Local Contextual Cuing in Visual Search

Joachim Hoffmann and Albrecht Sebald

University of Würzburg, Germany

Abstract. Previous research has indicated that covariations between the global layout of search displays and target locations result in contextual cuing: the global context guides attention to probable target locations. The present experiments extend these findings by showing that local redundancies also facilitate visual search. Participants searched for randomly located targets in invariant homogenous displays, i.e., the global context provided information neither about the location nor about the identity of the target. The only redundancy referred to spatial relations between the targets and certain distractors: Two of the distractors were frequently presented next to the targets. In four of five experiments, targets with frequent flankers were detected faster than targets with rare flankers. The data suggest that this local contextual cuing does not depend on awareness of the redundant local topography but needs the redundantly related stimuli to be attended to.

Keywords: visual search, context effects, cuing

Whatever one intends to do, one first has to determine the location of the target-object to which the intended behavior refers. Usually there are no problems localizing target-objects we are dealing with. For example, if we are going to switch on the light in our living room, we instantly attend the place where we know the switch to be and when we look for a bottle of wine in the fridge, we automatically attend the area where the wine is usually placed.

Besides daily experience, experimental data also show that objects are detected faster in familiar than in uncommon contexts (e.g., Antes, Penland, & Metzger, 1981; Biederman, 1972; Boyce, Pollatsek, & Rayner, 1989; Friedman, 1979; Palmer, 1975). A toaster, for example, is detected faster in a picture of a kitchen than in one of a harbor. However, this *congruency effect* only occurs if the objects are presented at their usual locations. If objects are to be searched in a congruent context, but are placed at an unusual location, searching typically takes even longer than in an incongruent context (Hoffmann & Klein, 1988; Meyers & Rhoades, 1978). Thus, the effortlessness with which we typically localize objects is apparently due to the search for them mostly being guided by expectations about their probable locations.

Although this ubiquitous guidance of visual search by familiar contexts is a fundamental aspect of behavior, only a few studies so far have explored the acquisition of the corresponding spatial knowledge. Shaw & Shaw (1977) were the first to show that when participants repeatedly search for a particular target presented in different locations, detection is faster the more frequently the target has previously been presented at the current location. This suggests that the deployment of attention adapts to the experienced location probabilities (Shaw, 1978).

Miller (1988) extended this finding. In his experiments, participants had to search for one of two target-letters in a four-letter string. Both targets were presented equally often, but occurred with different frequencies in the four locations. The results showed that detection was fastest at the location where targets were presented most frequently. This corresponds to the location probability effect reported by Shaw & Shaw (1977). Furthermore, there was an interaction between target location and target identity: In each location, the target that had been presented there more frequently was detected faster. Apparently, participants developed separate expectancies for each target at each of the different string locations.

Chun & Jiang (1998, 2003) additionally showed that visual search also adapts to covariations between varying contexts and varying target locations. Participants searched for rotated T's among heterogeneously rotated L-distractors. The target and the distractors were randomly arranged except for twelve fixed configurations that were repeatedly presented across blocks. Participants detected the targets increasingly

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faster in the repeating compared to the random configurations, suggesting that the contingencies between the layout of the fixed configurations and the respective target location were learned and used to guide the search.

Finally, Hoffmann & Kunde (1999) showed that participants even acquire knowledge about the probabilities with which different targets appear in different contexts at different locations. In this study, participants searched for the target-letters H and F among six distractor-letters that were arranged to form a shape like a wave or like a bird. In each of the configurations, one of the targets appeared with equal frequency at each of the possible locations, whereas the locations of the other target were distributed unequally. The data clearly showed that in whichever location the target was presented, the target presented there more frequently was detected faster. Apparently, participants learned about the probabilities with which each of the two targets appeared at the different locations in each of the two configurations (wave and bird) and they used this knowledge in order to guide the search for the targets (see also Kunde & Hoffmann, 1998).

Altogether, the reported findings consistently show that humans are very sensitive to the spatial arrangement of stimuli and to contingencies between the global layout and the location of relevant objects. When a searched object is repeatedly found at a particular place in a certain context, the global context guides attention to the locations where the object is most likely to be found. This contextual cuing of probable target location (Chun & Jiang, 1998) reveals a very effective adaptation of the visual system to redundancies in the spatial distribution of objects as the global aspects of visual stimulation that are available early and easy to find (e.g., Navon, 1977, 1981; Hoffmann & Zießler, 1983) guide visual processing to the small details which otherwise would be hard to find (see Hoffmann, 1995, for an elaborated discussion of this point).

Olson and Chun (2002) recently extended these findings in showing that it suffices for contextual cuing to occur if merely the neighborhood of the target is arranged redundantly. In their visual-search experiments, the spatial layout of some of the distractors was repeatedly presented together with a target at a fixed location. These "partial" covariations between the layout of some of the distractors and the target location facilitated search if the repeating context was placed in the neighborhood of the target. However, if there were intervening randomly located distractors between the target and the repeating context, no contextual cuing took place. Apparently, not only the global context, but also redundancies in the neighborhood of targets can be used to guide visual search to probable target-locations.

The present experiments further explore this apparent sensitivity of the visual system to local redundancies. In comparison to the study of Olson & Chun (2002), our experiments differ in several aspects: First, stimuli always appear in the same arrangement, i.e., there is no variation of the global layout of the search display. Second, the targets as well as the distractors appear equally probable at each possible location, i.e., the target-location is unpredictable in every trial. Finally, the only redundancy refers to the targets frequently appearing in a certain spatial relationship to particular distractors. Thus, we do not explore whether the visual search adapts to covariations between partial configurations and target-locations in otherwise random stimulus distributions, as Olson & Chun (2002) did, rather we are interested in whether the visual system is also sensitive to a repeating topography of certain details at random locations in a constant global context.

Invariant topographies of details are characteristic for most objects: the handle of a jug is opposite its muzzle, the keyhole is below the doorknob, the tap is above the sink, etc. The arrangement of the object-parts is typically dictated by their function and mostly goes along with a certain location on the object. However, sometimes details are redundantly arranged at unpredictable locations. For example, the spatial relation between tap and sink is fixed, but they may appear almost anywhere in the bathroom. Likewise, in German the letters *c*, *h*, and *s* are often arranged in the order *sch*, which can appear at any position within a word. The present experiments were designed in order to examine whether such repeating arrangements of details at random locations of a particular global context also affect visual search, as it has been shown for covariations between contextual information and target locations. To illustrate, imagine that in your bookcase a certain book is equally probable at each location but is frequently placed between two other books. The question we are going to explore is whether such a local redundancy would facilitate the search for this particular book.

Experiment 1

Participants performed a visual search task. In each individual trial, six letters were presented that always contained one of two target-letters. Participants were asked to determine target identity and to press a corresponding button as fast as possible. In order to keep the global layout of the search display constant, the six letters were always arranged in a circle (see Figure 1a). Furthermore, each target appeared with equal frequency at each of the six possible locations so that the global layout provided information neither about the identity of the target nor about its location. The only redundancy concerned the distractors that appeared next to the respective target. Two of the distractors were frequent flankers of the targets, whereas two other distractors framed the targets less frequently. Thus, the global context was kept constant but targets appeared either in a frequent or in a rare *local* context. A faster detection of targets embedded in the frequent local context would indicate that participants are sensitive for redundancies in the spatial relations of the targets to certain distractors, independent of the target location.

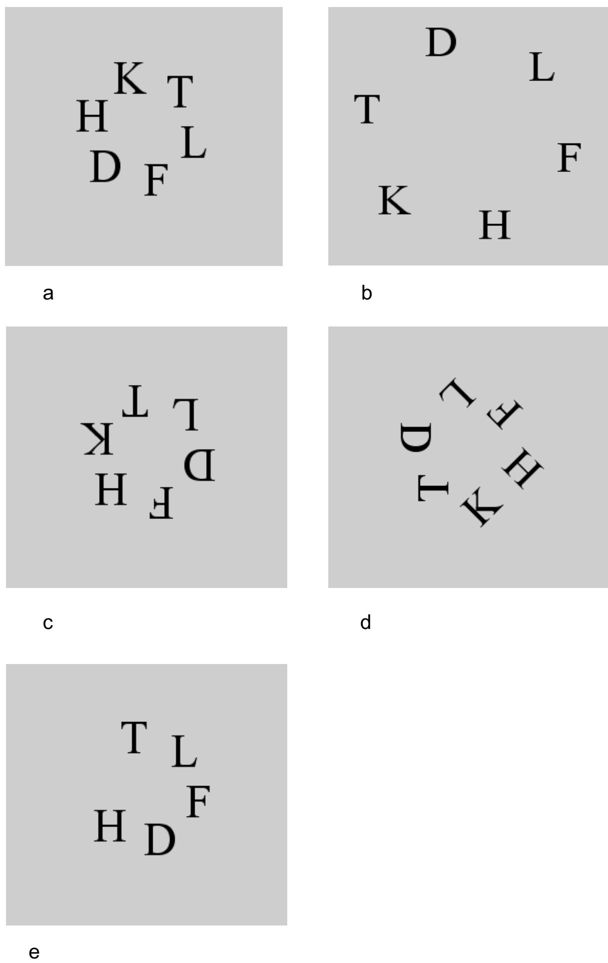

Figure 1. Illustration of the search displays as they appeared in Experiment 1 (a), in Experiment 2 (b), in Experiment 3 (c), in Experiment 4 (d) and after the response in Experiment 5 (e).

Method

Task, Apparatus, and Stimuli

Participants were requested to search for the target-letters K and P and to press the button assigned to the current target as fast as possible. The keys “c” and “m” on a standard computer keyboard served as response buttons and the target-key mappings were balanced between participants. The letters H, F, L, D, and T served as distractors. The letters were in Times New Roman font. They appeared on the screen with a height of 7.8 mm and were seen from a distance of about 60 cm. In each individual trial, one of the targets and five distractors were presented at the center of a 15-inch VGA monitor, evenly distributed around a virtual circle with a diameter of about 4 degrees. Reaction times (RTs) were measured from the onset of the letters until the onset of the response to the nearest millisecond.

The arrangement of targets and letters was organized in two basic sets that differed with respect to the distractors presented next to the target. A basic set was composed of 72 stimuli, 36 for each of the two targets[1]: The respective target was presented once at each of the six possible locations with two particular distractors next to it in a fixed relation. In each of the six target locations, the remaining three distractors were arranged in all possible six sequences resulting in 36 (6 times 6) stimuli. Consequently, in each set each target and each distractor appeared equally often at each of the six locations and all neighborhood relations between the letters were balanced except the flankers of the targets: There were two different pairs of flankers (H–T versus D–L). Throughout the experiment, the basic set with one of the two pairs was presented five times, whereas the set with the other flanker pair was presented once, resulting in a total of 432 trials (5 × 72 plus 1 × 72). In other words, in 432 trials, each of the two targets appeared 180 times framed by the distractors H and T and only 36 times framed by the distractors D and L (or vice versa), both cases being distributed equally across the six possible locations. Consequently, neither the location nor the identity of the target (and so the required response) correlated with the respective framing distractors.

[1] The number of stimuli was restricted to six in order to allow for balancing not only the frequency of the targets and distractors at each of the possible locations but also of the neighborhood relations between distractors. One additional distractor would require a basic set of 336 stimuli (7 × 24 × 2) and the number of necessary trials would increase to 2016.

Procedure

Each individual trial started with the presentation of a short tone (20 ms, 800 Hz) as a ready signal. Eleven hundred milliseconds after the onset of the tone, the ring of letters was presented. Participants were instructed to respond to the current target as fast as possible by pressing the corresponding key. With the response, the letters disappeared and an accuracy feedback was given for 1000 msec. After an intertrial interval of another 800 msec, the next trial started. The 432 trials were presented in random order. Trials with a false response were repeated. After the reaction time session was finished, participants were asked whether they had noticed that some of the distractors had been presented next to the targets more frequently than others, and they were invited to indicate which distractors they thought might have been the frequent flankers for each of the two targets.

Participants

Sixteen undergraduate students at University of Würzburg (14 female, 2 male) participated in exchange for a course credit for their undergraduate psychology course. The mean age was 21.25 years ($SD = 2.35$). All participants were naive regarding the context manipulation.

Results and Discussion

Erroneous responses (4.0%) and responses with RTs below 100 ms and above 3000 ms (0.2%) were excluded from the analysis of RTs. The mean RTs of the remaining responses were calculated for each participant separately for the frequent and the rare local context. The mean RTs amounted to 598 ms for the rare and 589 ms for the frequent context. A one-tailed *t* test for correlated samples revealed that the decrease of RTs to targets with the frequent context failed to reach significance, $t(15) = 1.475$, $p = 0.0805$. The error rates in trials with rare and frequent context were 3.86% and 3.95%, respectively. This difference was not significant either, $t(15) = -0.181$, $p = 0.4295$).

The failure to find a verifiable impact of the local context on search performance might have been due to the present task being too easy. As letters are highly overlearned stimuli, the targets often might have been detected at first sight so that the flankers could influence detection latencies only marginally, if at all. Other studies indeed have found that redundancies in the stimulus material influenced performance only, if task demands were neither too low nor too high (Hartman, Knopman, & Nissen, 1989; Musen, 1996). Accordingly, in the three following Experiments, we tried to make the search more difficult without changing the global arrangement and the number of stimuli on the display.

Experiments 2–4

In Experiment 2, we enlarged the diameter of the virtual circle at which the targets and the distractors were evenly distributed from about four to about eight degrees (see Figure 1b). As the size of the letters remained unchanged, the distance between letters increased from about 1.3 cm to about 2.6 cm. Consequently, an immediate detection of the target should be less probable, making search more difficult. In Experiment 3, letters were again evenly distributed around a virtual circle of four degrees as in Experiment 1, but now all letters were presented upside down (see Figure 1c). It is well known that deviations from the upright orientation make alphanumeric stimuli harder to recognize (Jolicoeur, 1985; Jolicoeur, Snow, & Murray, 1987; Tarr & Pinker, 1989). Finally, Experiment 4 further increased task difficulty by presenting each of the letters in a different deviation from the upright orientation (see Figure 1d). We expected that under these increased task demands targets with the frequent local context would be detected faster than targets with the rare context.

Method

Task, Apparatus, Stimuli, and Procedure

All conditions of Experiment 1 were replicated except for the distance between the letters in Experiment 2 and the orientation of the letters in Experiments 3 and 4. In Experiment 3 all letters were presented upside down. In Experiment 4 there were six possible deviations from the upright orientation (45°, 90°, 135°, 225°, 270°, and 315°) that were randomly distributed among the six letters in each trial.

Participants

Forty-eight undergraduate students at University of Würzburg (41 female, 7 male) participated in exchange for a course credit; 16 in Experiments 2, 3, and 4, respectively. The mean age was 22.42 years ($SD = 3.95$). All participants were naive regarding the context manipulation.

Results and Discussion

Erroneous responses (4.4%) and responses with an RT below 100 ms and above 3000 ms (0.3%) were excluded from the analysis. Mean RTs of the remaining responses and error rates were calculated for frequent and rare local context, separately for each of the experiments.

In Experiment 2 the mean RTs amounted to 636 ms for the rare and to 619 ms for the frequent context. A one-tailed *t* test for correlated samples revealed a significant decrease of RTs for trials with the frequent context, $t(15) = 2.77$, $p = 0.007$). Also the error rates were significantly reduced in trials with the frequent context (4.69% vs. 5.58%, $t(15) = 1.95$, $p = 0.035$; one-tailed).

In Experiment 3, the mean RTs amounted to 629 ms for the rare and to 606 ms for the frequent context. A one-tailed *t* test for correlated samples revealed a significant decrease of RTs in trials with the frequent context, $t(15) = 2.727$, $p = 0.008$). Also the error rates were reduced with the frequent context (3.56% vs. 4.74%), but this reduction failed to reach significance, $t(15) = 1.695$, $p = 0.055$, one-tailed).

In Experiment 4 mean RTs and error rates amounted to 691 ms and 4.38% for the rare and to 676 ms and 4.24% for the frequent context. One-tailed *t* tests for correlated samples revealed that in trials with the frequent context only the decrease of RTs approached significance, $t_{RT}(15) = 1.862$, $p = 0.041$; $t_{error}(15) = 0.223$, $p = 0.413$).

The data show a consistent impact of the local context on search performance. In all three experiments, targets that were embedded in frequent flankers were detected significantly faster than targets with rare flankers, despite target-locations within the global layout of the search display were always random. Thus, the results clearly indicate a sensitivity of the visual system for redundancies in the topographic relations of targets to adjacent objects, independent of target location.

In Experiments 2 to 4 the difficulty of search was enhanced by an increment of the distance between the letters or rather by making the letters harder to recognize. Both manipulations presumably resulted in the distractors having to be more attended to than in Experiment 1, which failed to reveal an impact of the local target-context on search performance. Thus, attending the redundant context might be a critical condition for context effects to occur. In accordance with this assumption, Jiang & Chun (2001) showed that contextual cuing only appears when the predictive context is attended. In their experiments, participants searched for either green or red targets embedded in green *and* red distractors. Participants were instructed to attend to the target color. Search was significantly improved only when some of configurations of the distractors in the attended color were consistently paired with certain target locations, whereas likewise predictive configurations of the distractors in the non-attended color had no effect. Accordingly, we assume that, also in the present experiments, the topographic relations of the target only to attended distractors will affect search performance. Experiment 5 was designed as a preliminary examination of this assumption.

Experiment 5

Experiment 5 was conducted in order to directly manipulate the amount of attention which participants pay to the flankers of the target. For this purpose, each response resulted in the disappearance of the target whereas the distractors remained on the screen for a further 1000 ms. Accordingly, the target-flankers now bordered the gap in the ring of letters left by the removed target (see Figure 1e). As the offset of the target would likely attract participants' attention (Yantis, 1998), attention was directed to the bordering flankers. As a result, we expect the context effects to be strengthened.

Method

Task, Apparatus, Stimuli, and Procedure

All conditions of Experiment 1 were replicated except that the target disappeared after the response and the distractors remained on the screen for a further 1000 ms.

Participants

Sixteen undergraduate students at University of Würzburg (11 female, 5 male) participated in exchange for course credit. The mean age was 21.38 years (*SD* = 2.66). All participants were naive regarding the context manipulation.

Results and Discussion

Erroneous responses (4.2%) and responses with an RT below 100 ms and above 3000 ms (0.7%) were excluded from the analysis. Mean RTs of the remaining responses amounted to 666 ms for targets with the rare and to 632 ms for targets with the frequent local context. A one-tailed t test for correlated samples revealed a significant decrease of RTs for targets with frequent flankers, $t(15) = 5.213$, $p < 0.001$). The error rates in trials with the rare and the frequent context were 4.24% and 4.05%, respectively. This difference was not significant, $t(15) = 0.349$, $p = 0.366$, one-tailed).

The data confirm the assumed impact of attention on the cuing effect. Directing participants' attention to the critical flanker resulted into a strong context effect. Participants responded to targets with frequent flankers 35 ms faster than to targets with rare flankers. This was the numerically strongest effect we observed.

Adaptation to Redundant Topographies of Details, Implicit or Explicit?

As already mentioned, after the reaction time session participants were asked whether they had noticed that some distractors were presented more often next to the targets than others. Participants who affirmed this question were considered as being aware of the context manipulation. However, regardless of their answer, every participant was asked to indicate which of the distractors might have been the frequent flankers of each of the two targets and the number of hits was recorded (maximum = 4). There were 9, 7, 11, 9, and 7 of 16 participants in Experiments 1, 2, 3, 4, and 5, respectively, who reported that they had noticed that certain distractors appeared more frequently than others as target flankers. However, when asked to indicate the frequent flankers of each of the targets, these "aware" participants on average only reached 1.60 of four possible hits, which does not differ from the mean number of hits reached by "unaware" participants, 1.68, $T(78) = 0.366$, $p = 0.715$, two-tailed) and exactly fits the expected value of a random distribution of hits. Thus, the results of the inquiry suggest that there was little concrete explicit knowledge about the context manipulation except that some participants noticed the manipulation per se.

As tentative the classification of participants into apparently aware and unaware is, it allows an assessment of the extent to which the observed context effects might be implicit or due to an explicit consideration of context frequencies. For this purpose, in each experiment, the mean RTs to targets in the frequent and the rare local context were separately calculated for participants considered as being aware and unaware of the context manipulation (see Table 1). A repeated measures analysis of variance (ANOVA) of the mean RTs with context (rare vs. frequent) and experiment (1, 2, 3, 4, and 5) and awareness (aware vs. unaware) as additional between participants variables only revealed a significant context effect, $F(1, 70) = 35.620$, $p < 0.001$. There was neither a main effect of awareness, $F(1, 70) = 2.251$, $p = 0.138$, nor did the interactions between context and awareness, $F(1, 70) = 1.676$, $p = 0.200$) and between context and experiment, $F(4, 70) = 1.671$, $p = 0.166$), or the three way interaction, $F(4, 70) < 1$) approach significance. Thus, the evaluation of the data across all Experiments confirms the robustness of the context effect and provides no hint that it is modified by awareness of the frequency manipulation.

General Discussion

Recent research produced convincing evidence for a remarkable sensitivity of the visual system to redundancies in the spatial distribution of stimuli (e.g., Chun & Jiang, 1998, 2003; Hoffmann & Kunde, 1999; Kunde & Hoffmann, 1998; Olson & Chun, 2002). If certain targets appear in different stimulus arrangements at different locations with unequal probabilities in a visual search experiment, search performance very closely adapts to these context-dependent distributions of target locations. This "contextual cuing" (Chun & Jiang, 1998) of target-locations suggests that the respective global layout of the search display guides the search to locations where the target currently searched for is probably to be found.

Table 1. Mean response latencies and standard errors (in milliseconds) to targets with rare and frequent local context for aware and unaware participants.

	Aware participants		Unaware participants	
	Rare	Frequent	Rare	Frequent
Experiment 1	602 (42.2)	589 (40.1)	592 (47.9)	589 (45.4)
Experiment 2	588 (48.3)	578 (46.9)	673 (42.6)	651 (41.3)
Experiment 3	633 (38.2)	613 (36.2)	619 (56.6)	589 (53.8)
Experiment 4	678 (42.2)	665 (40.1)	709 (47.9)	691 (45.4)
Experiment 5	586 (47.9)	566 (45.4)	729 (42.2)	684 (40.1)

The present experiments explore a further variant of this obvious sensitivity of the visual system to spatial redundancies. Participants searched for target-letters among different distractor letters that were evenly distributed around a virtual circle to form an invariant homogeneous global layout in each trial. Two particular distractors were frequently presented next to the target, whereas two other distractors rarely framed the target. As the global layout of the search display was kept constant and each target appeared at every location with equal frequency, the global context did not provide any information about the target location or its identity. The unequal frequencies of certain flankers were the only redundant information. We were interested in whether this redundancy in the local topography of certain details, independent of their location within an invariant and homogeneous global context, would also be used to guide visual search.

The data unequivocally confirmed the assumed impact of local topographic redundancies on visual search: In four experiments, participants detected targets with frequent flankers faster than targets with rare flankers. As the effect appeared independently of whether participants reported that they had noticed the different frequencies of the flankers, an implicit adaptation of the visual system to redundant local topographies seems to be likely. Redundant topographic relations between details of global layouts presumably can be filtered out without awareness of these relations, in the same way as redundant relations between layouts and target-locations are learned implicitly (e.g., Chun & Jiang, 1998, 2003).

Whereas conscious reflection apparently is not necessary for redundant local topographies to facilitate search, the redundantly related stimuli seemingly must be attended to in order to become effective. In Experiment 1, in which the targets presumably were often detected at first glance so that distractors rarely had to be attended, the effect disappeared. In contrast, in Experiment 5, in which attention was explicitly directed to the redundant target-flankers, the strongest effect was observed. Although the dependency of the effect strength on attention certainly needs further experimental examination, the assumption is well in line with the findings of Jiang and Chun (2001), as well as with further evidence for the strong impact attention has on implicit learning (see Hoffmann, Martin, & Schilling, 2003; Jiménez, 2003; Jiménez & Méndez, 1999; Musen & Viola, 2000; Wolfe, Klempen, & Dahlen, 2000).

Finally, the mechanisms by which the redundant local topographies may affect visual search deserve discussion. As the target locations within the ring of letters were random, cuing of these locations was excluded. Only the location of the target relative to the critical distractors could be predicted. However, as the distractors were also randomly located, cuing of relative target locations is also less likely, in particular as the critical distractors were the flankers of the targets. Therefore, search facilitation presumably was not based on any early available information that directed attention to a probable target location. We assume that the frequent co-occurrence of the target with certain distractors in the same topography induces the formation of a unified representation of this typical arrangement, which, as a whole, can be recognized and detected faster than the target alone (see Czerwinski, Lightfoot, & Shiffrin, 1992; O'Hara, 1980; Palmeri, 1997; Salasoo, Shiffrin, & Feustel, 1985; Schyns, Goldstone, & Thibaut, 1998; Schyns & Murphy, 1994). In the present experiments, unitization was facilitated by presenting the redundantly related distractors directly next to the targets. However, if one considers that in almost all objects the topography of relevant details such as buttons, handles, switches, etc. is almost always invariant, it is reasonable to assume that unitization is not restricted to flankers but includes any systematic topography, provided that the respective details are attended to.

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Adress for correspondence

Joachim Hoffmann
Department of Psychology
University of Würzburg
Röntgenring 11
D-97070 Würzburg
Germany
Tel. +49 931 312 645
Fax +49 931 312 815
E-mail hoffmann@psychologie.uni-wuerzburg.de

