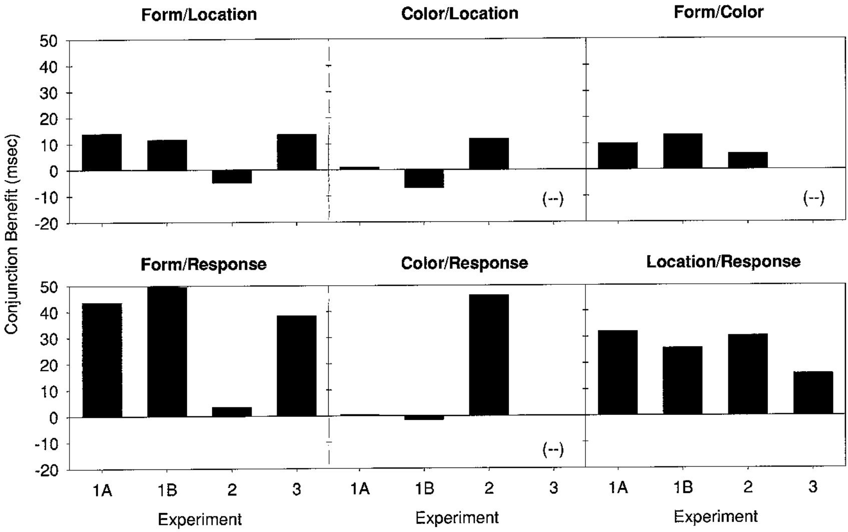

FIG. 6. Conjunction benefits for each combination of stimulus form, colour, and location (upper panel) and for the combination of response location with stimulus form, stimulus colour and stimulus location (lower panel) in Experiments 1–3. Conjunction benefits for the combination of features x and y are computed by taking the signed repetition benefit for x when y is repeated minus the signed repetition benefit for x when y alternates, divided by 2. A value of zero indicates independence between the respective features (i.e. between the effects of repeating versus alternating the features); values above zero indicate a repetition benefit for x if y is also repeated, but a cost if y alternates; values below zero indicate the opposite relationship.

of the three stimulus features. There are again two very systematic patterns. One is that the relevant stimulus feature—colour in Experiment 2 and form in the others—always interacts with the response. That is, repeating the relevant stimulus feature yields a benefit if the response is also repeated; but a repetition cost is observed if the response alternates. This suggests that binding does not only occur between stimulus features, as the object-file concept suggests, but between stimulus and response features as well. True, if such a binding does occur, the relevant stimulus feature and the relevant response feature are the most obvious candidates; yet the fact that stimulus-response binding is observed at all is remarkable. And there is evidence for a further binding: As the right-most graph in the lower panel of Fig. 6 shows, bindings between stimulus location and response location were obtained in all four experiments. This is partly consistent with the general consideration of Henderson (1996) that object files could contain information about both stimulus and response location.

Perhaps the most surprising outcome of this study is the absence of any three- or four-way interaction. The presence of such interactions would have suggested that all the stimulus and response features are integrated into one single structure, as both the extended-object-file hypothesis and the uniform-event-file hypothesis would lead us to expect. The absence of higher-order interactions, however, strongly suggests the formation of many local bindings instead of a unitary whole. That is, the present results point to a distributed and differentiated multi-layered network of stimulus- and response-feature codes with many local interconnections, rather than to the existence of a single, integrated episodic memory structure. Hence, it seems that an event file does not so much resemble a bundle of sheets put into one folder, but rather a system of hyperlinks connecting information stored at distant locations.

However, it must be emphasised that we should not overinterpret the present indications for local bindings only. It may be that the construction of a unitary global memory structure takes time, perhaps more time than was available in the task used here. It is possible that forming local bindings only represents the first stage of a more extended and more complex integration process that eventually results in a fully integrated episodic memory trace. If so, the present findings only represent a single snapshop of a dynamic consolidation process. And there is evidence that this is more than mere speculation: In further studies in our laboratory, we manipulated the stimulus-onset asynchrony between S1 and S2, thus varying the time available for consolidating the S1–R1 memory trace. Although much remains to be done to systematically track the consolidation process, it seems clear that the type of binding, as indicated by interactions between repetition effects, changes over time. So, the absence of more global bindings (i.e. bindings involving more than two features) in the present study does not mean that such bindings are not formed at all—it only shows that there is some point in time where they are only local, not global, bindings.

With these reservations in mind, it is still worthwhile considering the implications of local bindings. Let us begin with the bindings between stimulus features. Interestingly, there was systematic evidence across all four experiments for the binding of form and colour, independent of location. This finding is not consistent with the original object-file concept as proposed by Kahneman and Treisman (1984; Kahneman et al., 1992), where location information was assumed to be the most important ingredient of object files. It also suggests that the crucial binding does not take place on, has direct access to, or used information from, spatiotopically organised feature maps, such as in V1. More plausible sites would be higher areas, where (precise) location information is lost. It is possible that temporary chunks, at least, are formed at the type level, the non-spatial part of which can be roughly localised at V4/IT (Schneider, 1995). This does not necessarily exclude some role of location information, and thus, representations from other areas, in the process of forming form–colour conjunctions. It may be that, as Treisman (1988, 1993) has maintained, spatial codes are functional in sampling to-be-integrated information from lower-level colour and form maps. However, the present results suggest that, once integration has taken place, location is no longer represented.

The second stimulus-related binding observed here, that between stimulus location and the relevant stimulus feature, is much less critical for the object-file approach. It is true that the original approach does not draw a distinction between task-relevant and -irrelevant features that would allow for relevance-modulated binding: If "spatial attention" highlights a particular area of the location map, information from all corresponding feature-map locations is sampled and put into an object file (e.g. Treisman, 1988, 1993). However, this does not necessarily exclude the existence of a mechanism that attenuates information from maps coding task-irrelevant information, so that irrelevant information is less likely to be integrated or integrated only weakly, and thus decays quickly over time. That is, the observation of selective stimulus-feature bindings may indicate that the object-file approach is insufficient, but it does not stand in opposition to it.

Let us now turn to the bindings involving response location. As already pointed out, the consistent findings of bindings between the relevant stimulus feature and response location may be explained along the lines of Logan's (1988; Logan & Etherton, 1994) instance theory of automatisation. The basic idea is that each stimulus–response episode is stored and retrieved automatically if the same stimulus or response occurs again. If we further assume that this only applies to task-relevant stimulus and response features, which seems to be consistent with Logan's proposal that instance storage requires attention, the present interaction can be easily understood. However, another implication, which does not seem to be fully consistent with Logan's approach, arises from the fact that S1–R1 instances were stored even though the pair of S1 and R1 was only accidental. In other words, the mapping rule between S2 and R2 was "learned" by performing R1 to S1, although the latter did not result from applying the rule. How could this happen if, as Logan assumes, attention to co-occurrence is required to store an instance?

A possible answer could be that our subjects may have (more often than not) failed to distinguish between the S1–R1 task and the S2–R2 task. Although the former was a simple reaction task and the identity of S1 was not important, subjects may have been unable to simply "forget" the S2–R2 mapping rule and thus may have tended to apply this rule in the S1–R2 task as well. Some support for this comes from the reaction times in the first task, which ranged from 342 to 376 msec. For a simple reaction, this is actually very slow, although the dual-task context must also be taken into account. Therefore, could subjects have reacted to, or at least have been influenced by, S1 identity? If so, there should have been an interaction between the relevant stimulus feature and response in the RTs or R1, that is, R1 should have been quicker if it was combined with an S1 that obeyed the S2–R2 mapping rule. However, although this interaction approached significance in Experiment 1B ($p = .055$), it was far from significant in Experiments 1A ($p = .95$), 2 ($p = .50$) and 3 ($p = .43$). That renders an account in terms of inadequate rule application untenable and suggests that attention to co-occurrence is not necessary to store stimulus–response relationships.

Response location did not only interact with the relevant stimulus feature, it also interacted in a very consistent fashion with stimulus location. Therefore, even though stimulus location was not involved in as many interactions as the original object-file approach suggests, it did play a major role. Interactions between spatial stimulus and response codes are a common finding: Not only are spatial stimulus cues know to facilitate spatially corresponding actions (e.g. Fitts & Seeger, 1953; for general overviews see Hommel & Prinz, 1997; Protor & Reeve, 1990), even if stimulus location is completely irrelevant to the task (e.g. Simon & Rudell, 1967), spatial action can also be shown to facilitate (Deubel & Schneider, 1996; Hommel & Schneider, submitted) or to impair (Müsseler & Hommel, 1997) the processing of corresponding stimuli, depending on the particular temporal conditions. As already mentioned, these findings are consistent with Henderson (1996) and the basic tenet of the premotor theory of attention (Rizzolatti et al., 1994), that spatial stimulus and response codes may be coupled in some way. However, the particular type of interaction obtained here is not really predicted by this view, because the observed coupling between stimulus and response location did not depend on correspondence. This suggests that correspondence and relationship-repetition effects are produced by two different processes or mechanisms: On the one hand, there seem to be direct spatial interactions during a trial that foster the processing of spatially corresponding stimuli and responses. A plausible candidate for this to happen would be the dorsal "where" pathway, especially the posterior parietal cortex (Rizzolatti et al., 1994; Schneider, 1995), although at least with eye movements the superior colliculus also seems to be heavily involved (Wurtz, Goldberg, & Robinson, 1980). On the other hand, there seems to be a mechanism that monitors the spatial stimulus- and response-coding processes occurring in these areas, or at least registers their outcome, and binds the resulting codes together, whether they correspond or not.

To summarize, the present findings clearly suggest that binding effects, as indicated by mutually interacting repetition effects, are not restricted to stimulus features, but can also be shown to occur between stimulus and response features. This again demonstrates that object files, if they really exist, are only part of the binding story, and thus may be though of as only one component of more complex, and possible widely distributed, event files. One interpretation of the observation of several local, but not global, bindings would be that event files are multi-layered structures comprising bindings that serve different functions: Bindings between stimulus form and location may be a product of a (pre-attentive?) object-construction process; binding stimulus location and the relevant stimulus feature may serve to spatially index the relevant information; binding response location and the relevant stimulus feature may reflect a mechanism subserving the automatisation of mapping rules; and spatial stimulus–response bindings may serve to coordinate visual attention with spatial motor action. However, according to another, not necessarily exclusive interpretation, the formation of local bindings represents only some intermediate stage of a temporally extended event-file construction process that ultimately will produce a single, fully integrated trace connecting all aspects of the experienced stimulus–response episode. Which of these interpretations is correct, and whether they represent theoretical alternative at all, should not be too difficult to determine.

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