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Familiar Interacting Object Pairs Are Perceptually Grouped

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Identification of objects in a scene may be influenced by functional relations among those objects. In this study, observers indicated whether a target object matched a label. Each target was presented with a distractor object, and these were sometimes arranged to interact (as if being used together) and sometimes not to interact. When the distractor was semantically related to the label, identification was more accurate for targets arranged to interact with that distractor. This effect depended on observers' ability to perceptually integrate the stimulus objects, suggesting that it was perceptual in nature. The effect was not attributable to attentional cuing and did not depend on expectation of certain object pairs. These data suggest that familiar functional groupings of objects are perceptually grouped.

Keywords: scene perception, object recognition, context effects, functional group, perceptual grouping

Human beings encounter and identify familiar objects, new instances of known object types, and objects of novel types on a regular basis. It often seems that an object's surroundings and observer knowledge or expectations can affect the efficiency of object recognition. This intuitive hypothesis—that object recognition is subject to contextual influences—is supported by a substantial body of research accumulated over the last 4 decades. Although object recognition is driven in part by analysis of component features (Biederman, 1987), there is considerable evidence that it is also driven by analysis of the context in which objects appear (e.g., Boyce & Pollatsek, 1992; Davenport & Potter, 2004; Hollingworth & Henderson, 2000; Moores, Laiti, & Chelazzi, 2003; Palmer, 1975). However, there has been little inquiry into how, specifically, visual representations of scenes affect object recognition. We present four experiments exploring the nature of the higher level representations behind context effects. Specifically, we consider the hypothesis that functional relations between objects—that is, relations that reflect the manner in which objects are used together, as when a pitcher is arranged as to pour water into a glass— both form an explicit part of the visual representation of scenes and affect the visual processing of the objects engaged in those relations.

Contextual Effects on Object Recognition

Several lines of evidence support the conclusion that the larger context of a visual scene can influence the perception and recognition of objects in that scene. Both object search and object recognition are sensitive to semantic associations between objects (Auckland, Cave, & Donnelly, 2004; Biederman, Blickle, Teitelbaum, & Klatzky, 1988; Boyce & Pollatsek, 1992; Henderson, Weeks, & Hollingworth, 1999; Hollingworth & Henderson, 2000; Moores, Laiti, & Chelazzi, 2003), spatial relations among objects (Bar & Ullman, 1996; Biederman, Mezzanotte, & Rabinowitz, 1982; Biederman, Rabinowitz, Glass, & Stacy, 1974; Henderson, 1992), and global scene properties (Biederman, 1972; Davenport & Potter, 2004; Torralba, Oliva, Castelhano, & Henderson, 2004).

These findings led to what is known as the *schema hypothesis*, the proposal that visual information makes rapid contact with high-level representations of scenes and that these high-level representations affect subsequent perceptual processing (see Henderson, 1992). Potter (1975) showed that observers needed only a brief glimpse of a scene (as little as 125 ms) to extract its general meaning (*gist*). Similarly, Biederman (1981) demonstrated that both scene category information and object identities can be extracted from images that are stripped of almost all visual detail. The objects in Biederman's images are depicted only as simple geometric solids (*geons*), and are therefore completely ambiguous in isolation but are unambiguous in the context of the whole scene. These results suggest that scene recognition and object recognition

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operate interactively and in parallel; visual information simultaneously drives the activation of both object-level and scene-level representations (see McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982, for similar ideas with respect to word and letter perception). Although it is well known that scene context affects object processing, little is known about the specific manner in which it does so: What kind(s) of information present in a scene constrain the processing and identification of the scene's individual objects?

Scene Representation

Evidence has suggested that the visual system does not maintain representations that exhaustively specify the visual details of a scene in the absence of ongoing visual input. For instance, Grimes (1996) presented observers with a visual scene and asked them to report any changes they noticed while studying the scene for a later memory test. When changes occurred during a saccade, observers failed to report them, suggesting that the representations of scenes that persisted across saccades did not include a great deal of visual detail. Grimes interpreted this result as indicating that "the internal representation is based more on the information carried by the visual objects rather than on the details themselves" (p. 108). Implicit in this statement is the idea that raw perceptual information is not a central component of scene representations.

Mandler and colleagues (Mandler & Parker, 1976; Mandler & Ritchey, 1977) explored the content scene representations and argued that scene schemata should improve the encoding of schema-consistent information. They noted that improved encoding should be expressed in better recall and recognition of schema-consistent information (a similar argument was made previously by Brewer & Treyens, 1981). That is, whatever information is found to be best retained from scenes is taken to correspond to information that forms the basis of scene schemata. Mandler and Parker (1976) asked observers to study a number of line drawings of scenes. Later, some of the studied scenes were presented along with unstudied scenes (lure scenes), and observers were asked to determine whether each scene had appeared during the study phase of the experiment (a recognition task). Lure scenes were created by making subtle changes to studied scenes, and observer sensitivities to different types of changes were measured. Some changes were detected more easily than others: object type changes (e.g., a mug changing to a plate) were more easily noticed than object token changes (e.g., a mug changing to a different mug). This result suggests that some basic semantics of objects are encoded in visual representations of scenes but that specific perceptual details are typically omitted (the same conclusion was drawn by Grimes, 1996). With respect to spatial or relational information, categorical relations (e.g., "facing") were better retained than were metric relations (e.g., "1.5 m left"). For example, when a chair was turned toward a table in the target scene, observers were less prone to commit false alarms to a lure that had the chair turned away from the table than they were to commit false alarms to lures in which the chair was still facing the table but was moved farther away. As with object semantics, the spatial relations in a scene seem to be encoded categorically or qualitatively, without specific perceptual (or metric) detail.

In summary, Mandler's studies (Mandler & Parker, 1976; Mandler & Ritchey, 1977) suggested that observers encode object type information and important categorical spatial relations when viewing an organized scene. We suggest that this information is retained because it is critical to scene function: the types of objects present and the general arrangement of those objects both constrain the activities or functions that are appropriate and available in the scene.

Green and Hummel (2004) recently hypothesized that functional groups of objects— groups of objects arranged in functional interactions (as defined previously)—may form an explicit component of the visual representation of scenes for the purposes of scene recognition and categorization. Specifically, they suggested that functional groups are explicitly represented in the perceptual system and that these representations mediate the flow of information between perceptual systems engaged in visual processing and cognitive systems engaged in scene comprehension and action planning. This *functional relations hypothesis* predicts context effects on object perception that depend on the presence of multiobject functional groups. The experiments presented here explore the effects of functional groups on object recognition.

Perception and Action

Previous findings with neuropsychological populations suggest the existence of interactions between object function and identity in visual object identification (Harman, Humphrey, & Goodale, 1999). Humphreys and Riddoch (2001) studied visual search in patients with unilateral visual neglect. Their work demonstrated that functional information about targets facilitated search for such patients. For example, a patient who had difficulty locating targets in a visual search task performed consistently better when functional (i.e., action-based) information about the target was provided as a search cue (as opposed to the target's name or a featural description). In addition, the advantage for functional cues disappeared when the patient tried to select targets from an array of object names instead of pictures of the objects, suggesting that the physical affordances of the stimuli were crucial to successful use of action cues. Humphreys and Riddoch (2001) concluded that functional information influenced search independently of the specific visual features of target objects. Further, functional information seemed to facilitate the recognition of the target object but did not actually speed search.[1]

In related work, Riddoch, Humphreys, Edwards, Baker, and Willson (2003; see also Humphreys, Riddoch, Forti, & Ackroyd, 2004) studied parietal patients who showed extinction when trying to report the names of two simultaneously presented objects. When stimulus objects were presented together but were not positioned

[1] That recognition was aided by functional information, whereas localization was not aided, meshes well with evidence that the spatial relations encoded by the perceptual system (for recognition) are categorical, lacking precise metric information. Relations within objects (Biederman, 1987; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996; Rosielle & Cooper, 2001) and within scenes (Mandler & Parker, 1976; Mandler & Ritchey, 1977) seem to be encoded qualitatively. Although categorical relations are probably not useful for search guidance, they might be useful for recognizing familiar or meaningful configurations of objects in a visual scene. Objects arranged to facilitate a common action or to serve an important function might be described by explicit perceptual representations employing categorical relations.

to interact (i.e., were not working together to accomplish some larger goal), these patients could report the name of one object but not of both (i.e., patients showed extinction for the second object). When the objects were presented together and positioned so that they did interact, both objects were reported accurately significantly more often. Control conditions indicated that semantic associations between objects were not sufficient to explain the improved performance, suggesting instead that functional information played a crucial role in the identification of the second object (see also Gilchrist, Humphreys & Riddoch, 1996).

Current Approach

The work by Humphreys, Riddoch, and colleagues (Humphreys & Riddoch, 2001; Humphreys et al., 2004; Riddoch et al., 2003) supported the hypothesis that functional information is an important component of scene representations. For instance, one explanation for their proposed facilitation of selection is that interacting objects are perceived as constituents of larger functional groupings that are, themselves, explicitly represented visual entities. However, it is important to determine whether the effects described by Riddoch et al. (2003) resulted from the deficit(s) suffered by their patient population or whether they are a property of normal perception and cognition that was made more apparent by the presence of parietal damage. In addition, if sensitivity to functional information is a property of normal scene processing, then it is worthwhile to determine whether the effect is strong enough to manifest itself when observers are otherwise unimpaired.

We present four experiments exploring the influence of functional interactions on object identification in normal observers. Our experiments examine whether functional interactions between objects affect their identification and whether or not such effects are attributable solely to semantic associations between objects (Experiment 1). In addition, de Graef, Christaens, and d'Ydewalle (1990) noted that certain scene context effects can be explained as consequences of post-perceptual decision processes (see also de Graef, de Troy, & d'Ydewalle, 1992). Accordingly, our experiments test whether effects of functional information are dependent on observers' ability to perceptually integrate the stimulus objects (Experiments 1 and 2), which would suggest a perceptual basis for the effect. We also investigate whether the effects of functional information are due to attentional cuing (Experiment 3) and whether such effects are dependent on the expectations of the observer (Experiment 4).

Experiment 1

Experiment 1 required observers to verify whether the second object in a two-object sequence matched a label presented prior to the trial. A target object appeared to the left or to the right of fixation shortly after a distractor object appeared at fixation. We manipulated the semantic relationship between the distractor object and the label and whether the distractor was arranged to interact with the target object (see Figure 1 for examples).

Method

Participants. Ten University of California, Los Angeles undergraduate students participated to fulfill a requirement for a psychology course. All participants had normal or corrected-to-normal vision.

Materials. Twenty black and white line drawings of common objects (approximately 2.3° of visual angle in width) served as stimuli. The objects consisted of 10 semantically associated pairs (e.g., pitcher–glass, hammer–nail) that could be arranged to form a familiar functional group (see Figure 1 and Figure 2). Within each pair, one object was designated the *target object* and one the *distractor object*. The distractor was always *functionally asymmetric*, operating primarily in one direction (e.g., a pitcher typically pours from only one side). All of the images are shown in Figure 2. Eight of the stimulus objects were taken from Snodgrass and Vanderwort (1980) and 12 were created specifically for this work.

Each of the 10 object pairs was associated with a label that named the target object in the pair. Labels were displayed on the computer screen in black, 24-point, Arial font on a white background.

Stimuli were presented on MacIntosh PCs with observers seated approximately 66 cm from the computer monitor. SuperLab (Version 1.5; Cedrus Corporation, 1992) was used to manage stimulus presentation and data collection in all experiments.

Procedure. Each subject completed 320 trials (see Figure 3). Each trial began with the presentation of a label. The label was displayed in the center of the screen until the observer pressed a key. Upon keypress, a fixation cross replaced the label and remained on the screen for 750 ms. A distractor object was then presented for 50 ms, followed by an interstimulus interval

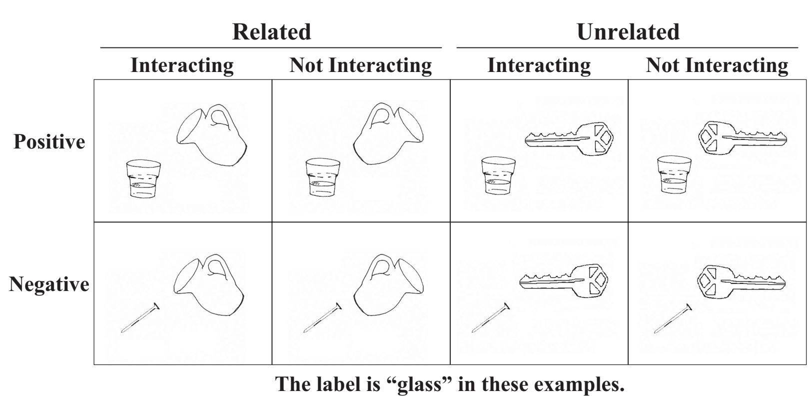

Figure 1. Examples of stimuli in each condition. Here, the label is "glass." Distractors could be related (R) or unrelated (U) to the label and could be oriented to interact (I) or not interact (N) with the target (the target matched the label on positive trials [top row] and did not match the label on negative trials [bottom row]). The same set of stimuli was used in all experiments.

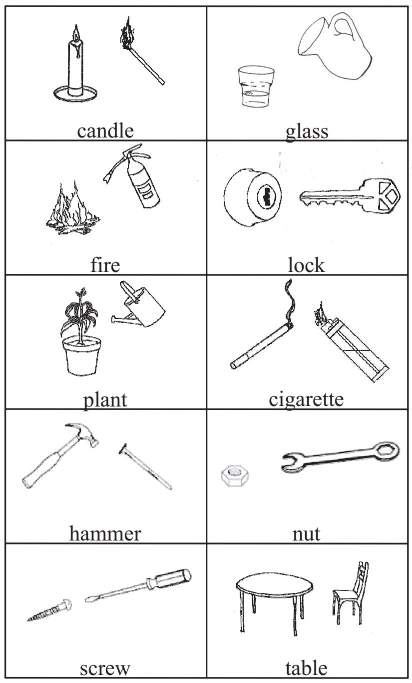

Figure 2. Ten pairs of semantically associated objects were used as stimuli. Here, the pairs are arranged to interact. In each pair, the object on the left served as the target, and the object on the right served as the distractor. The labels corresponding to target objects are shown, as well. Note that many trials used objects that came from different pairs, and that the arrangement of objects varied depending on the conditions implemented in a trial.

(ISI) of 50 ms (stimulus onset asynchrony [SOA] = 100 ms), during which a blank white screen was shown. A target object then appeared for 50 ms, followed by a blank screen, which remained until the observer pressed the *Z* key (present) or the */* key (absent) indicating whether the target object matched the label presented prior to the trial. Target objects appeared lateralized approximately 4.5° to the left or to the right of fixation. Observers did not know whether the target object would appear to the left or to the right, and the locations were used equally often. The trial timed out if no response was made within 2,500 ms of the onset of the target object. The next trial began after a 1,000-ms intertrial interval. Observers were instructed to respond as quickly as possible without making mistakes.

Design. Three within-subjects factors were orthogonally crossed: Label-Distractor Relatedness (related or unrelated), Functional Interaction (interacting or not interacting) and Trial Type (positive or negative). On related trials, the distractor object came from the stimulus pair associated with the label; on unrelated trials, the distractor came from a different pair. On interacting trials, the distractor was oriented to function toward the target object; on not interacting trials, the distractor was oriented to function away from the target (see Figure 1). On positive trials, the target matched the label; on negative trials, the target did not match the label.

It is important to note that label–distractor relatedness describes the relationship between the distractor and the label, not the relationship between the distractor and the target. For example, in the related–interacting–negative trial depicted in Figure 1, lower left corner, the label was “glass” and the distractor (*pitcher*) came from the same semantic pair as the label, but the target (*nail*) and the distractor (*pitcher*) were unrelated. We manipulated the relationship between the distractor and label instead of the relationship between the distractor and the target so that we might better observe any bias produced by the presence of a distractor that was semantically related to the label.

Predictions. Our functional grouping hypothesis predicts that objects engaged in familiar functional interactions will be better identified than objects not engaged in such interactions.

The existence of perceptual representations of functional groups would eliminate competition for selection among objects in that group and would thus lead to enhanced perception relative to objects in otherwise similar groups that are not explicitly represented as groups. In the context of Experiment 1, we predicted a simple main effect of Functional Interaction on target identification for related trials such that performance in the related–interacting condition would exceed performance in the related–not interacting condition. That is, for two object pairs with equally strong within-pair semantic association (e.g., *table–chair* and *hammer–nail*), we predicted that an interaction between the objects (on the basis of their orientations) would have a facilitatory effect on the identification of the target.

To be consistent with the functional grouping hypothesis, the simple main effect of Functional Interaction for related trials must be positive and it must be larger than the simple main effect of Functional Interaction for unrelated trials (or else the effect would be merely a main effect of object orientation). Failing to find this result would be inconsistent with our hypothesis that functional groups are explicitly represented and influence visual processing. The size and direction of the simple main effect of Functional Interaction on unrelated trials are not explicitly predicted by the functional grouping hypothesis: Unrelated–interacting stimuli may be perceived better, the same, or worse than unrelated–not interacting stimuli.

Analysis. In all experiments, response time (RT; in ms), accuracy data (d'), and observer bias ($ln[\beta]$) were analyzed by using within-subject analyses of variance.[2] Trials for which RT was longer than 2,500 ms were counted as errors. RTs were analyzed only for trials to which observers responded correctly. RTs did not differ reliably across conditions in any experiment. Throughout this article, we focus our discussion on measures of accuracy (d') and bias ($ln[\beta]$), but we also present mean hit rates, mean false alarm rates, and mean RTs for each condition.

Results

Means and standard errors from Experiment 1 are presented in Table 1.

Accuracy. As predicted, there was a significant Label–Distractor Relatedness × Functional Interaction interaction with respect to accuracy, $F(1, 36) = 51.234$, $MSE = 0.070$, $p < .05$.

Simple main effect analyses indicated that mean d' was significantly higher in the related–interacting condition (mean $d' = 3.22$) than in the related–not interacting condition ($d' = 2.81$), $t(9) = 3.303$, $SE = 0.124$, $p < .05$. In contrast, mean d' was significantly lower in the unrelated–interacting condition ($d' = 2.19$) than in the unrelated–not interacting condition ($d' = 2.98$), $t(9) = 4.277$, $SE = 0.185$, $p < .05$.[3]

[2] In the few cases in which a cell contained no errors, a standard method was used to adjust that cell’s value so that d' and $ln(\beta)$ could be calculated: When a cell containing proportion correct of n observations had a value 1, we used the adjusted value $1 - [1/(2n + 1)]$ in that cell for all accuracy and bias analyses (see Wickens, 2002, p. 26).

[3] There was no evidence that these differences changed over the course of the experiment. In all four experiments, breaking the data into quartiles on the basis of the serial position of trials showed that the differences between the related/interacting and related/not interacting conditions, as well as differences between the unrelated/interacting and unrelated/not interacting conditions, were generally stable over the course of the experiment.

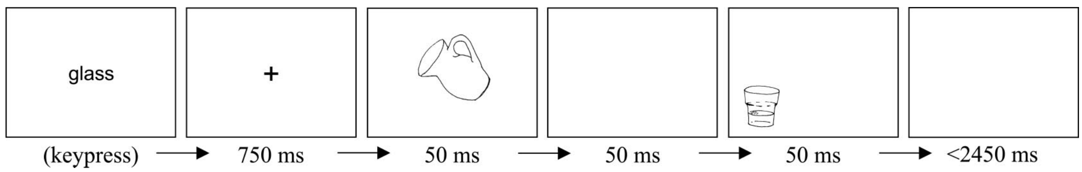

Figure 3. Example of a trial in Experiment 1.

Bias. There was a Label–Distractor Relatedness × Functional Interaction interaction with respect to observer bias. ($ln[\beta]$) $F(1, 36) = 8.9799$, $MSE = 4.5396$, $p < .05$. Pairwise comparisons indicated that observers showed a significant bias toward positive responses in the unrelated–interacting condition, $t(9) = 3.4949$, $SE = 0.2366$, $p < .05$. In all other conditions, there was a significant bias toward negative responses, and there were no differences in bias between conditions.

Discussion

Experiment 1 revealed a Label-Distractor Relatedness × Functional Interaction interaction with respect to the accuracy of object identification. Identification of the target object was more accurate on trials in which it interacted with a distractor that was semantically related to the label than on trials in which it did not interact with a distractor that was semantically related to the label (see Table 1, column 1, rows 1 and 2). For example, it was easier for participants to determine whether an object was a *glass* when it interacted with a *pitcher* than when it did not.

We also observed comparatively poor performance when the target object interacted with a distractor that was unrelated to the label (see Table 1, column 1, rows 3 and 4). This impairment reflects a significantly elevated false alarm rate in the unrelated–interacting condition (see Table 1, column 4, row 3). For example, it was harder for observers to determine that an object (e.g., *nail*) was not a *glass* when it interacted with a *chair* than when it did not interact with a *chair*. The origin of this effect is unclear. It is possible that it results from competition between objects that are arranged to interact but do not form a familiar functional group. Together, these results suggest that functional interactions influence object identification and that the familiarity of object pairings (here, their semantic association) is important in determining the direction of the effect.

It is unlikely that the effects in Experiment 1 derive solely from semantic associations between the stimulus objects. If improved identification resulted solely from guessing based on the semantic association of the label and the distractor objects, there should have been no difference in performance between the interacting and not interacting conditions (within levels of Label–Distractor Relatedness). The semantic associations were equivalent in the related–interacting and related–not interacting conditions and also in the unrelated–interacting and unrelated–not interacting conditions. Yet, in each pair of conditions there was a difference in performance.[4]

Although the data from Experiment 1 are inconsistent with a purely semantic association account (specifically, because it matters whether the objects are arranged to interact, i.e., it is not sufficient that they merely be "associated"), they do not rule out the possibility that the observed effects are postperceptual. For example, the advantage for familiar functional groups might reflect the use of (strictly postperceptual) schemas that encode conceptual or linguistic descriptions of visual scenes. The availability of schemas matching familiar functional pairings may allow preservation of conceptual or linguistic representations of stimulus objects that can be used to improve response accuracy. Although this (postperceptual) schema-based account shares an important assumption with our original functional groups hypothesis (i.e., both postulate explicit representations of functional relations above the level of single objects), our functional groups hypothesis differs from the postperceptual schema account in that it assumes that the functional relations have a perceptual (rather than strictly conceptual) basis. As such, Experiment 2 sought to determine whether the effects observed in Experiment 1 were perceptual in nature.

Experiment 2

Experiment 2 replicated Experiment 1 with a longer SOA (250 ms instead of 100 ms). Di Lollo, Hogben, and Dixon (1994) demonstrated that stimuli presented at very short SOAs can be perceptually integrated (i.e., built into a single percept), whereas stimuli presented at longer SOAs are perceptually segregated. The temporal window within which two stimuli must appear in order to be perceptually integrated is short: Brockmole, Wang, and Irwin (2002) demonstrated that the integration of visual percepts occurs for stimuli with an ISI of less than or equal to 100 ms. If the effects observed in Experiment 1 simply reflect the role of (postperceptual) schemas, then they should persist with longer SOAs between the distractor and the target–lure. In contrast, to the extent that the effects in Experiment 1 were the result of perceptual grouping, the longer (250 ms) SOA of Experiment 2 should diminish or eliminate the effects.

Method

Ten University of California, Los Angeles undergraduate students participated to fulfill a requirement for a psychology course. These participants were from the same subject pool as those in Experiment 1 but were

[4] In addition to our data, neuropsychological work has provided evidence against a semantic explanation for similar effects. Riddoch et al. (2003) included a comparison that is analogous to our comparison of related/interacting and related/not interacting stimuli. They reached the same conclusions that we reached here: An explanation based only on semantic associations is inconsistent with differences produced by manipulations of object orientations. In addition, Riddoch et al. (2003) included experiments in which observers were presented with word stimuli instead of objects, and a different pattern of results emerged. In short, both the data presented here and data from the neuropsychological literature are inconsistent with an account based on semantic associations.

Table 1
Means and Standard Errors of all Measures in all Conditions for Experiment 1

Condition	d' *M*	d' *SE*	$ln(\beta)$ *M*	$ln(\beta)$ *SE*	Hits *M*	Hits *SE*	False alarms *M*	False alarms *SE*	RTs *M*	RTs *SE*
Related										
Interacting	3.22	0.29	−0.50	0.25	0.916	0.018	0.068	0.024	729	67
Not interacting	2.81	0.26	−0.71	0.24	0.871	0.025	0.081	0.026	741	66
Unrelated										
Interacting	2.19	0.20	0.82	0.24	0.897	0.027	0.225	0.019	738	67
Not interacting	2.98	0.31	−0.73	0.17	0.866	0.033	0.062	0.021	718	60

Note. RTs = response times (in ms).

not the same individuals. In Experiment 2, target objects were presented after the distractors with 250 ms SOAs (see Figure 4). Otherwise, the methods and materials used in Experiment 2 were identical to those of Experiment 1.

Results

Means and standard errors for Experiment 2 are presented in Table 2.

Accuracy. As in Experiment 1, accuracy data revealed a significant interaction between Label–Distractor Relatedness and Functional Interaction, $F(1, 36) = 13.617$, $MSE = 0.025$, $p < .05$. However, unlike the previous experiment, analyses of simple main effects indicated that the mean d' in the related–interacting condition (3.07) was not different from that of the related–not interacting condition (3.20), $t(9) = 0.657$, $SE = 0.199$, $p > .50$.[5] As in Experiment 1, mean d' was significantly lower in the unrelated–interacting condition (2.04) than in the unrelated–not interacting condition (3.34) in Experiment 2, $t(9) = 6.806$, $SE = 0.191$, $p < .05$.

Bias. Experiment 2 showed an interaction between Label–Distractor Relatedness and Functional Interaction with respect to observer bias, $F(1, 36) = 5.7226$, $MSE = 9.2990$, $p < .05$. Pairwise comparisons indicated that observers were biased toward positive responses in the unrelated–interacting condition, $t(9) = 3.4375$, $SE = 0.1768$, $p < .05$. Once again, there were no differences in bias among the other conditions, all of them showing significant biases toward negative responses.

Discussion

An important qualitative change in the data resulted from the increased SOA in Experiment 2 as compared with Experiment 1: The facilitatory effect of familiar interacting pairs (the advantage for related–interacting over related–not interacting trials) observed at the 100 ms SOA did not persist at the 250 ms SOA. This finding suggests that the facilitation in Experiment 1 depended on observers' perceptually integrating the distractor and target–lure objects. This result is consistent with a perceptual account of the effects observed in Experiment 1 and inconsistent with a purely postperceptual schema-based account.

By contrast, the difference between the unrelated–interacting and unrelated–not interacting conditions observed in Experiment 1 also obtained in Experiment 2, and in fact it grew numerically larger (Experiment 1: unrelated–not interacting – unrelated–interacting = 0.79; Experiment 2: unrelated–not interacting – unrelated–interacting = 1.30). Thus, the impairment of unrelated–interacting stimuli did not depend on perceptual integration of the stimulus objects. There are at least two possible explanations for this result: The impairment might result from (relatively) long-lasting inhibitory competition initiated by the unrelated distractor object (independent of perceptual integration), or the impairment might result from a postperceptual process (such as encoding the "new functional group" into long-term memory). We discuss these possibilities further in the General Discussion.

Together, the results of Experiments 1 and 2 suggest an interaction advantage effect: Familiar interacting object pairs are more easily identified than familiar noninteracting object pairs and that this advantage is at least partly perceptual in nature. Although we have interpreted these findings in terms of the interacting objects forming a perceptual group (i.e., a functional group), the results of Experiments 1 and 2 are also consistent with an account based on simple attentional cuing: Perhaps the orientation of the distractor affected detection of the target–lure, not by forming a perceptual group with it, but simply by directing attention to the location where the target–lure would (in the interacting condition) or would not (in the not interacting condition) appear. The former (grouping) explanation is consistent with our original functional grouping hypothesis and with prior neuropsychological work on this topic (Riddoch et al., 2003; Humphreys et al., 2004), so it is important to explicitly test these alternative accounts against one another. Experiment 3 directly examined whether the facilitatory effects observed in Experiment 1 were the product of attentional cuing or perceptual grouping.

Experiment 3

Experiment 3 was similar to Experiment 1 but reversed the presentation order of the distractor and the target objects in order to determine whether the advantage for related–interacting over related–not interacting trials in Experiment 1 could be explained as a cuing effect. If the interaction advantage effect observed in Experiment 1 was due to attentional cuing by the distractor object, then the effect should be reduced or eliminated when the distractors are presented after the target. If the effect was the product of

[5] When compared directly, the sensitivity advantage for related/interacting over related/not interacting trials in Experiment 1 (3.22 – 2.81 = 0.41) was significantly greater than in Experiment 2 (3.07 – 3.20 = −0.13), $t(18) = 2.3044$, $SE = 0.1657$, $p < .05$.

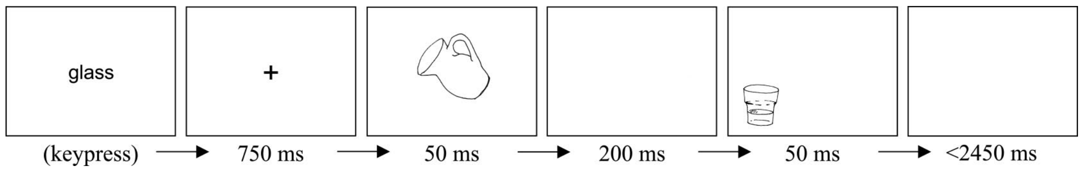

Figure 4. Example of a trial in Experiment 2. Experiment 2 was identical to Experiment 1 except that the stimulus onset asynchrony was extended to 250 ms instead of 100 ms.

perceptual grouping, then it should be insensitive to the order of presentation, provided the SOA is short enough to permit perceptual grouping (see Brockmole, Wang & Irwin, 2002; di Lollo, Hogben, & Dixon, 1994). Such an outcome would be consistent with our general hypothesis that functional groups are explicitly represented mental entities.

Method

Ten University of California, Los Angeles undergraduate students participated to fulfill a requirement for a psychology course. The methods and materials used in Experiment 3 were identical to those used in Experiment 1, with one exception. In Experiment 3, observers were required to perform the same verification task on the target object but were informed that the target would appear as the first object in each trial's two-object sequence (see Figure 5). Like Experiment 1, Experiment 3 used a 100-ms SOA, enabling observers to perceptually integrate the stimuli.

Results

Means and standard errors for Experiment 3 are presented in Table 3.

Accuracy. The pattern of accuracy results from Experiment 3 was nearly identical to that of Experiment 1. There was a significant Label–Distractor Relatedness × Functional Interaction interaction with respect to accuracy, $F(1, 36) = 20.236$, $MSE = 0.249$, $p < .05$, and analyses indicated that mean d' was marginally higher in the related–interacting condition (3.51) than in the related–not interacting condition (3.15), $t(9) = 2.207$, $SE = 0.164$, $p = .055$. Mean d' was lower in the unrelated–interacting condition (2.12) than in the unrelated–not interacting condition (3.18), $t(9) = 3.508$, $SE = 0.301$, $p < .05$.

Bias. There was a Label–Distractor Relatedness × Functional Interaction interaction with respect to observer bias, $F(1, 36) = 4.4076$, $MSE = 3.9630$, $p < .05$. Pairwise comparisons indicated that observers were significantly biased toward positive responses in the unrelated–interacting condition. Otherwise, there were no differences in bias between conditions. In this experiment, only in the unrelated–interacting condition were bias scores significantly different than zero, $t(9) = 3.4771$, $SE = 0.2437$, $p < .05$. Observers were neutral ($ln[\beta]$ was not significantly different than zero) in the related–interacting, related–not interacting, and not interacting conditions.

Discussion

Even though the distractor was presented 100 ms after the onset of the target in Experiment 3, observers were better able to identify the target on related–interacting trials than on related–not interacting trials. The magnitude of this advantage was approximately equal to that observed in Experiment 1 (the difference in mean d' was 0.40 in Experiment 1 and 0.36 in Experiment 3). Once again, the reverse effect obtained on unrelated trials: Object identification was less accurate on unrelated–interacting trials than on unrelated–not interacting trials.

The similarity of the data patterns observed in Experiments 1 and 3 suggests that attentional cuing is not the basis of the advantage of related–interacting over related–not interacting stimuli. If distractor objects served to direct visual attention in the direction of their typical function, then there should have been substantial asymmetry in the results of Experiments 1 and 3. Specifically, distractor objects presented prior to target objects (Experiment 1) should have improved performance but those presented afterward (Experiment 3) should not have done so. The results of Experiment 3 thus suggest that perceptual grouping is more likely to be the source of the interaction advantage effect.

Experiment 4

If the interaction advantage effects obtained in Experiments 1 and 3 are in fact perceptual, then they should be largely immune to

Table 2
Means and Standard Errors of all Measures in all Conditions for Experiment 2

	d'		$ln(\beta)$		Hits		False alarms		RTs	
Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Related										
Interacting	3.07	0.18	−0.99	0.30	0.868	0.028	0.041	0.013	612	48
Not interacting	3.20	0.20	−0.84	0.27	0.890	0.024	0.040	0.010	602	47
Unrelated										
Interacting	2.04	0.14	0.61	0.18	0.883	0.026	0.227	0.014	618	51
Not interacting	3.34	0.27	−0.75	0.23	0.893	0.029	0.036	0.013	601	32

Note. RTs = response times (in ms).

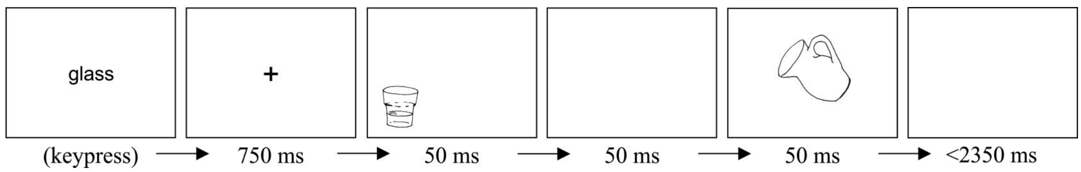

Figure 5. Example of a trial in Experiment 3. Experiment 3 was identical to Experiment 1 except that target objects were presented prior to distractors, instead of the opposite.

observers' expectations about the identity and configuration of the objects composing a stimulus. More specifically, the effects obtained in Experiments 1 and 3 should not depend on the target being named prior to the presentation of the stimulus. Experiment 4 tests this prediction by presenting the label after the stimulus instead of before the stimulus.

Method

Ten University of California, Los Angeles undergraduate students participated to fulfill a requirement for a psychology course. The methods and materials used in Experiment 4 were identical to those of Experiment 1, with the exception that on each trial the label was presented after, instead of before, the stimulus objects (see Figure 6). Each trial began with a ready signal (a small circle presented at fixation) that remained on the screen until the observer pressed a key. Immediately upon keypress, a fixation cross appeared, followed by the presentation of the distractor object and then by the target object. After the offset of the target object, a label appeared and observers were required to indicate whether the target object matched the label. The functional grouping hypothesis predicts that the results will be the same as those of Experiments 1 and 3.

Results

Means and standard errors for Experiment 4 are presented in Table 4.

Accuracy. The pattern of results from Experiment 4 was nearly identical to the patterns in Experiments 1 and 3. There was a significant Label–Distractor Relatedness × Functional Interaction interaction with respect to accuracy, $F(1, 36) = 29.376$, $MSE = 0.150$, $p < .05$. Analyses indicated that mean d' was higher in the related–interacting condition (3.40) than in the related–not interacting condition (3.03), $t(9) = 3.235$, $SE = 0.114$, $p < .05$. Mean d' was again lower in the unrelated–interacting condition (2.23) than in the unrelated–not interacting condition (3.19), $t(9) = 5.598$, $SE = 0.171$, $p < .05$.

Bias. There was a Label–Distractor Relatedness × Functional Interaction interaction with respect to observer bias, $F(1, 36) = 8.3963$, $MSE = 5.7359$, $p < .05$. Pairwise comparisons indicated that observers were more biased toward positive responses in the unrelated–interacting condition than in any other condition. Otherwise, there were no differences in bias among conditions. Only in the unrelated–interacting condition were bias scores significantly different than zero, $t(9) = 2.8283$, $SD = 0.2701$, $p < .05$.

Discussion

Presenting the label after the stimulus objects did not eliminate the interaction advantage effect. In addition, the effect in Experiment 4 was similar in magnitude (related–interacting – related–not interacting = 0.37) to corresponding effects in Experiments 1 and 3. That this effect does not depend on observer expectations is consistent with the hypothesis that the observed advantage is perceptual.

In addition, the impairment for unrelated–interacting stimuli relative to unrelated–not interacting stimuli remained when the label was presented after the stimulus. As elaborated shortly, it is unclear how to interpret this result.

General Discussion

In four experiments, we investigated the effects of functional relations among objects on object identification. Experiment 1 demonstrates that both the semantics of objects and their arrangement influence object identification and that these factors interact. When distractor objects were semantically related to the label, identification was more accurate when the target and distractor were arranged to work together than when they were not arranged to work together (i.e., we observed an interaction advantage effect). When distractor objects were unrelated to the label, arrang-

Table 3
Means and Standard Errors of all Measures in all Conditions for Experiment 3

	d'		$ln(\beta)$		Hits		False alarms		RTs	
Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Related										
Interacting	3.51	0.25	−0.18	0.40	0.946	0.015	0.080	0.048	690	65
Not interacting	3.15	0.29	−0.21	0.23	0.921	0.020	0.095	0.054	690	66
Unrelated										
Interacting	2.12	0.25	0.85	0.24	0.929	0.018	0.290	0.076	673	60
Not interacting	3.18	0.49	−0.45	0.30	0.939	0.022	0.140	0.096	696	55

Note. RTs = response times (in ms).

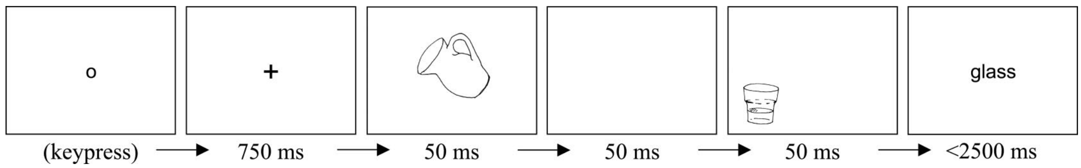

Figure 6. Example of a trial in Experiment 4. Experiment 4 was identical to Experiment 1 except that the label was presented after—instead of before—the stimulus objects on each trial.

ing the target and distractor to work together made identification less accurate than when they did not work together. Specifically, observers made more false alarms in this condition (i.e., stating that a lure matched the label) than they did in other conditions. These results support the hypothesis that knowledge about object functions can influence object identification. In particular, the observed influence is predicted by the functional grouping hypothesis advanced by Green and Hummel (2004).

Experiment 2 sought to establish whether the effects observed in Experiment 1 were due to perceptual or postperceptual processes. An extended SOA between distractor and target objects was predicted to eliminate the interaction advantage effect observed in the prior experiment by preventing perceptual integration of the stimulus objects. Indeed, the effect disappeared in Experiment 2, suggesting that it has a perceptual basis. However, the impairment on related–interacting trials relative to unrelated–not interacting trials remained in Experiment 2, suggesting a postperceptual explanation of this effect. Differential sensitivity to changes in SOA (as well as differences in measures of bias) suggests that these two effects may have separate causes (as elaborated shortly).

In Experiment 3, we tested the hypothesis that the interaction advantage effect was the result of attentional cuing by the distractor object. In Experiment 1, we presented the distractor prior to the target (allowing the observer to orient to the target location in advance of target onset), and in Experiment 3 we reversed the presentation order so that distractors appeared after the target object (eliminating the opportunity to orient prior to target onset). The results show that reversing the stimulus order had no effect, providing strong evidence that attentional cuing did not underlie the advantage for related interacting objects. We conclude that the effects observed in Experiments 1 and 3 are the result of perceptual grouping processes relating to the explicit representation of functional groups in the systems supporting visual scene recognition.

In Experiment 4, we tested the hypothesis that the effects observed in Experiments 1–3 were dependent on observer expectations as a result of the prepresentation of a target label (i.e., prior to the presentation of the target–lure and distractor). The first three experiments presented the observer with a label prior to each trial, and it may be argued that this label might have caused the observer to expect a particular functional group in the coming stimulus. In Experiment 4, we presented the label after the target–lure and distractor were presented, eliminating any possible effects of expectation. The results, which replicated those of Experiments 1 and 3, indicate that the effects observed in Experiments 1–3 were not dependent on presentation of the label prior to the stimulus. These results further strengthen the conclusion that the effects of functional groups observed in Experiments 1 and 3 are due to perceptual, rather than to cognitive, processes.

An Interaction Advantage Effect for Familiar Functional Groups

An immediate conclusion that can be drawn from this work concerns the results of Humphreys, Riddoch, and colleagues (Humphreys & Riddoch, 2001; Humphreys et al., 2004; Riddoch et al., 2003). Those studies demonstrated effects of functional information on object search and identification in a neuropsychological population. The experiments presented here produced similar results in normal observers. In turn, this finding suggests that neurological damage did not produce the effects observed by Humphreys, Riddoch, and colleagues, but rather created an opportunity for an aspect of normal cognition to make itself more apparent. In combination, our results, and those of Humphreys, Riddoch, and colleagues, suggest that functional groups of objects are, themselves, perceptual objects that help people comprehend and process visual scenes.

Table 4
Means and Standard Errors of all Measures in all Conditions for Experiment 4

	d′		*ln*(β)		Hits		False alarms		RTs	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Related										
Interacting	3.40	0.24	−0.69	0.21	0.905	0.028	0.034	0.009	764	66
Not interacting	3.03	0.19	−0.61	0.17	0.897	0.018	0.052	0.011	773	64
Unrelated										
Interacting	2.23	0.15	0.76	0.27	0.888	0.035	0.204	0.012	758	62
Not interacting	3.19	0.20	−0.68	0.35	0.887	0.030	0.047	0.016	765	58

Note. RTs = response times (in ms).

Green and Hummel (2004) suggested that scene comprehension relies on representations that incorporate functional information derived from individual objects as well as meaningful (functional) relations between those objects. The experiments reported here empirically demonstrate that objects and their functional relations interact during object identification.

An important theoretical implication of these results concerns the nature of the perceptual–cognitive interface and the ability of functional knowledge to influence perception. Although these data do not indicate whether the percept generated from a visual stimulus is affected by knowledge about objects and functional interactions, they do provide evidence that perceptual grouping processes are influenced by such knowledge (see Pylyshyn, 1999).

That abstract knowledge affects perceptual grouping is documented elsewhere. One notable instance is the Reicher–Wheeler effect (i.e., the word-superiority effect). Letters are better identified when they are presented as part of a familiar word than when they are presented within a nonsense string or alone. At least one account of the word-superiority effect attributes this difference to the existence of word-level mental representations that are selectively activated by the presence of familiar groupings of letters (i.e., words; Johnston, 1981; Johnston & McClelland, 1980; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982).

Functional group representations might play a role in the perception of individual objects in the same way that word representations play a role in letter identification. Riddoch et al. (2003) concluded that action-based representations serve to reduce competition for selection among visual objects in neuropsychological populations. We have demonstrated a similar phenomenon here, with normal observers. Access to familiar functional object group representations may enable the simultaneous selection of constituent objects. Such selection could be the basis of observers' advantage for identifying target objects that were part of familiar functional groups. This description meshes well with the view that systems dedicated to action planning or to control and those dedicated to perception and to recognition interact (Goodale & Humphrey, 1998).

Impairment for Unfamiliar Interacting Objects

In all four experiments, observer performance was substantially reduced in the unrelated–interacting condition, and in particular, on the negative trials in that condition (e.g., the observer is looking for *glass*, the unrelated distractor is *chair*, and the lure is *nail*): False alarm rates for unrelated–interacting trials were nearly double those in other conditions. What is the cause of this impairment?

One possible explanation emerges from theories of visual attention that include both excitatory and inhibitory mechanisms (e.g., Neill, 1977; Neill & Westberry, 1987; Tipper, 1985; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991). Some researchers have noted that visual attention includes inhibitory effects that operate over a longer time course than do facilitatory effects, routinely lasting 1 s (Maylor & Hockey, 1985) and as long as 7 s, in some cases (Tipper et al., 1991).

In our experiments, it is possible that the interaction advantage effect is short-lived and dependent on perceptual grouping but that longer lasting competition for selection among objects makes unrelated–interacting objects particularly difficult to perceive. For example, perhaps the unrelated distractor *chair* primes a collection of functional groups that are inconsistent with—and thus inhibit—the lure *nail*, making the nail less clearly perceived and more difficult to reject as not being the target (i.e., *glass*). It is unclear from this account, however, why the related–interacting stimuli are not subject to such long-lasting competitive effects, especially on negative trials (e.g., target: *glass*; distractor: *pitcher*; lure: *nail*), wherein the objects that actually appeared (i.e., *pitcher* and *nail*) were not, themselves, related.

Another possibility is that the high false alarm rate in the unrelated–interacting condition results from the action of a (comparatively long-lasting) cognitive process (e.g., encoding or consolidation) that is initiated when an observer encounters a novel interaction between two previously unrelated objects (following our previous example, a *chair* [unrelated distractor] facing a *nail* [lure]) and that interferes with the perception of the lure. That the deleterious effect of the unrelated distractor is insensitive to SOA might reflect the temporal extent of this cognitive process. Measures of bias in all experiments indicate that observers were using a different criterion in their unrelated–interacting responses than in other conditions. Although criterion differences sometimes reflect changes in strategy, the within-subjects design of these experiments makes it unlikely that observers explicitly switched strategies between conditions. (To do so would require the observer to select a strategy at the beginning of each trial, and thus without knowledge of what kind of trial was about to begin.) If unrelated–interacting stimuli invoke some kind of additional cognitive process, and if that process has its own (different) response criterion, then the output of that process may have interfered with the output of any purely perceptual mechanisms with respect to generating responses.

To investigate this hypothesis, we examined the time course of hit and false alarm responses in the different conditions for each experiment. There were no obvious differences between the distributions of RTs for hits across conditions or experiments. In every case, the RTs of hits were distributed as gamma functions with peaks around 400 ms. The distributions of false alarm RTs, by contrast, were more interesting. As noted earlier, the most prominent feature of the false alarms was the large number of them in the unrelated–interacting condition. And although the false alarm rates in this condition were similar across experiments, the shape of the RT distributions in this condition varied across experiments. The distribution of false alarm RTs for unrelated–interacting trials in Experiment 1 (with 100-ms SOAs) was noticeably bimodal, with peaks near 300 and 600 ms; in Experiment 2 (with 250-ms SOAs), the distribution of false alarm RTs in the unrelated–interacting condition was clearly unimodal, with a single peak at 500 ms (see Figure 7). It is possible that the bimodal distribution in Experiment 1 reflects the separate contributions of perceptual and cognitive mechanisms, whereas the unimodal distribution from Experiment 2 reflects the production of responses from a single, slower, cognitive mechanism.

Although the patterns of false alarms observed in the unrelated–interacting conditions across the experiments are generally consistent with both accounts presented in this section, we certainly do not claim to have demonstrated the sufficiency or reality of either account. Nor are the patterns of data in the unrelated–interacting condition especially central to our primary hypothesis that functional relations are an explicit component of scene representations that can influence the perception and identification of the related

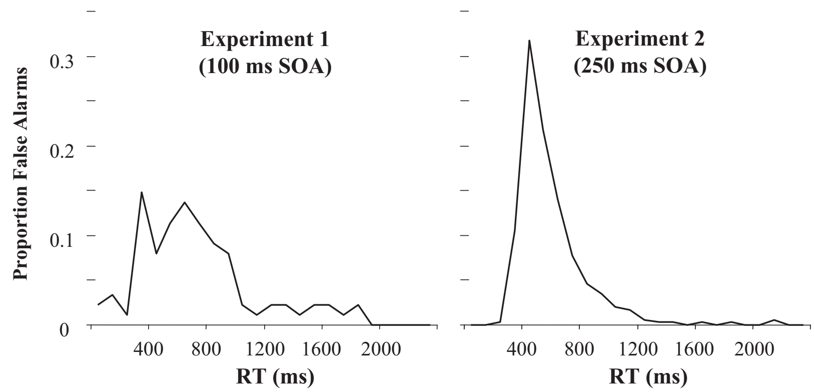

Figure 7. Distributions of false alarm response times (RTs; in ms) for unrelated/interacting stimuli in Experiment 1 (100-ms stimulus onset asynchrony [SOA]) and Experiment 2 (250-ms SOA). In Experiment 1, the distribution of false alarm RTs is noticeably bimodal. In Experiment 2, the distribution is clearly unimodal. This difference may reflect the presence of two mechanisms at work in Experiment 1. Distributions include false alarms in the unrelated/interacting condition from all observers in each experiment. Responses were binned by RT into 100-ms bins.

objects. These two explanations are admittedly speculative: Because none of our manipulations changed this effect, our data cannot discriminate between the accounts we offer here, nor can they eliminate other possible explanations of this aspect of the results.

Functional Groups and Scene Processing

The mysterious effect of the unrelated–interacting condition notwithstanding, the results of all four experiments suggest an important role for functional information in the processing of visual scenes: Our findings, like those we reviewed from the neuropsychological literature (Humphreys et al., 2004; Riddoch et al., 2003), show that the presence of a familiar functional relation facilitates the detection and identification of the objects engaged in that relation. And the role of SOA between the objects engaged in the relation suggests that this effect is at least partially perceptual, in turn, suggesting that functional relations are an explicit component of the perceptual representation of scenes.

The problem of visually categorizing a scene is complicated by the fact that the visual–mental representation of scenes must be highly flexible (e.g., able to recognize different offices as instances of the category office, despite the differing locations of the desks, filing cabinets, etc., across different offices), without being promiscuous (e.g., incorrectly "recognizing" the interior of an office supply store as an "office" because of the presence of office-related paraphernalia). For the purposes of flexibility, it is insufficient to code scenes in terms of the literal spatial relations between the objects they contain; but simply ignoring these spatial relations—representing a scene instead as a simple list of objects—would render scene categorization entirely too promiscuous. Green and Hummel (2004) proposed that one potential solution to this problem is to visually represent scenes, not in terms of the literal spatial relations between their objects (e.g., "desk to the left of chair") but in terms of the functional relations between those objects (e.g., "desk facing chair"). Such representations provide a means by which visual information can be connected to abstract knowledge about scene categories as well as actions and goals relevant to the environment. The findings reported here suggest that functional relations also assist (or, if novel, interfere) in the processing of action-relevant objects and object groupings.

These results suggest that research on scene perception (especially the role of context in scene perception) must take into account both the semantic and relational context in which a target object is identified. In the past, researchers have manipulated the identity or location of objects in a scene without considering the creation and disruption of meaningful relations between objects (e.g., Henderson, Weeks, & Hollingworth, 1999; Hollingworth & Henderson, 2000; Loftus & Mackworth, 1978; Mackworth & Morandi, 1967; Moores, Laiti, & Chelazzi, 2003). Other experiments have differentiated between *meaningful* and *nonmeaningful* changes to scenes (e.g., Werner & Thies, 2000). We suggest that *meaningful* changes are those that create or disrupt familiar functional groupings of objects. The results presented here suggest that changes in functional groupings of objects must be considered in addition to (or as a component of) changes in overall scene context.

In summary, object detection in multiobject scenes cannot be understood solely in terms of object semantics, or solely in terms of object relations (layout). Associations between objects and the spatial arrangement of objects both influence processing. Perceptual and/or attentional grouping processes are affected by observers' knowledge about the uses of object groupings within a scene, and these effects are not restricted to objects or groupings that are expected or goal relevant. It remains an open question whether functional information similarly affects the natural viewing of more complex stimuli. The present results highlight the need for consideration of both object semantics and relations as they jointly pertain to functional information in real environments.

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