The Structure of Distractor-Response Bindings: Conditions for Configural and Elemental Integration

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Human action control is influenced by bindings between perceived stimuli and responses carried out in their presence. Notably, responses given to a target stimulus can also be integrated with additional response-irrelevant distractor stimuli that accompany the target (*distractor-response binding*). Subsequently reencountering such a distractor then retrieves the associated response. Although a large body of evidence supports the existence of this effect, the specific structure of distractor-response bindings is still unclear. Here, we test the predictions derived from 2 possible assumptions about the structure of bindings between distractors and responses. According to a configural approach, the entire distractor object is integrated with a response, and only upon repetition of the entire distractor object the associated response would be retrieved. According to an elemental approach, one would predict integration of individual distractor features with the response and retrieval due to the repetition of an individual distractor feature. Four experiments indicate that both, configural and elemental bindings exist and specify boundary conditions for each type of binding. These findings provide detailed insights into the architecture of bindings between response-irrelevant stimuli and actions and thus allow for specifying how distractor stimuli influence human behavior.

Keywords: action control, distractor-response binding, feature-response binding, event-file

For purposeful behavior in a rich environment, we need to deal not only with those few stimuli that are currently relevant for us, but also with numerous irrelevant stimuli that surround us at any given moment. More precisely, research on the processing of distractor stimuli suggests that the representation of a distractor stimulus is automatically linked to responses that are performed at the time of stimulus encounter. Stimulus response retrieval theory (Rothermund, Wentura, & De Houwer, 2005; see also Mayr & Buchner, 2006) further suggests that encountering the distractor again will automatically retrieve the associated response. Such retrieval impedes performance if a different response has to be executed. However, if a repetition of the same response is required, retrieval of the earlier response would enhance performance.

A large body of evidence indicates that distractor stimuli can indeed be integrated with the response given to a target and trigger its retrieval later on, an effect that has been termed *distractor-response binding* (e.g., Frings, Rothermund, & Wentura, 2007; Giesen & Rothermund, 2011; Mayr & Buchner, 2006). Effects of distractor-response binding have been demonstrated in various

modalities (e.g., Frings & Möller, 2010; Moeller & Frings, 2011; Moeller, Rothermund, & Frings, 2012) and several parameters have been identified that modulate the extent to which this mechanism influences behavior (e.g., Frings & Rothermund, 2011; Giesen, Frings, & Rothermund, 2012; Moeller & Frings, 2014).

It thus seems safe to assume that distractor-response associations are readily established and that distractor repetition can retrieve the associated response. Furthermore, distractor-response bindings seem to be compiled simultaneously with and independently of bindings between distractors and targets (Giesen & Rothermund, 2014). Although these findings indicate that the same stimulus can become part of multiple bindings, it is not clear whether the same holds true for individual features of one and the same distractor object. That is, the functional structure of distractor-response bindings is virtually unknown. Is it, for example, sufficient to vary parts of a distractor stimulus to prevent response retrieval or would the unchanged parts still retrieve the associated response? To answer this question, we need to know how exactly response retrieval is triggered by distractor stimuli. At least two scenarios seem plausible in light of previous research. On the one hand, it is possible that associations are formed between the entire distractor stimulus and the response. We will refer to this speculation as the *configural hypothesis* in the following. On the other hand, separate features of the distractor could be bound independently of each other to the response, a speculation that we will refer to as the *elemental hypothesis*.

Configural Versus Elemental Integration

Direct evidence for the configural hypothesis can be found in studies on negative priming. In negative priming paradigms (e.g.,

see Fox, 1995, for a review), participants carry out a response to a target in two consecutive displays, a prime display and a probe display. Each target is accompanied by a distractor stimulus and, crucially, the distractor stimulus of the prime display can become a target in the probe display. Probe responses tend to be slowed down in such distractor-to-target (ignored repetition) sequences and this effect is called negative priming. According to retrieval theories, this effect is due to the reactivation of the prime response by the repeated presentation of the former distractor stimulus (e.g., Neill, 1997). Because distractor stimuli are mapped to different responses than target stimuli in negative priming paradigms, the probe target in an ignored repetition trial requires a different response than given in the prime. Hence, response retrieval due to stimulus repetition leads to response impairment in ignored repetition trials, accounting for the negative priming effect. In some studies however, negative priming effects were only found if the entire configuration of the distractor stimulus was repeated as the probe target. If only parts of the distractor were repeated in the probe target, responses were even facilitated, which can be accounted for by the assumption of residual activation of the repeated features' representations facilitating perceptual processing (Treisman, 1998; Khurana, Smith, & Baker, 2000). These results suggest that the distractor stimulus is integrated with the response as an entirety and not in terms of its individual features, which is in line with the configural hypothesis.

Moreover, a recent study on distractor-response bindings used auditory and visual stimuli relating to the same object (sounds and pictures of different animals), and allowed changes of distractor modality from prime to probe (Frings, Moeller, & Rothermund, 2013). That is, in case of a distractor modality change between prime and probe presentation, distractor objects were repeated without repeating individual distractor features. Nevertheless, even if none of the physical distractor features was repeated, the repetition of a distractor object retrieved responses given during the prime. These findings are again compatible with the configural hypothesis because the observed retrieval effects were not due to individual bindings between physical distractor features and responses.

However, support for the elemental hypothesis can be found in the literature as well. In a recent review on stimulus-response bindings in priming, Horner and colleagues suggested that bindings between individual stimulus features and responses might explain congruency effects of semantically related stimuli and also priming from stimuli that occur only once in an experiment (Henson, Eckstein, Waszak, Frings, & Horner, 2014). More specifically, De Houwer, Rothermund, and Wentura (2001) found a negative priming effect for individual features that had to be ignored during a prime response (i.e., valence of words). By contrast, responding to features of the former distractor that had not been ignored during the prime response was not impaired. Similarly, stronger negative priming effects were found for the task-relevant feature of stimuli than for a task-irrelevant feature of the same stimuli (Frings & Wentura, 2006). Hence, these studies indicate that the effect of negative priming can also be feature-specific in certain conditions, which would be in line with the assumption of elemental bindings between distractor stimuli and responses.

Regarding a possible theoretical background for the structure of distractor-response binding, again, both approaches seem plausi-

ble. The theory of event coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001) assumes that any activated codes concerning a given response and the corresponding situation are jointly integrated into episodic memory traces that are called event files (Hommel, 1998, 2004). More precisely, according to the TEC, features of a response, and stimulus features are integrated in an event file at the time of responding and the entire event file can be reactivated as a whole if any of the integrated features are repeated. Notably, bindings between target features and response features have been found to be "binary" (i.e., elemental; see Hommel, 2004, 2007; Hommel & Colzato, 2004). For example, if one target feature is integrated with a response, the repetition of this target feature can trigger response retrieval independent of whether or not other target features are repeated, as well. If integration of distractor stimuli and responses resembles bindings between targets and responses, we would expect elemental bindings between individual distractor features and the response. That is, each individual distractor feature repetition would contribute to the retrieval effect indicating distractor-response binding as suggested by the elemental hypothesis. Then again, attentional weighting according to the current task (i.e., feature based attention) modulates stimulus integration. In particular, stimuli including task relevant features are more likely to become part of an event file (e.g., Hommel, Memelink, Zmigrod, & Colzato, 2014; Ihrke, Behrendt, Schrobsdorff, Herrmann, & Hasselhorn, 2011; Memelink & Hommel, 2012; Moeller & Frings, 2014). With distractor stimuli arguably receiving less attention than target stimuli, multiple bindings between distractors and responses might seem unlikely. Thus, also regarding the TEC, it remains unclear whether elemental binding holds for distractor stimuli as it does for targets.

The Present Study

With the present study we aimed to get a better understanding under what circumstances the structure of distractor-response bindings is better described in terms of elemental, and when in terms of configural bindings. In four experiments, we used distractor objects that included more than one feature and orthogonally varied the repetition of these features as well as orthogonally varied feature repetitions to response relation. Binding between a distractor feature and the response is then indicated by an interaction of response relation and distractor feature relation. Distractor feature repetition should facilitate responding if the response has to be repeated as well. If the response has to be changed, distractor feature repetition should lead to significantly less response facilitation as compared to response repetition trials, or even to response impairment.

According to the elemental hypothesis, we would predict retrieval effects due to the repetition of individual distractor features. More precisely, according to the elemental hypothesis, retrieval effects due to the repetition of one distractor feature should not be modulated by a repetition of the other distractor feature. Moreover, retrieval effects due to the repetition of individual features should sum up to retrieval effects due to a combined distractor feature repetition. That is, the elemental hypothesis can be rejected, when observing a significant three-way interaction (i.e., a modulation of one Distractor Feature Relation × Response Relation interaction by the relation of the other distractor feature). By contrast, a

significant three-way interaction would support the configural hypothesis, stating that bindings occur between entire combinations of distractor features and responses.

Four experiments tested to what extent these hypotheses applied for distractor-response bindings. In Experiment 1, we used artificial distractor objects and systematically varied two of their features (shape and color); in Experiment 2 and 3, we used complex objects (human faces) and systematically varied two complex features (person and facial expression). In Experiment 4, we finally presented face distractors upside-down to prevent automatic extraction of these complex features.

Experiment 1

In the first experiment, we manipulated very simple distractor features that were both salient, and easily identifiable. Participants categorized target letters that were superimposed on colored shapes as distractors. That is, each distractor included a combination of two basic, perceptual features. Participants responded to the identity of central target letters in both, a prime display and a probe display. Of main interest was the relation between the distractor features—color and shape—in prime and probe: Either shape and color simultaneously, only the shape, only the color, or none of the distractor features could be repeated. Response retrieval effects could then be calculated for color, shape, and joint distractor feature repetition by comparing distractor feature repetition effects in response repetition trials with those effects in response change trials (see Table 1 for examples of the different conditions; note that response repetition can be induced by target repetition or by repetition of the target category while the target changes). That is, distractor repetition effects were expected to differ between response repetition and response change trials. Notably, this difference is statistically independent of the actual size of the distractor repetition effect in response change trials (Giesen et al., 2012). Depending on the size of a distractor inhibition effect (leading to generally better performance if a distractor is repeated), distractor

repetition in response change trials might lead to a relatively small effect of response facilitation or to response impairment. Response retrieval is thus indicated by a larger effect of response facilitation due to distractor repetition in response repetition trials as compared to response change trials.

Following this reasoning, the configural hypothesis predicts that distractor-response bindings should manifest only if color and shape were both repeated from prime to probe. That is, a significant three-way interaction of color relation, shape relation, and response relation would support this hypothesis whereas both two-way interactions of Shape Relation × Response Relation and Color Relation × Response Relation would be expected not to reach significance. By contrast, the elemental hypothesis predicts that separate and independent effects should emerge for each individual feature. That is, we would expect both two-way interactions of Shape Relation × Response Relation and Color Relation × Response Relation to be significant, whereas the three-way interaction should not be significant.

Method

Participants. Thirty-two students (24 women) from the University of Trier took part in the experiment. Their median age was 23 years with a range from 19 to 28 years. All participants took part in exchange for partial course credit.

Design. The design of Experiment 1 comprised three within-subjects factors, namely response relation (response repetition/ target repetition vs. response repetition/target change vs. response change), distractor shape relation (repetition vs. change), and distractor color relation (repetition vs. change).

Materials. The experiment was conducted using the E-prime 2.0 software. Instructions were shown in white on black background on a standard thin film transistor (TFT) screen. Target stimuli were the letters D, F, J, and K. All letters subtended a horizontal visual angle of 0.8° to 1.1° and a vertical visual angle of 0.9° to 1.0°. Distractors were the four shapes rectangle, ellipse,

Table 1
Examples for Trials in the Different Conditions Resulting From the Factors Response Relation, Distractor Color Relation, and Distractor Shape Relation

Note. D and F are mapped to the left response and K and J are mapped to the right response.

plus sign, and triangle in the colors green, red, blue, or yellow. The shapes had a horizontal extension of 4.5° and a vertical extension of 2.9°. Viewing distance was approximately 60 cm.

Procedure. Participants were tested individually in sound-proof chambers. Instructions were given on the screen and summarized by the experimenter. Participants were instructed to place their left index finger on the D key and their right index finger on the K key of a standard computer keyboard. Their task was always to categorize the target letter by pressing a key with the corresponding finger. The letters D and F were mapped to the left response and the letters J and K were mapped to the right response. Each prime display and each probe display included one target letter (D, F, J, or K) that was superimposed on a colored distractor shape. Shape and letter were presented in the center of the display. Participants were instructed to react as quickly and as correctly as possible.

Individual responses were grouped into microsequences of two responses (one trial). Each trial was started self-paced by the participant. Each probe response was immediately followed by a fixation mark indicating that the next trial could be started. Each trial featured a prime-probe sequence with the following events (cf. Figure 1). First, participants started each trial by pressing the space bar. After 500 ms, the prime ($n - 1$) display appeared and stayed on the screen until the participant responded; response time (RT) was not restricted by a response window. After an additional 500 ms, the probe (n) display appeared and stayed on the screen until the participant responded; again RT was not restricted. In response repetition trials, the target letters that were presented on the prime and on the probe were mapped to the same response, while on response change trials, the prime and probe target letters were mapped to different responses. Half of the response repetition trials included a target repetition and the other half included a target change. Distractor shape relation and distractor color relation between prime and probe were varied orthogonally and also orthogonally to the response relation, yielding 12 experimental conditions in total. In distractor shape repetition trials prime and probe distractor had the same shape, whereas in distractor shape change trials the shape of the distractor changed from prime to probe. Similarly, in distractor color repetition trials, prime and probe distractor had the same color, whereas in distractor color change trials the color of the distractor changed from prime to probe. For example, in a trial with response repetition, distractor shape change, and distractor color repetition, a left response could be required both to the prime and to the probe target, the prime distractor could be a yellow rectangle, and the probe distractor a yellow ellipse.

Each participant worked through a single experimental block of 240 prime-probe sequences. Target letters, distractor shapes and distractor colors were randomly assigned to prime and probe targets and distractor features. Prime target letter or distractor features were then changed to match the current trial type (, e.g., if the trial included distractor color repetition, prime distractor color was set to the distractor color presented in the probe display). Before the experimental block, participants worked through a practice block of 32 prime-probe sequences in which they received feedback after each response. Everything else was exactly as during the experimental trials.
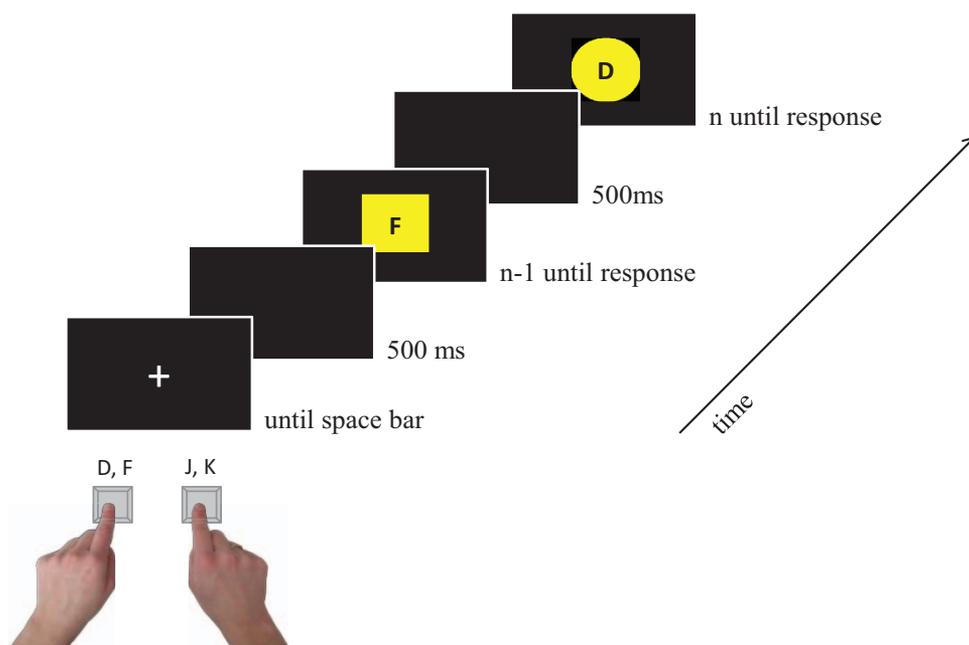
Figure 1. Trial structure in Experiment 1. A prime display ($n - 1$) that was followed by a probe display (n) and participants responded to the target letters and ignored the colored shapes in each display. Required response, distractor shape, and distractor color could repeat or change independently from prime to probe. The example illustrates a trial with response repetition, distractor shape change, and distractor color repetition. Stimuli are not drawn to scale. See the online article for the color version of this figure.

Results

For the analysis of RTs, we considered only those trials with correct responses to the prime and to the probe (probe error rate was 5.2%, prime error rate was 5.1%). RTs that were more than 1.5 interquartile ranges above the third quartile of the reaction time (RT) distribution of the sample (Tukey, 1977), and those that were shorter than 200 ms were excluded from the analysis. Due to these constraints, 15.4% of all trials were discarded.

Overall analysis. Our main analysis was a 3 (Response Relation: response repetition/target repetition vs. response repetition/target change vs. response change) × 2 (Distractor Shape Relation: repetition vs. change) × 2 (Distractor Color Relation: repetition vs. change) repeated-measures ANOVA (see Table 2 for the corresponding descriptive statistics for RTs and error rates).

For RTs, this analysis yielded significant main effects of response relation, $F(2, 30) = 171.13$, $p < .001$, $\eta_p^2 = .92$, and distractor shape relation, $F(1, 31) = 20.23$, $p < .001$, $\eta_p^2 = .40$. Responses were faster for response repetition/target repetition trials than for response repetition/target change trials, and marginally faster for response repetition/target change than for response change trials ($M_{RRtr} = 482$ ms, $SD_{RRtr} = 44$ ms; $M_{RRtc} = 564$ ms, $SD_{RRtc} = 47$ ms; $M_{RC} = 577$ ms, $SD_{RC} = 55$ ms). Responses were also faster if the distractor shape was repeated ($M = 535$ ms, $SD = 44$ ms) than if the shape changed ($M = 546$ ms, $SD = 47$ ms). Importantly, the two-way interactions of Distractor Shape Relation × Response Relation, $F(2, 30) = 8.47$, $p = .001$, $\eta_p^2 = .36$, and Distractor Color Relation × Response Relation, $F(2, 30) = 8.16$, $p = .001$, $\eta_p^2 = .35$, were significant, as well, indicating response facilitation for distractor repetition trials in the response repetition conditions, but not in the response change condition. In contrast, the three-way interaction of Response Relation × Shape Relation × Color Relation was not significant, $F < 1$, $\eta_p^2 < .06$. Planned contrasts indicated that the two-way interactions were due to differences between response change and the two response repetition conditions, Shape × Response Relation: $F(1, 31) = 9.71$, $p = .004$, $\eta_p^2 = .24$; for, Color × Response Relation: $F(1, 31) = 13.17$, $p = .001$, $\eta_p^2 = .30$, and not due to differences between the two levels of response repetition, Shape × Response Relation: $F(1, 31) = 3.75$, $p = .062$, $\eta_p^2 = .11$; Color × Response Relation: $F(1, 31) < 1$, $\eta_p^2 < .02$. None of the remaining effects was significant, $Fs < 1$, $\eta_p^2 s < .02$.

In the same ANOVA on error rates, the main effect of response relation was significant, $F(2, 30) = 22.12$, $p < .001$, $\eta_p^2 = .60$, indicating that participants made fewer errors in the response repetition/target repetition than in the response change condition and fewer errors in the response change than in the response

repetition/target change conditions. Other than that, the result pattern was identical to that of the RTs. The interaction of response relation and distractor shape relation was not significant, $F(2, 30) = 2.53$, $p = .097$, $\eta_p^2 = .14$, whereas the interaction of response relation and distractor color relation was significant, $F(2, 30) = 4.84$, $p = .015$, $\eta_p^2 = .24$. Neither the three-way interaction, $F < 1$, $\eta_p^2 = .06$, nor any of the other effects were significant, all $Fs < 1$, $\eta_p^2 s < .03$.

Additivity of distractor-response bindings. In a second step, we took a closer look at the data to determine how closely our results mirrored *additive* effects of individual distractor feature-response bindings. Based on the previous omnibus analyses, we decided to collapse target repetition and target change trials in response repetition conditions and conducted further analyses for the factor response relation (repetition [with and without target repetition] vs. response change).

More precisely, we compared retrieval effects due to the repetition of individual distractor features *while the other distractor feature changed*, with those retrieval effects due to a combined repetition of the distractor features. For this analysis, we computed the retrieval effects due to the repetition of individual features by subtracting the facilitation due to distractor feature repetition (while the other distractor feature changed, respectively) in response change trials from the facilitation effect due to distractor feature repetition (while the other distractor feature changed) in response repetition trials. More precisely, two RT differences—for response repetition and response change—were calculated and subtracted from each other for the distractor repetition effects in each feature repetition condition (i.e., $[RT_{ResponseRepetition/ShapeChange/ColorChange} - RT_{ResponseRepetition/ShapeRepetition/ColorChange}] - [RT_{ResponseChange/ShapeChange/ColorChange} - RT_{ResponseChange/ShapeRepetition/ColorChange}]$ for retrieval due to distractor shape repetition and $[RT_{ResponseRepetition/ShapeChange/ColorChange} - RT_{ResponseRepetition/ShapeChange/ColorRepetition}] - [RT_{ResponseChange/ShapeChange/ColorChange} - RT_{ResponseChange/ShapeChange/ColorRepetition}]$ for retrieval due to distractor color repetition). The retrieval effects due to the repetition of individual features (shape: $M = 13$ ms, $SD = 34$ ms, color: $M = 13$ ms, $SD = 36$ ms) did not differ from each other, $t(31) = 0.006$, $p = .995$, $d = 0.001$, that is, similar response retrieval was triggered by distractor shape repetition (when color changed) and by distractor color repetition (when shape changed). Interestingly, the effects of color-response binding and shape-response binding were highly correlated, $r = .670$, $p < .001$, indicating that participants showing large binding effects regarding one feature also had a large binding effect regarding the other feature.

Table 2

Mean Response Times (in ms) and Mean Error Rates (in Percent) in Experiment 1 as a Function of Response Relation, Distractor Shape Relation, and Distractor Color Relation

	Response repetition/ Target repetition		Response repetition/ Target change		Response change	
	Distractor color repetition	Distractor color change	Distractor color repetition	Distractor color change	Distractor color repetition	Distractor color change
Distractor shape repetition	463 (.4)	477 (.4)	557 (8.1)	561 (9.8)	581 (7.3)	572 (7.0)
Distractor shape change	490 (.9)	496 (1.1)	567 (7.4)	572 (10.7)	581 (6.6)	573 (4.5)

We then computed the retrieval effect due to the combined repetition of both distractor features by subtracting the facilitation due to distractor repetition (i.e., repetition of both distractor features as compared to an alternation of both distractor features) in response change trials from the facilitation effect due to combined distractor feature repetition in response repetition trials ($M = 31$ ms, $SD = 44$ ms).[1] This joint binding effect was larger than both individual retrieval effects, $t(31) = 2.74$, $p = .010$, $d = 0.48$, for distractor shapes, and $t(31) = 2.40$, $p = .023$, $d = 0.42$, for distractor colors. Most importantly, when adding both single retrieval effects due to individual distractor feature repetition, the sum did not differ significantly from the retrieval effect due to the joint repetition of both distractor features, $t(31) = 0.58$, $p = .566$, $d = 0.10$ (see Figure 2).

The same analysis on error rates also revealed a correlation between the effects of color-response-binding and shape-response binding, $r = .552$, $p = .001$. Although the pattern was identical to that in the RTs, none of the differences between the retrieval effects due to individual feature repetition, joint feature repetition, and the sum of retrieval effects due to individual feature repetition were significant, all $|t|$s < 1.4, ps $> .17$.

Discussion

In Experiment 1, we investigated the structure of distractor-response bindings by employing distractors that varied with regard to two features. Participants responded to target letters and ignored distractors that were composed of the two features shape and color. We found binding between individual distractor features and the executed responses, indicated by two-way interactions of Response Relation × Distractor Shape Relation and of Response Relation × Distractor Color Relation, respectively. Importantly,
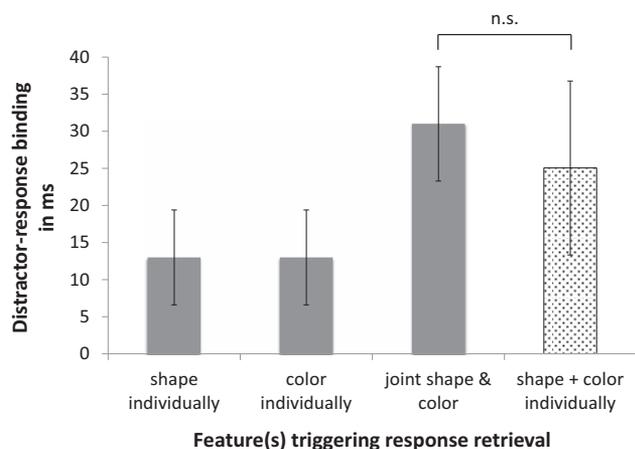
Figure 2. Response retrieval effects due to repetition of distractor features in Experiment 1. Distractor-response binding effects are calculated as the distractor feature repetition effect (as compared to complete change of distractor features) in response repetition trials minus distractor feature repetition effects in response change trials. Note that distractor feature repetition means repetition of only one distractor feature in individual effects, and simultaneous repetition of both distractor features in the joint effect. The rightmost bar shows the sum of the two individual retrieval effects that are visualized in the left two columns. Error bars depict standard errors of the mean. n.s. = nonsignificant.

the interactions between response relation and relation of each distractor feature were not modulated by whether or not the other distractor feature was also repeated. Hence, it is safe to assume that bindings between distractor features and responses were elemental, and that binding processes regarding distractor stimuli are very similar to those regarding target stimuli and the corresponding response (see, Hommel, 1998, 2004).[2]

Moreover, our second analysis substantiated that response retrieval due to individual distractor features worked additively. We found no significant difference between the added retrieval effects of individual features and the retrieval effect due to joint feature repetition. Apparently, every individual distractor feature contributes to the retrieval effect due to a repetition of the entire distractor stimulus. With regard to this conclusion, an intriguing question is, what can be interpreted as an individual distractor feature, and is in turn likely to contribute to action control via response retrieval. This question can of course be answered easily for the artificial stimuli of Experiment 1, but an answer might not be as obvious for many other kinds of stimuli. The following experiments therefore provide additional data on more complex distractor stimuli.

Experiment 2

The distractor stimuli in Experiment 1 were very simple geometrical shapes and only two relatively simple and salient physical features were varied in the design. Arguably, this setup is a suboptimal operationalization of most natural distractor stimuli. Importantly, parts of natural objects are often more complex, leading to the question, what the boundary conditions are for a feature to be individually integrated with a response. For example, it is conceivable that common feature combinations are actually not perceived as separate but rather as a unified, more complex feature.

Evidence for this assertion comes from studies on visual search. Treisman and Paterson (1984), for instance, reported nearly parallel search in identification of arrows and triangles, indicating that these shapes were extracted preattentively. This might be a first indication, that these stimuli were processed as including a single, complex feature rather than a conjunction of lines and angles. Similarly, combinations of polarity and shape, motion and shape, and stereoscopic depth and color or motion seem to be processed as individual—more complex—features (McLeod, Driver, & Crisp, 1988; Nakayama & Silverman, 1986; Theeuwes & Kooi, 1994). Moreover, it has been shown

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[1] ($RT_{ResponseRepetition/ShapeChange/ColorChange}$ − $RT_{ResponseRepetition/ShapeRepetition/ColorRepetition}$) − ($RT_{ResponseChange/ShapeChange/ColorChange}$ − $RT_{ResponseChange/ShapeRepetition/ColorRepetition}$).

[2] Note that changes in the distractor stimulus from display $n − 1$ to display n may have distracted participants to a larger extent than distractor repetitions. This might have boosted the main effect of distractor shape relation. Importantly, though, distraction due to changes in the distractor stimuli cannot account for the reported binding effects as they merely boost the main effect of distractor relation. The critical effect for a binding interpretation is the interaction of distractor feature relation and response relation. A response that is retrieved by a repeated distractor feature facilitates responding only in response repetition trials but has a tendency to impede responding in response change trials. In contrast, distraction due to change in the background information should impede responding both in response repetition and response change trials, and thus cannot explain the relevant interaction.

that combinations of simple two-dimensional features, such as lines, can be perceived as basic three dimensional features (Enns & Rensink, 1991; He & Nakayama, 1992). For example, Enns and Rensink (1991) found rapid detection of arrow- and Y-junctions both if these line combinations were presented in isolation and also if they were presented as parts of more complex objects. The authors conclude that three-dimensional properties of line drawings are processed preattentively, again suggesting that a single feature can be rather complex under certain conditions.

A particularly relevant stimulus that might come with distinct complex features is the human face. Indeed, classic models of face perception distinguish the perception of face identity as being achieved separately from other aspects such as facial expression and possibly additional dynamic aspects of a face such as eye gaze and lip movements (Bruce & Young, 1986; Haxby, Hoffman, & Gobbini, 2000; see also Posamentier & Abdi, 2003). Evidence for such a distinction comes from both, experimental studies with healthy participants (Campbell, Brooks, de Haan, & Roberts, 1996; Young, McWeeny, Hay, & Ellis, 1986) as well as from neuropsychological dissociations of identity processing on the one hand and expression processing on the other hand (e.g., Humphreys, Donnelly, & Riddoch, 1993). Even though it is currently debated whether these functional and anatomical dissociations are best understood either as separate systems (Bruce & Young, 1986; Haxby et al., 2000) or rather as different instantiations of a single system (Calder & Young, 2005), the principal distinction between identity and expression is a widely accepted property of face processing. Furthermore, both identity and expression are extracted automatically and effortlessly (Allison, Puce, Spencer, & McCarthy, 1999; Pizzagalli, Regard, & Lehmann, 1999; cf. Adolphs, 2002; Rossion, 2014), rendering them prime candidates for being coded as complex features (cf. Khurana et al., 2000 for evidence from a negative priming paradigm).

Experiment 2 tested the configural hypothesis against the elemental hypothesis in the light of such face stimuli and their more complex features. The setup was similar to Experiment 1 but instead of colored shapes we used photographs of persons showing a certain affect as distractors, while participants still responded to target letters. That is, a photograph of one of two different persons showing one of two different affects (happy vs. angry) was presented as the background to each target letter. Either person, affect, or a combination of person and affect was repeated (or changed) between responses which, in turn, allowed us to compare response retrieval effects due to person-, affect-, and a joint distractor-feature repetition. We expected the identified person to be interpreted as one feature and the affect, displayed by the person, as a second feature of the distractor face. Support for elemental integration of the features person and response would be indicated by significant interactions of Person Relation × Response Relation and Affect Relation × Response Relation while the three-way interaction of person Relation × Affect Relation × Response Relation should not reach significance. Significance of this three-way interaction, on the other hand, would be an indication of configural integration of the person showing a certain affect with the response.

Method

Participants. Twenty-four participants (20 women) from the city of Würzburg, Germany, were recruited and received monetary compensation. Their median age was 27 years with a range from 19 to 55 years.

Design and materials. Design and materials were similar to Experiment 1 with the following exceptions. Distractor stimuli were four pictures from the Karolinska Directed Emotional Faces library (Lundqvist, Flykt, & Öhman, 1998; 4.7° v.a. × 6.2° v.a.; see Figure 3A for the stimulus set). These pictures constituted the orthogonal combination of two face identities (persons) and two affects (happy vs. angry). Participants responded with the F and J key of the computer keyboard to a target letter (X, H, S, or N) that was superimposed on the distractor picture. Target-response mapping was counterbalanced across participants with two letters being mapped onto the left response key and two letters being mapped onto the right response key.

Procedure. Instead of an explicit prime-probe sequence, we used a random series of trials and analyzed each trial (n) in relation to the preceding trial ($n-1$; see Figure 3B). Each trial started with a fixation cross (500 ms), followed by target and distractor. This display stayed on the screen until the participant responded but for a maximum duration of 1,000 ms. Inaccurate responses and omissions triggered an error message (1,500 ms) whereas the next trial started immediately after a correct response. Participants worked through a training block and six experimental blocks of 112 trials each, corresponding to seven repetitions of each combination of target letter, distractor person, and distractor affect within each block.

Results

Only trials with correct answers to the current and the directly preceding display were considered. RTs that were more than 1.5 interquartile ranges above the third quartile of the RT distribution of the participant (Tukey, 1977), and those that were shorter than 200 ms were excluded from the analysis. Due to these criteria, 15.6% of all trials were discarded. Mean RTs and error rates are depicted in Table 3.

Overall analysis. In a 3 (Response Relation: response repetition/target repetition vs. response repetition/target change vs. response change) × 2 (Distractor Person Relation: repetition vs. change) × 2 (Distractor Affect Relation: repetition vs. change) ANOVA on RTs, the main effect of response relation, $F(1, 23) = 71.48$, $p < .001$, $\eta_p^2 = .87$, was significant, indicating faster responses for target repetition trials than for response repetition trials, and faster responses for response repetition than for response change trials ($M_{RRtr} = 421$ ms, $SD_{RRtr} = 37$ ms; $M_{RRtc} = 455$ ms, $SD_{RRtc} = 52$ ms; $M_{RC} = 484$ ms, $SD_{RC} = 41$ ms). The two-way interactions of Person Relation × Response Relation, $F(2, 22) = 8.12$, $p = .002$, $\eta_p^2 = .43$, and Affect Relation × Response Relation, $F(2, 22) = 11.09$, $p < .001$, $\eta_p^2 = .50$, were also significant, indicating response facilitation for distractor repetition trials in the response repetition conditions, but response impairment due to distractor repetition in the response change condition. Importantly, the three-way interaction of Response Relation × Person Relation × Affect Relation, was not significant, $F < 1$, $\eta_p^2 < .03$. Planned contrasts indicated that the two way interactions were due to differences between response change and the two
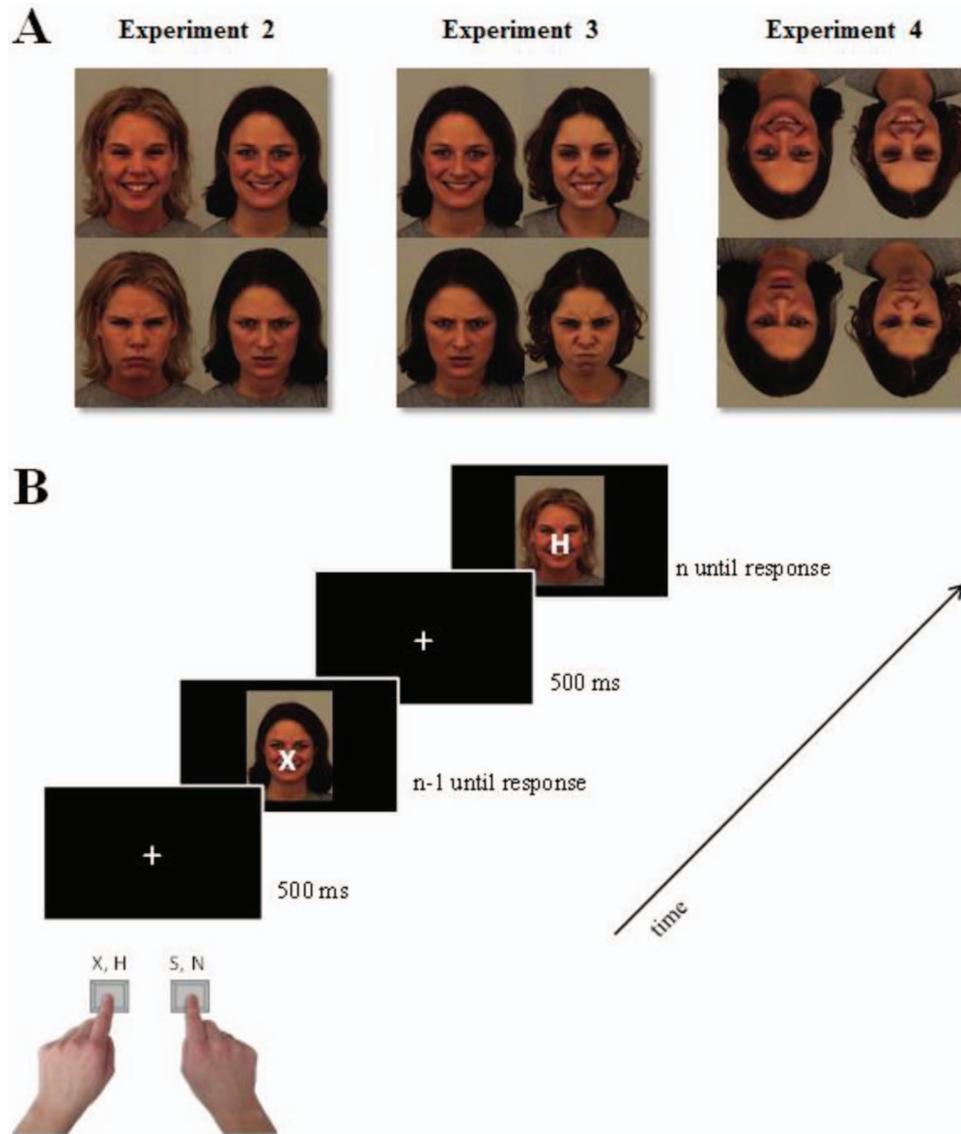
Figure 3. (A) Distractor stimuli used in Experiments 2 through 4. (B) Trial structure and trial sequence in Experiment 2. Participants responded to the letters and ignored the persons and their affect. Required response, distractor person, and distractor affect could repeat or change independently between trials. The example illustrates a trial with response repetition, distractor person change, and distractor affect repetition. Stimuli are not drawn to scale. See the online article for the color version of this figure.

response repetition conditions, $F(1, 23) = 16.38$, $p = .001$, $\eta_p^2 = .42$, for Person × Response Relation and $F(1, 23) = 16.37$, $p = .001$, $\eta_p^2 = .42$, for Affect × Response Relation, and not due to differences between the two levels of response repetition, $F < 1$, $\eta_p^2 < .02$ for Person × Response Relation and $F(1, 23) = 1.45$, $p = .240$, $\eta_p^2 = .06$ for Affect × Response Relation. The main effects of person relation, $F(1, 23) = 4.07$, $p = .056$, $\eta_p^2 = .15$, and affect relation, $F(1, 23) = 3.23$, $p = .085$, $\eta_p^2 = .12$, approached significance, while the interaction of person relation and affect relation was not significant, $F(1, 23) = 1.70$, $p = .261$, $\eta_p^2 = .07$.

The same ANOVA on error rates yielded a significant main effect of response relation, $F(2, 22) = 54.84$, $p < .001$, $\eta_p^2 = .83$.

Although the pattern was descriptively similar to the analyses on RTs, none of the other effects was significant, $Fs < 2.8$, $ps > .1$.

Additivity of distractor-response bindings. As for Experiment 1, we collapsed target repetition and target change trials in response repetition conditions and conducted further analyses for the factor response relation (response repetition [with and without target repetition] vs. response change). Again, we took a closer look at the data to decide how closely these findings conformed to additivity of individual distractor feature-response bindings by conducting follow-up analyses to probe for elemental bindings.

We again compared retrieval effects due to the repetition of individual distractor features (while the other distractor feature

Table 3

Mean Response Times (in ms) and Mean Error Rates (in Percent) in Experiment 2 as a Function of Response Relation, Distractor Person relation, and Distractor Affect Relation

	Response repetition/ Target repetition		Response repetition/ Target change		Response change	
	Distractor affect repetition	Distractor affect change	Distractor affect repetition	Distractor affect change	Distractor affect repetition	Distractor affect change
Distractor person repetition	411 (1.4)	422 (1.1)	449 (7.3)	456 (7.0)	488 (8.5)	483 (6.9)
Distractor person change	421 (2.5)	428 (1.4)	458 (7.9)	458 (8.9)	484 (7.0)	478 (6.0)

changed) with those retrieval effects due to a combined repetition of the distractor features. Retrieval effects due to the repetition of individual features (person: $M = 9$ ms, $SD = 19$ ms, affect: $M = 10$ ms, $SD = 18$ ms) and the retrieval effect due to the combined repetition of both distractor features ($M = 23$ ms, $SD = 23$ ms) were computed as in Experiment 1.[3] As before, the retrieval effects due to the repetition of individual features did not differ from each other, $t(23) = 0.16$, $p = .874$, $d = 0.03$. That is, similar response retrieval was triggered by distractor person repetition (when affect changed) and by distractor affect repetition (when the person changed). The positive correlation between the retrieval effect due to person-repetition and the retrieval effect due to affect repetition was significant, $r = .586$, $p = .003$. More importantly, both retrieval effects due to the repetition of an individual distractor feature were significantly smaller than the retrieval effect due to the combined repetition of both distractor features, $t(23) = 3.05$, $p = .006$, $d = 0.62$, for person, and $t(23) = 3.11$, $p = .005$, $d = 0.63$, for affect retrieval effects. Most importantly, the added retrieval effects due to individual distractor feature repetition did not differ significantly from the retrieval effect due to the combined repetition of both distractor features, $t(23) = 0.01$, $p = .995$, $d = 0.001$, see Figure 4.
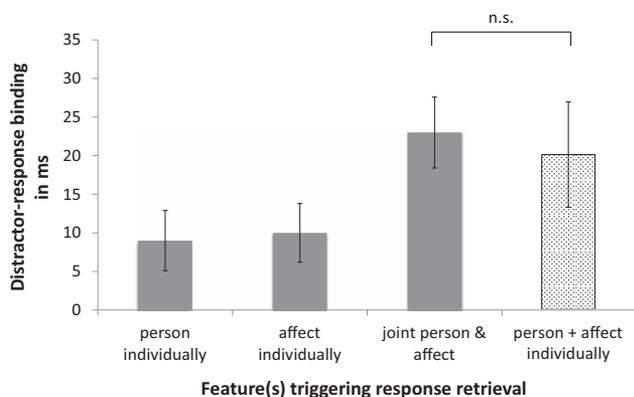
Figure 4. Response retrieval effects due to repetition of distractor features in Experiment 2. Distractor-response binding effects are calculated as the distractor feature repetition effect (as compared to complete change of distractor features) in response repetition trials minus distractor feature repetition effects in response change trials. Note that distractor feature repetition means repetition of only one distractor feature in individual effects, and simultaneous repetition of both distractor features in the joint effect. The rightmost bar shows the sum of the two individual retrieval effects that are visualized in the left two columns. Error bars depict standard errors of the mean. n.s. = nonsignificant.

The same analyses on error rates revealed the same pattern, although not all effects reached significance. We found a significant positive correlation between the retrieval effects due to individual feature repetitions, $r = .642$, $p = .001$. The difference between the retrieval effects due to individual affect repetition and due to the joint repetition of both distractor features was marginally significant, $t(23) = 1.84$, $p = .079$, $d = 0.38$. None of the other differences was significant, all $|t|s < 1.2$, $ps > .26$.

Discussion

Experiment 2 investigated rather complex distractors, consisting of faces of different persons showing different affects. The repetition of either the person or the affect induced response retrieval although both of these "features" were combinations of more basic physical features. Moreover, we found the same pattern of elemental and additive bindings for these complex features as we did in Experiment 1 for simpler geometric stimuli. That is, the combinations of many physical features that were part of the identified person or the identified affect were encoded as individual features of the distractor stimuli in Experiment 2.

Note, however, that hair color was one salient feature that differed between the stimuli. Therefore, for the retrieval effect due to person repetition in Experiment 2, it was not essential to combine several basic physical features to one more complex feature "person identity." Hair color repetition or change alone might have been sufficient for response retrieval. This reasoning does of course not undermine the interpretation of affect-response bindings that included rather complex features. Nevertheless, we cannot rule out that person identification in the absence of a single salient discriminating feature might rely more on integration according to a configural approach. To test this assumption, we decided to rerun Experiment 2 with more closely matched face stimuli.

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[3] $(RT_{ResponseRepetition/PersonChange/AffectChange} - RT_{ResponseRepetition/PersonRepetition/AffectChange}) - (RT_{ResponseChange/PersonChange/AffectChange} - RT_{ResponseChange/PersonRepetition/AffectChange})$ for retrieval due to distractor person repetition, $(RT_{ResponseRepetition/PersonChange/AffectChange} - RT_{ResponseRepetition/PersonChange/AffectRepetition}) - (RT_{ResponseChange/PersonChange/AffectChange} - RT_{ResponseChange/PersonChange/AffectRepetition})$ for distractor affect repetition, and $(RT_{ResponseRepetition/PersonChange/AffectChange} - RT_{ResponseRepetition/PersonRepetition/AffectRepetition}) - (RT_{ResponseChange/PersonChange/AffectChange} - RT_{ResponseChange/PersonRepetition/AffectRepetition})$ for joint distractor feature repetition.

Experiment 3

Experiment 3 was a conceptual replication of Experiment 2 with the difference that the depicted persons that were shown in the distractor pictures had the same hair color.

Method

Participants. Thirty-one participants (28 women) from the city of Würzburg were recruited and received monetary compensation. Their median age was 22 years with a range from 18 to 55 years. One participant had to be excluded from the analyses because of an extreme error rate.

Design, materials, and procedure. Design, materials and procedure were identical to Experiment 2 with the exception that both persons that were depicted as distractors had brown hair (see Figure 3A). As in Experiment 2, these pictures resembled the orthogonal combination of two face identities (persons) and two affects (happy vs. angry).

Results

According to the same criteria as in Experiment 2, 18.4% of all trials were discarded. Mean RTs and error rates are depicted in Table 4.

Overall analysis. In a 3 (Response Relation: response repetition/target repetition vs. response repetition/target change vs. response change) $\times$ 2 (Distractor Person Relation: repetition vs. change) $\times$ 2 (Distractor Affect Relation: repetition vs. change) ANOVA on RTs, the main effect of response relation, $F(2, 29) = 98.39$, $p < .001$, $\eta_p^2 = .87$, was significant, indicating faster responses for response repetition/target repetition trials than for response repetition/target change trials, and faster responses for response repetition/target change than for response change trials ($M_{RRtr} = 442$ ms, $SD_{RRtr} = 42$ ms; $M_{RRtc} = 481$ ms, $SD_{RRtc} = 47$ ms; $M_{RC} = 507$ ms, $SD_{RC} = 50$ ms). The two way interactions of Person Relation $\times$ Response Relation, $F(2, 29) = 8.89$, $p = .001$, $\eta_p^2 = .38$, and Affect Relation $\times$ Response Relation, $F(2, 29) = 13.15$, $p < .001$, $\eta_p^2 = .48$, were also significant, indicating response facilitation for distractor feature repetition trials in the response repetition conditions, but response impairment due to distractor feature repetition in the response change condition. The three way interaction of Response Relation $\times$ Person Relation $\times$ Affect Relation was not significant, $F(2, 29) = 1.98$, $p = .156$, $\eta_p^2 = .12$. Planned contrasts indicated that the two way interactions were due to differences between response change and the two response repetition conditions, $F(1, 30) = 14.57$, $p < .001$, $\eta_p^2 = .33$ for Person $\times$ Response Relation and $F(1, 30) = 19.20$, $p < $

$.001$, $\eta_p^2 = .39$ for Affect $\times$ Response Relation, and not due to differences between the two levels of response repetition, $F(1, 30) < 1$, $\eta_p^2 < .01$ for Person $\times$ Response Relation and $F(1, 30) < 1$, $\eta_p^2 = .02$ for Affect $\times$ Response Relation.

The same ANOVA on error rates yielded a significant main effect of response relation, $F(2, 29) = 71.55$, $p < .001$, $\eta_p^2 = .83$, indicating that participants made fewer errors in the response repetition/target repetition than in the response change condition and fewer errors in the response change than in the response repetition/target change condition. Similar to the result pattern of the RTs, both interactions of Person Relation $\times$ Response Relation, $F(2, 29) = 8.39$, $p = .001$, $\eta_p^2 = .37$, and of Affect Relation $\times$ Response Relation, $F(2, 29) = 6.44$, $p = .005$, $\eta_p^2 = .31$, were significant. Interestingly, the three-way interaction was significant, as well, $F(2, 29) = 6.78$, $p = .004$, $\eta_p^2 = .32$, indicating that the repetition of one distractor feature increased the effect of response retrieval due to the other distractor feature. None of the other effects was significant, $Fs < 1$, $ps > .03$.

Additivity of distractor-response bindings. For further analyses we again collapsed the data of the target repetition and target change conditions in response repetition trials and included only the factor response relation (repetition [with target repetition and target change] vs. change). As in the first two experiments, we took a closer look at the data to decide how closely these findings conformed to additivity of individual distractor feature-response bindings.

We again compared retrieval effects due to the repetition of individual distractor features (while the other distractor feature changed) with those retrieval effects due to a combined repetition of the distractor features. Retrieval effects due to the repetition of individual features and the retrieval effect due to the combined repetition of both distractor features were computed as in Experiment 2. As before, the retrieval effects due to the repetition of individual features (person: $M = 8$ ms, $SD = 22$ ms, affect: $M = 8$ ms, $SD = 20$ ms) did not differ from each other, $t(30) = 0.87$, $p = .932$, $d = 0.02$. That is, similar response retrieval was triggered by distractor person repetition (when affect changed) and by distractor affect repetition (when the person changed). The positive correlation between the retrieval effect due to person-repetition and the retrieval effect due to affect repetition was significant, $r = .466$, $p = .008$. More importantly, both retrieval effects due to the repetition of an individual distractor feature were significantly smaller than the retrieval effect due to the combined repetition of both distractor features ($M = 23$ ms, $SD = 22$ ms), $t(30) = 4.45$, $p < .001$, $d = 0.80$, for person, and $t(30) = 4.19$, $p < .001$, $d = 0.75$, for affect retrieval effects. The added retrieval effects due to individual distractor feature repetition did not differ

Table 4

Mean Response Times (in ms) and Mean Error Rates (in Percent) in Experiment 3 as a Function of Response Relation, Distractor Person Relation, and Distractor Affect Relation

	Response repetition/ Target repetition		Response repetition/ Target change		Response change	
	Distractor affect repetition	Distractor affect change	Distractor affect repetition	Distractor affect change	Distractor affect repetition	Distractor affect change
Distractor person repetition	435 (1.6)	441 (2.2)	474 (7.8)	483 (10.3)	513 (10.6)	506 (7.3)
Distractor person change	442 (2.5)	449 (2.9)	486 (11.1)	483 (10.6)	508 (8.4)	502 (7.4)

significantly from the retrieval effect due to the combined repetition of both distractor features, $t(30) = 1.44$, $p = .162$, $d = 0.26$, see Figure 5.

In the same analyses on error rates, we found a significant positive correlation between the retrieval effects due to individual feature repetitions, $r = .461$, $p = .009$. The difference between the retrieval effects due to individual feature repetitions and due to the joint repetition of both distractor features were significant, $t(30) = 4.55$, $p < .001$, $d = 0.82$, for person relation, and $t(30) = 4.69$, $p < .001$, $d = 0.84$, for affect relation. Notably, the retrieval effect due to joint distractor feature repetition was larger than the added retrieval effects due to the individual distractor features, $t(30) = 3.11$, $p = .004$, $d = 0.56$.

Discussion

Using photographs of persons with the same hair color, Experiment 3 replicated the results found in Experiment 2 in the analyses of the RTs. In contrast to Experiment 2, this finding cannot be driven by retrieval effects due to the very simple feature hair color. Instead, we can assume that the complex feature "person" was integrated with and later on retrieved a response. Yet, the pattern of the error rates provided a first indication that complex stimuli (i.e., pictures of faces) tend to be integrated with responses according to a configural approach. Participants showed significantly more response retrieval due to person repetition if the exact picture (with the previous affect) was repeated than if a different picture of the person (showing a different affect) was presented. Taken together Experiments 2 and 3 indicate that more complex features like a person or an affect can become individually integrated with a response and retrieve it later on.

Although configural integration of distractors with responses might have influenced the results of Experiment 3, still RTs clearly indicate elemental integration of person and affect with the re-

Figure 5. Response retrieval effects due to repetition of distractor features in Experiment 3. Distractor-response binding effects are calculated as the distractor feature repetition effect (as compared to complete change of distractor features) in response repetition trials minus distractor feature repetition effects in response change trials. Note that distractor feature repetition means repetition of only one distractor feature in individual effects, and simultaneous repetition of both distractor features in the joint effect. The rightmost bar shows the sum of the two individual retrieval effects that are visualized in the left two columns. Error bars depict standard errors of the mean. n.s. = nonsignificant.

sponses. Notably, this result pattern is likely due to the particular way faces are processed (Adolphs, 2002; Rossion, 2014; Allison et al., 1999; Pizzagalli et al., 1999). While identity and facial expression (the two features that were varied in Experiments 2 and 3) are automatically extracted from upright pictures, presenting faces upside-down is known to counter automatic extraction of individual features of the face (Murray, Yong, & Rhodes, 2000; Yin, 1969), especially emotional expressions (McKelvie, 1995). That is, presenting the faces in an upright manner was likely critical in the previous experiments, to enable identification of more complex individual features. To test this assumption, we presented the same face distractors rotated by 180° (i.e., upside-down) in Experiment 4.

Experiment 4

The fourth experiment was designed to maximize the likelihood that not repetition of individual features of the photographs, but only of the entire distractor configuration is integrated with the response and hence triggers response retrieval. Experiment 4 therefore was a replication of Experiment 3, with the difference that distractor faces were presented upside-down. If the extraction of the features "person" and "affect" relies on the way of processing that is typical for face stimuli, elemental binding of these automatically extracted features should only be possible for upright faces. If automatic processing of face stimuli is prevented by inverting the face, person identity and affect should not be easily extracted. Consequently, distractor-response binding effects cannot rely on elemental binding of these individual features to the response, but only on binding of the entire stimulus configuration to the response. That is, for inverted faces, we predicted significantly more response retrieval due to the joint repetition of both features as compared to the sum of the repetition effects due to the individual repetition of each feature. This pattern would be indicated by a significant three-way interaction of response relation, distractor person relation, and distractor affect relation and, possibly, absent two-way interactions involving each individual feature.

Method

Participants. Thirty-two participants (26 women) from the city of Würzburg were recruited and received monetary compensation. Their median age was 21 years with a range from 18 to 55 years.

Design, materials, and procedure. Design, materials and procedure were identical to Experiment 3 with the exception that all distractor faces were presented upside-down.

Results

According to the same criteria as in Experiment 2, 16.6% of all trials were discarded. Mean RTs and error rates are depicted in Table 5.

Overall analysis. In a 3 (Response Relation: response repetition/target repetition vs. response repetition/target change vs. response change) × 2 (Distractor Person Relation: repetition vs. change) × 2 (Distractor Affect Relation: repetition vs. change) ANOVA on RTs, the main effect of response relation was signif-

Table 5
Mean Response Times (in ms) and Mean Error Rates (in Percent) in Experiment 4 as a Function of Response Relation, Distractor Person Relation, and Distractor Affect Relation

	Response repetition/ Target repetition		Response repetition/ Target change		Response change	
	Distractor affect repetition	Distractor affect change	Distractor affect repetition	Distractor affect change	Distractor affect repetition	Distractor affect change
Distractor person repetition	420 (1.9)	424 (1.6)	458 (8.1)	462 (8.7)	492 (9.1)	484 (7.5)
Distractor person change	421 (2.0)	425 (2.2)	466 (8.2)	463 (9.0)	484 (7.7)	488 (6.6)

icant, $F(1, 31) = 101.55$, $p < .001$, $\eta_p^2 = .87$, indicating faster responses for response repetition/target repetition trials than for response repetition/target change trials, and faster responses for response repetition/target change than for response change trials ($M_{RRtr} = 423$ ms, $SD_{RRtr} = 44$ ms; $M_{RRtc} = 462$ ms, $SD_{RRtc} = 55$ ms; $M_{RC} = 487$ ms, $SD_{RC} = 48$ ms). The two way interaction of Affect Relation × Response Relation, $F(1, 30) = 4.85$, $p = .015$, $\eta_p^2 = .24$, was also significant, indicating response facilitation for distractor repetition trials in the response repetition conditions, but not in the response change condition, while the two-way interaction of Person Relation × Response Relation, $F(1, 30) = 3.17$, $p = .056$, $\eta_p^2 = .18$, just missed significance. Importantly, the three-way interaction of Person Relation × Affect Relation × Response Relation was significant as well, $F(1, 30) = 4.48$, $p = .020$, $\eta_p^2 = .23$, indicating more response retrieval due to distractor repetition, if both features were repeated together than when the features were repeated individually. Planned contrasts indicated that the interactions including response relation were due to differences between response change and the two response repetition conditions, $F(1, 31) = 6.46$, $p = .016$, $\eta_p^2 = .17$ for Person × Response Relation, $F(1, 31) = 4.01$, $p = .054$, $\eta_p^2 = .12$ for Affect × Response Relation, and $F(1, 31) = 8.84$, $p = .006$, $\eta_p^2 = .22$ for the three-way interaction, and not due to differences between the two levels of response repetition, $F(1, 31) < 1$, $\eta_p^2 = .02$ for Person × Response Relation, $F(1, 31) < 1$, $\eta_p^2 = .02$ for Affect × Response Relation, and $F(1, 31) = 1.20$, $p = .28$, $\eta_p^2 = .04$ for the three-way interaction. None of the other effects was significant, all $Fs < 1$, η_p^2s < .03.

The same ANOVA on error rates showed a similar pattern and yielded a significant main effect of response relation, $F(2, 30) = 55.87$, $p < .001$, $\eta_p^2 = .79$. The interaction of Affect Relation × Response Relation, $F(2, 30) = 4.30$, $p = .023$, $\eta_p^2 = .22$, was significant, while the interaction of Person Relation × Response Relation, $F(2, 30) = 2.36$, $p = .111$, $\eta_p^2 = .14$, and the three-way interaction, $F < 1$, $\eta_p^2 < .01$, were not significant. None of the other effects was significant either, $Fs < 1$, $ps > .02$.

Additivity of distractor-response bindings. For further analyses we again collapsed the data of the target repetition and target change conditions in response repetition trials and included the factor response relation (repetition [with target repetition and target change] vs. change). As in Experiments 1 through 3, we took a closer look at the data to decide how closely these findings conformed to additivity of individual distractor feature-response bindings.

To this end, we again compared retrieval effects due to the repetition of individual distractor features (while the other distractor feature changed) with those retrieval effects due to a combined

repetition of the distractor features. Retrieval effects due to the repetition of individual features and the retrieval effect due to the combined repetition of both distractor features were computed as in the previous experiments (person: $M = -2$ ms, $SD = 17$ ms; affect: $M = -3$ ms, $SD = 19$ ms). The (nonsignificant) retrieval effects due to the repetition of individual features did not differ from each other, $t(31) = 0.58$, $p = .564$, $d = 0.10$. That is, similar for both features, no response retrieval was triggered by distractor person repetition (when affect changed) and by distractor affect repetition (when the person changed). Both retrieval effects due to the repetition of an individual distractor feature were significantly smaller than the retrieval effect due to the combined repetition of both distractor features ($M = 10$ ms, $SD = 21$ ms), $t(31) = 3.60$, $p = .001$, $d = 0.64$, for person, and $t(31) = 3.57$, $p = .001$, $d = 0.63$, for affect retrieval effects. Most importantly, the retrieval effect due to the combined repetition of both distractor features was significantly larger than the added retrieval effects due to individual distractor feature repetition, $t(31) = 2.97$, $p = .006$, $d = 0.53$, see Figure 6.

The same analyses on error rates showed a similar numerical pattern but only revealed a significant positive correlation between
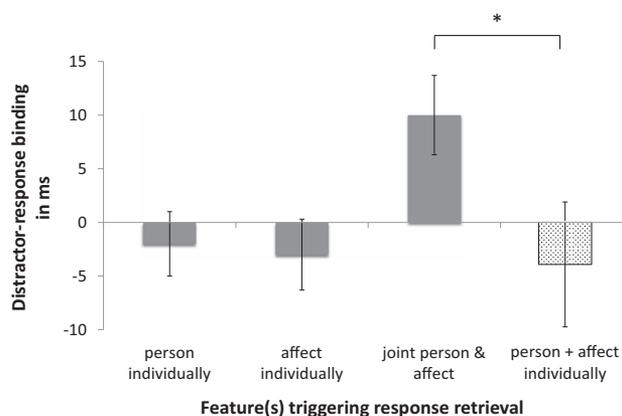
Figure 6. Response retrieval effects due to repetition of distractor features in Experiment 4. Distractor-response binding effects are calculated as the distractor feature repetition effect (as compared to complete change of distractor features) in response repetition trials minus distractor feature repetition effects in response change trials. Note that distractor feature repetition means repetition of only one distractor feature in individual effects, and simultaneous repetition of both distractor features in the joint effect. The rightmost bar shows the sum of the two individual retrieval effects that are visualized in the left two columns. Error bars depict standard errors of the mean.

the retrieval effects due to individual feature repetitions, $r = .419$, $p = .017$. None of the other effects was significant, $|t|$s < 1.8, ps $> .08$.

Discussion

When presenting inverted face distractors, we found clear overadditivity of joint feature repetition in Experiment 4. Apparently, if faces are presented upside-down, integration of very basic forms and colors to the more sophisticated "concept features" *person* and *affect* is unlikely (see, e.g., Yin, 1969, or Murray et al., 2000). For upside-down faces that repeat the depicted person (but not the affect) some basic forms and colors are repeated, but most likely more than half of these features will differ between the two pictures. Hence, the difference of this case to a complete picture repetition is larger than in cases in which a picture can easily be encoded as being composed of the two features person and color (i.e., in upright faces). In contrast to the previous experiments, we found significantly more response retrieval due to joint person and affect repetition as compared to the added retrieval effects due to individual repetition of person and affect (i.e., overadditivity of the individual retrieval effects).

General Discussion

Summary

The present study aimed to elucidate the structure of bindings between irrelevant stimuli and responses. We analyzed under what circumstances distractor-response binding effects can be accounted for by either configural or elemental associations between distractor stimulus (features) and a response. The configural hypothesis predicted response retrieval only due to the repetition of an entire distractor object, while the elemental hypothesis assumed response retrieval to be a combination of individual retrieval effects due to distractor feature repetition. In four experiments, we compared response retrieval effects due to individual distractor feature repetition with the retrieval effect due to a repetition of the distractor feature combination (i.e., the entire distractor stimulus). Both, for simple distractor features (Experiment 1), as well as for more complex distractor features (Experiment 2), we found elemental bindings between features and responses. Moreover, additional tests substantiated that retrieval effects due to individual distractor feature repetitions work additively. Hence, the data of these two experiments clearly seem to support the elemental view of distractor-response binding: A response-retrieval effect due to distractor stimulus repetition is the sum of all individual response retrieval effects that are due to the repetitions of the individual features of the distractor stimulus. Yet, when stimulus identification became more difficult by using more similar distractor pictures (Experiment 3), we found a first indication that distractor feature-response integration tended to have an additional benefit due to configural binding (while at the same time showing evidence for response retrieval due to elemental binding). Finally, preventing automatic stimulus encoding by presenting face pictures upside-down (Experiment 4), we found clear evidence for exclusively configural distractor-response binding.

Interestingly, a comparison of the effects observed in Experiment 1 and 2 reveals that the pattern of distractor-response bind-ings does not differ between very simple and more complex distractor stimuli. Apparently, the mechanism of response retrieval works in a similar way for distractor affect (and person) repetition as for distractor color (and shape) repetition. Notably, we found this similarity although only the repetition of color or shape (Experiment 1) ensured the repetition of salient physical features. In contrast, repeating distractor affect but changing distractor person also involved some variation of colors and shapes that had to be combined to encode the distractor affect. This pattern indicates that different interpretations of a distractor are simultaneously integrated with responses. More specifically, one can assume that the interpretations of the distractor stimuli as (a) a certain person who shows (b) a certain affect in Experiments 2 and 3 were individually integrated with the executed response and could retrieve the response later on.

Conditions for Configural and Elemental Integration

But what exactly determines which aspects of a complex distractor stimulus are coded as individual features? For the face stimuli used in Experiments 2 and 3, specific processing systems are well-documented in the literature (Bruce & Young, 1986; Haxby et al., 2000), suggesting that the distinction of person and affect as individual features might actually be due to the architecture of the human cognitive system, and specific for this class of stimuli. For stimuli that do not draw on such specialized processes, it seems likely that the task context determines what is coded as a feature. This assumption would explain why Frings et al. (2013) found distractor-response binding effects for purely semantic rather than perceptual relations between distractors that were associated with a response and distractors that triggered response retrieval later on (e.g., the sound of a frog retrieving the response that was given in the presence of a visual representation of a frog). Notably, increasing the difficulty of distinguishing the persons in Experiment 3 already provided a context that enabled additional retrieval due to the specific stimulus configuration as suggested by the corresponding error data. This may be another indication that compound features can be integrated with responses as long as they are clearly associated with a certain concept. Because the two persons looked rather similar in Experiment 3 and no other information about them was available, participants were unlikely to have two clearly differentiable concepts of the depicted persons.

A profound impact of task context on how distracting information is processed also seems likely when considering evidence from studies on subliminal priming. In these studies, participants were to classify stimuli according to different categories that were mapped to different responses. In these settings, participants can adopt one of two different strategies to determine the correct response: They can either apply the mapping rule in each trial anew to arrive at the correct semantic classification or they can opt for learning item-specific responses that are retrieved if the item in question is encountered. Which of the two strategies is used in a given setting can be addressed by using subliminal prime stimuli that never occur as targets and that are therefore never perceived consciously. For these "novel primes," priming effects can only emerge due to semantic classifications (if at all), whereas influences based on item-specific coding (e.g., in terms of perceptual features) are obviously restricted to prime stimuli that have been experienced as targets before.

Now, if participants were confronted with only a limited number of potential targets per category, novel primes did not elicit any priming effects. By contrast, the same novel primes elicited robust priming effects if the mere number of potential targets was increased (Kiesel, Kunde, Pohl, & Hoffmann, 2006; Pohl, Kiesel, Kunde, & Hoffmann, 2010). These findings suggest that participants seem to restrict distractor processing to perceptual features if the task context favors such a level of analysis (at least for subliminal stimuli) whereas they process semantic features if the task context favors this higher level of analysis (see also Kunde, Kiesel, & Hoffmann, 2003).

Whether such effects also apply to supraliminal stimuli in general, and distractor-response bindings in particular is of course speculative; in any case, these findings seem to suggest that at least two factors determine what is processed as individual distractor feature: Special mechanisms for certain classes of relevant stimuli (such as faces or other domains of expertise) on the one hand, and more flexible processing adjustment to current task contexts on the other hand. No matter which of these processes applies to a given situation, the present results provide evidence that *multiple* features for one and the same distractor can be integrated with a response simultaneously, and that each of these bindings independently of the others contributes to the retrieval of the response.

The present findings are further in accordance with evidence that distractors are independently integrated with the response and the target stimulus that prompts the response (Giesen & Rothermund, 2014). These authors found distractor-response- and distractor-target bindings to work in parallel and in an additive way. That is, their results indicated that distractors can be integrated with more than one code simultaneously, suggesting that event files include multiple bindings regarding distractor stimuli. Similarly, we found evidence for multiple bindings between a distractor stimulus and the response. Hence, the present study gives insight into the specific structure of bindings between distractors and other items included in the event file. Moreover, it provides a first characterization of situational factors that can influence this structure: Only easily distinguishable concept features of a distractor are separately integrated with and can retrieve the response. One might speculate that distractor-target bindings have a similar structure as we found for distractor-response bindings. Regarding both studies in concert, it can be concluded that event files are retrieved via several bindings. These retrieval processes apparently function in parallel and add up to the eventual reactivation of larger parts of (or the entire) event file.

It might also be interesting to note that the individual distractor-response binding effects for shape and color were correlated across participants, in Experiment 1. In addition, the same pattern was found regarding person and affect bindings to responses in Experiments 2 and 3. This can be interpreted as a first indication that the extent to which mechanisms of distractor-response binding influence behavior, reflect (reliable) interindividual differences in binding. If someone tends to integrate response irrelevant stimuli with responses, such integration seems to be generally probable across different situations and stimuli. Whether or not such individual differences are also stable over time or whether it resembles a more transient state cannot not be decided based on the present data.

The current results also allow for a first characterization of how other people are coded for action control. The view that separate features of our social partners and their perceivable behavior can become linked to own motor action fits with recent findings on the role of action effect anticipations in social contexts (Pfister, Dignath, Hommel, & Kunde, 2013). In these studies, participants worked in pairs and a model response—a short or a long keypress—was either imitated or counterimitated by the second participant. Model responses that were to be imitated were initiated faster than model responses that were to be counterimitated, indicating that the anticipation of the upcoming response affects action control (for converging evidence with face stimuli, see Kunde, Lozo, & Neumann, 2011). Assuming that response features are encoded in the same representational systems as stimulus features, it is conceivable that also individual response features can become part of elemental bindings. In this respect, the present results might suggest that it is not the imitator action itself that is integrated into the corresponding event file, but rather only an individual feature such as the response duration.

Relations to Learning

Our notion of elemental and configural associations between stimulus features and a response are similar to elemental and configural accounts for classical conditioning mechanisms (Pearce & Bouton, 2001; Shanks, Charles, Darby, & Azmi, 1998). Rescorla and Wagner (1972), for instance, proposed elemental associations of individual conditional stimulus (CS) features with the appearance of the unconditional stimulus (US). That is, different stimuli (CS) that occur together to predict an outcome (US) gain individual associative strengths with the US. This structure is similar to the individual bindings between different distractor features and the response that we observed. The opposite applies to negative patterning, however (i.e., the combination of AB is not reinforced and thus does not gain any associative properties, while A and B individually become associated with the outcome). This phenomenon is more easily explained by a configural approach, but can be accounted for by elemental accounts if a *unique-cue* hypothesis is added: A compound stimulus creates a property unique to a particular configuration of elements and via this cue the compound stimulus can function as a single element predicting a certain US. Applying the same considerations to bindings between stimulus features and responses might provide one answer to the present question of the boundary conditions for when an element can be composed of a number of more basic elements. Assuming that similar mechanisms are at work in conditioning and in binding, a "combined element" might be defined via its predictive value. For example, if a certain combination of colors and forms predict that you will have to deal with an angry person, these feature combinations can form a sort of unique cue and be encoded as one more complex feature. Note that such a predictive value outside of experimental situations might more generally be described as a concept (of anger in the example). Regarding these parallels between the mentioned findings in conditioning and our present findings, one might consider that the presently investigated mechanisms are indeed early processes in learning.

The present data may also give insight into the more general representation of the used distractor stimuli. Being presented as the background on which the targets appeared, one might assume that either feature was encoded as a general context. Based on research on conditioning, different binding effects would be expected if a

feature was interpreted as context as compared to an interpretation as individual stimuli comprising both features. Bouton and colleagues found that performance to a CS does not rely on a summation of context-US and CS-US associations (Bouton, 1984; Bouton & King, 1986). Instead a context seems to retrieve CS-US associations (Bouton & Bolles, 1985). Assuming that context-response and stimulus-response bindings are comparable to the associations mentioned earlier, one might have expected retrieval effects only in complete stimulus repetition trials. Instead, distractor stimulus features in the first three experiments were integrated with and independently retrieved the response. A different possibility is that the entire distractor stimuli were encoded as contexts. Yet, although contexts should not be integrated with responses, we found significant binding between entire distractor stimuli and responses. In sum, we assume that distractor stimuli were represented as individual stimuli and neither individual distractor features nor the entire distractors were interpreted as context.

Conclusions

In conclusion, we presented evidence that bindings between distractor stimuli and responses are similarly nuanced as target-response bindings. Particularly, each individual feature of a distractor stimulus can in principle become part of an elemental binding with the current response and, in turn, repetition of each distractor feature contributes to the effect of response retrieval due to distractor repetition. Such features can be relatively complex or be defined by interpretations of certain distractor properties, as long as each feature is easily encoded and interpreted. With increasing difficulty to distinguish different features from each other, however, such elemental binding mechanisms are supported or even substituted by configural processing of entire distractor objects. This seems to be a mechanism that is well adjusted to help everyday action control, facilitating retrieval of an earlier response more in situations that share an increasing number of salient details with the previous situation.

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