Reuniting Categories, Language, and Perception

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Abstract

Familiar objects are more easily processed than unfamiliar objects. Familiar objects are also generally meaningful, and comprise members of named categories. Previous work examining familiarity effects in visual processing has confounded perceptual experience with meaningfulness and with nameability. The present experiments use the visual search paradigm to (1) manipulate category membership while controlling for novelty and perceptual similarity, and (2) investigate the role of on-line linguistic labels on visual perception. Search performance is dramatically improved when participants are simply told to think of novel stimuli as members of a familiar category. Search performance is further improved when targets or distractors are named compared to trials on which target and distractor identity is known, but the stimuli are not verbally labeled.

Keywords: categorization; visual perception; visual search; language; labeling

Introduction

Familiar stimuli are not simply perceived, but are quickly categorized as members of meaningful categories (e.g., Grill-Spector & Kanwisher, 2005). It might therefore seem surprising that theories of visual perception have for a long time ignored the possible contributions of conceptual categories to visual perception (Wolfe & Horowitz, 2004 for discussion). One reason for this seeming oversight is that familiarity and category membership are correlated. Stimuli that are conceived as being members of a category are generally also ones that participants have experienced before. Conversely, unfamiliar stimuli are not only perceptually unfamiliar, but also meaningless. Finding that participants are poorer at processing unfamiliar stimuli may be merely the function of their novelty. Alternatively, poor performance on unfamiliar stimuli may be due to a failure to represent them as meaningful category members. Discriminating between these alternatives can help us understand the nature of bottom-up and top-down processes in perception.

An example helps to clarify this distinction. Frith (1974) found that searching for the unfamiliar target И among N's is very efficient, while searching for the familiar N among unfamiliar И's is quite difficult (see also Wang, Cavanagh, & Green, 1994). If the distractors are unfamiliar (И), search is hard. If they are familiar (N), search is easy.[1] This result has been replicated with a variety of stimuli, e.g., upright vs. rotated numbers and familiar upright "live" vs. upside-down "dead" elephants (Wolfe, 2001).

While the character И is unfamiliar to English-speakers, for someone familiar with the Cyrillic alphabet, И is a familiar letter. One may therefore predict that familiarity with the Cyrillic alphabet would lead to efficient search for a N among И's. This is indeed the case (Malinowski & Hubner, 2001). But notice the confound. For English-speakers, N is not just a familiar percept. Rather, it has meaning as the letter "N." The symbol И is not only unfamiliar perceptually, it is also meaningless. Among the bilinguals tested by Malinowki & Hubner, both N and И were familiar, and both were meaningful as letters with sounds /n/ and /i:/ respectively. If the difficulty English-speakers have searching through И's arises from a lack of experience, then performance can improve with additional exposure (in effect making the stimuli familiar). If, on the other hand, the difference is due to categorical status (a difference in meaningfulness), then simply getting participants to treat the unfamiliar symbols as members of a category, can lead to more efficient search. The first aim of the present work is tease apart these alternatives by using a classic perceptual task (visual search) and manipulating category membership while controlling for perceptual novelty.

Categories and Perception

The impact of categorization on perception has been explored most thoroughly in the aptly named field of categorical perception. The most common finding is that practice discriminating between stimuli by placing them into separate categories increases between-category perceptual differences, and sometimes decreases within-category differences (Goldstone, 1994; 1998). While this work has shown how perceptual representations can be shaped by experience, less effort has been made to understand the contribution of conceptual categories to perception, controlling for perceptual familiarity.

The question whether category membership affects performance in visual search, the paradigm used here, has generally taken the form of manipulating the categorical relationship between targets and distractors. Most famously, Jonides and Gleitman (1972) demonstrated that "O" labeled as an "oh" is easier to find among numbers than letters, while the reverse is true for a "O" labeled as a "zero." This finding, however, has failed multiple attempts at replication (Duncan, 1983; cf. Taylor & Hamm, 1997). More generally,

[1] Additional work has shown that the major determinant of search efficiency in tasks like these is familiarity of the distractors, with the status of the target having minimal effect (Rauschenberger & Yantis, 2006). The most obvious reason why distractor identity is more important than target identity is that there is at most one target, but numerous distractors.

finding of faster search rates when targets and distractors belong to different conceptual categories than when they belong to the same conceptual category, is most often confounded by perceptual variables. For instance, efficient search for an artifact among animals can be distilled to perceptual rather than conceptual differences—pictures of man-made artifacts tend to be more rectilinear than pictures of animals (Levin, Takarae, Miner, & Keil, 2001; but see Wolfe, Stewart, Friedmanhill, & Oconnell, 1992).

Categories and Language

Just as it is useful to categorize frequently encountered stimuli (e.g., see Harnad, 2005), it is also useful to name them. On seeing the symbol "5" we not only recognize it as a member of a familiar category (that can be perceptually instantiated using a wide variety of forms, e.g., V, 5), but we also know its name. That is, in addition to whatever semantics we have associated with "5," also associated with it is the name of the category to which it belongs. Why is naming useful? The answer that comes to mind first—communication—may seem too obvious to warrant discussion. However, a number of proposals have been made that extend the function of words to domains beyond communication. For instance, it has been argued that words stabilize abstract ideas in working memory and make them available for inspection (Clark, 1997; James, 1890; Rumelhart, Smolensky, McClelland, & Hinton, 1986). This general hypothesis has been explored using computational simulations that have found that augmenting perceptual information with category labels improves categorization performance by enhancing differences between the representations while at the same time collapsing across within-category differences (Cangelosi, Greco, & Harnad, 2000; Lupyan, 2005). Lupyan, Rakison & McLelland (in press) have found that equating for categorization experience, participants who learn names for novel stimuli learn to categorize them more quickly and show more robust category knowledge than those who perform the identical categorization task without verbal labels.

One way to account for such a finding is to view perception and categorization as interactive processes, combining bottom-up perceptual information, with top-down conceptual information. Because a learned category label becomes strongly associated with features that are most diagnostic (or typical) of the named category, *using* the label can in effect make an object a "better" object by augmenting its idiosyncratic perceptual features with features typical to the named category. A labeled stimulus might therefore produce a perceptual representation that is more influenced by top-down conceptual information than a stimulus that is not named.

Perhaps because dominant theories of visual search (Duncan & Humphreys, 1989; Treisman & Gelade, 1980) have focused on purely perceptual variables, there have been few attempts to isolate and examine involvements of language in perceptual tasks such as visual search. Some exceptions are the studies of Spivey and colleagues (Spivey, Tyler, Eberhard, & Tanenhaus, 2001), that have shown that linguistic delivery of target information ("find the green vertical") can make an inefficient conjunction search efficient if the dimensional adjectives are delivered concurrently with the search display rather than immediately prior to it. The authors suggested that hearing "green" followed by "vertical" effectively divided the conjunction search into two simpler feature searches, allowing the items to first compete on the "green" dimension and then on the "vertical" dimension. This division of labor was seemingly not possible in the absence of the verbal information.

Aims and Hypotheses

The present work has two aims. First, I examine the influence of meaningfulness on visual performance while controlling for perceptual experience. Experiment 1 presents participants with unfamiliar stimuli and examines what happens when participants are told to consider them as members of a particular category. It was hypothesized that in instructing participants to treat perceptually unfamiliar symbols as members of familiar categories would facilitate visual processing as revealed by shallower search slopes.

If search is more efficient when items are categorized, and verbal labels, by virtue of their strong association with category exemplars, make object representations more categorical, then hearing a category label may further facilitate performance. In experiments 2a and 2b, the distractors or the target were labeled on some trials, and performance was compared to trials on which no labeling occurred (but participants knew the identity of the target/distractors). It was hypothesized that labels would further facilitate search even though they contributed no additional information to the participants.

Experiment 1

Subjects

Sixty-one subjects, 18-22 years old volunteered for the experiment in exchange for course credit or $7. None of them had previously participated in any visual search experiments with similar stimuli.

Stimuli

The stimuli used in Experiment 1 were the symbols  and . The characters were white on a black background and had a visual-angle size of .7° x .8°. The characters were arranged along the circumference of an imaginary circle having a diameter of 7° around a fixation cross (.5° diameter). The placement of the target and distractors was random with the stipulation that the same number of items were present on the left and right sides of the display.

Procedure

Participants were randomly assigned to one of two groups. Participants in the *number* group were told to think of the targets/distractors as rotated 2s and 5s. This instruction was omitted for participants in the *symbol* group. In one part, participants were instructed to find a among . During the other part, the target and distractor identity was reversed (with the order counterbalanced between participants). At the start of each part the target was shown on the screen accompanied with a reminder that it should be viewed as a rotated number (*number* condition). For the *symbol* group, the target was shown by itself.

Each part consisted of 20 blocks of 6 trials (target-present vs. target-absent x 3 display sizes—4, 6, or 10). Trial order was random with the target present on exactly half the trials. Participants gave 2-alternative target *present* / *absent* responses using a gamepad controller. Participants were instructed to respond as quickly as possible without compromising accuracy. If the accuracy dipped below 92% for 24 trials, participants saw a display asking them to try to be more accurate. Response mapping (left hand *present* vs. right-hand *present*) was counterbalanced between participants. Each part began with 12 practice trials. The inter-trial interval was 750 ms. Feedback in the form of a buzzing sound was provided for incorrect responses.

After completing the experiment, participants were given a written questionnaire that asked whether they thought of the symbols / as any kind of number or letter, and if so which one(s)? Participants were also queried about their consistency of label use. A question asked, "did you use this label at the beginning / middle / end of the experiment (circle all that apply)." Consistency was coded based on whether participants claimed to use labels throughout the task (*consistent group)*, or only for part of the task (*inconsistent group)*.

The questionnaire was necessary because participants in the *symbol* condition may have considered the stimuli as meaningful on their own without external experimenter-provided instructions. Conversely, participants in the *number* condition may have failed to conceive of the stimuli as rotated numbers despite the instruction to do so.

Results

For the *symbol* group, the responses fell into three categories. First, participants who consistently self-labeled the stimuli, either as rotated 2s/5s, or thought of them as other (often creative) symbols/symbol combinations (N=14). For instance, several participants thought of / as NU / UN, respectively. Second, participants who labeled the stimuli inconsistently (i.e., only part of the time) (N=11). Third, participants who did not report labeling the stimuli (N=16). Participants in the *number* condition fell into two categories: those who reported consistently thinking of the stimuli as rotated 2s and 5s, as instructed (N=15), and those who although instructed to do so, did not report labeling the stimuli (N=5).

The mean proportion of misses was 8% and did not differ among conditions, $F(1,60)<1$. The false alarm rate, however, was greater in the *symbol* condition ($M = .05$) than the *number* condition ($M = .01$), $F(1,60) = 4.74$, $p < .05$. Reaction time (RT) analyses that follow include only correct responses and exclude RTs shorter than 150 ms. as anticipations. Response times greater than 3 standard deviations of participants' means were also excluded. Analyses were conducted using ANOVAs with display size as a within-subjects factor, and instruction-condition as a between-subject factor. Figure 1 shows target-present trials (top) and target-absent trials (bottom). Analyses for target-present and target-absent trials closely paralleled each other, so only

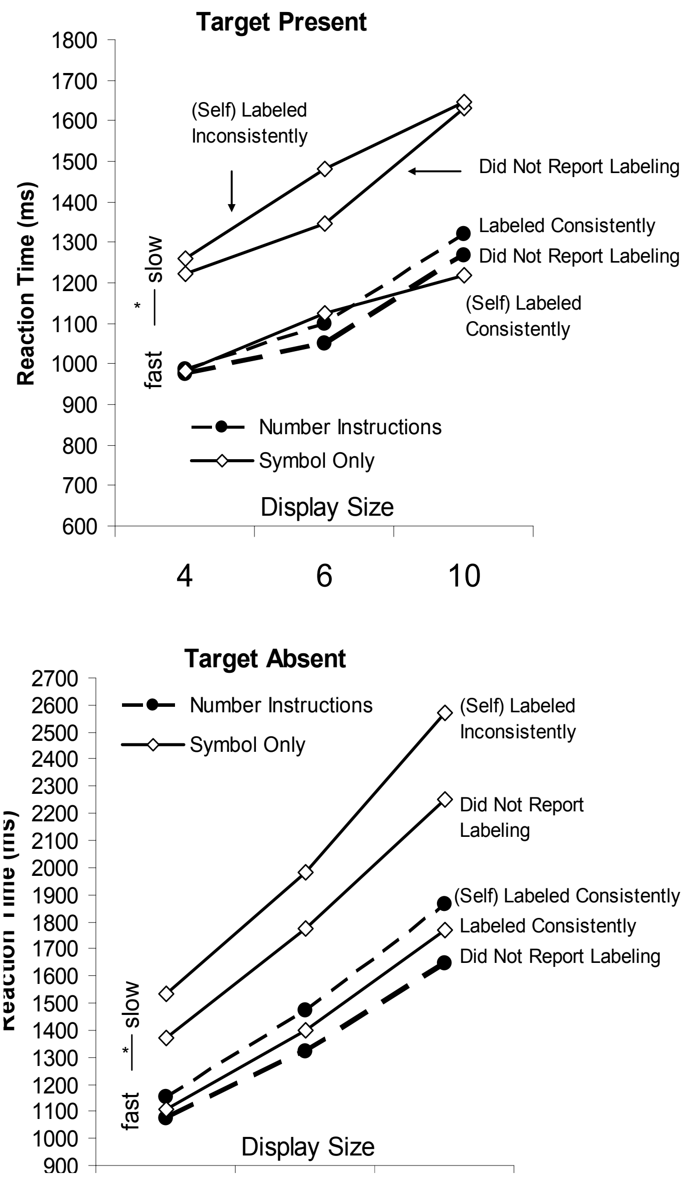


Figure 1 Search performance as a function of instruction and reported use of labels.

target-present analyses will be presented here.

Initial analysis with instruction-condition as the between-subject factor revealed significantly slower responses for the *symbol* group, $F(1,60) = 7.31$, $p < .01$. The condition × display-size interaction was not significant, $F(2, 60) < 1$. Correlating performance with questionnaire responses made it apparent that participants' judgments of whether they thought of the characters in terms of any familiar symbols predicted performance. Using the 5 groups derived from the questionnaire responses as the between-subjects variable revealed a significant main effect $F(4, 57) = 6.47$, $p <.0005$, and a significant group × display size interaction, $F(5,57) = 2.26$, $p < .05$. Participants in the symbol condition who reported consistently thinking of the characters in terms of familiar categories had mean RTs that were statistically indistinguishable from participants who were explicitly told to think of the characters as numbers, whether or not the latter reported thinking of the characters as numbers, $F(2,32) < 1$. These three groups were collapsed for the subsequent analysis (the "fast" group in Figure 1). Participants in the *symbol* group who reported either inconsistently labeling the stimuli, or not labeling them had mean search times were not significantly different, $F(1,25) < 1$. The search slopes also did not differ, $F(2,25) = 1.54$, $p > 2$. These two groups were therefore collapsed into the "slow" group shown in Figure 1.

A mixed ANOVA with display-size as a within-subjects factor and collapsed groups ("slow"/"fast") as a between-subjects factor revealed a highly significant difference in mean search times, $F(1,60) = 26.36$, $p <.0005$, and a significant group × display-size interaction, $F(2, 60) = 3.77$, $p < .05$. Search slopes for all experiments are listed in Table 1.

Discussion

Instructing participants to consider novel stimuli as instances of a familiar category significantly improved mean search times and search efficiency. The benefit of representing perceptually novel items as members of meaningful categories was also observed in individuals who reported *consistently* self-labeling the stimuli without being told to do so. While finding faster search through familiar (and hence meaningful) distractors is nothing new (Rauschenberger & Yantis, 2006), the current experiments show that having participants ascribe meaning to unfamiliar stimuli dramatically improves visual processing.

Experiments 2a-b

Experiment 1 revealed a facilitation of visual search performance by conceptual knowledge in the absence of any perceptual differences. Over the course of using words to refer to categories, the two become linked such that hearing a label for a familiar item may augment its perceptual information with information associated with the category. This augmentation may lead to increased processing fluency by, for instance, increasing the effective similarity between similarly named distractors. If labels affect visual processing through their association with visual forms, then their effects should be greater for stimuli more strongly associated with the label (i.e., more typical stimuli) than for stimuli used in Experiment 1 leading to a further prediction: the effect of hearing a category label should be strongest for more typical category exemplars. Because manipulations of distractors leads to greater effects than similar target-manipulations (Rauschenberger & Yantis, 2006), labels were applied to the distractors in Experiment 2a. Experiment 2b extended the labeling manipulation to targets.

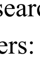
Table 1: Search slopes (ms/item) for Experiments 1-2 for target-present and target-absent trials. Data for Experiment 1 are collapsed into two groups, indicated on Figure 1 as "fast" and "slow."

Experiment	Condition	Target Present	Target Absent
Experiment 1		ms/item	ms/item
	"Fast" group	47	110
	"Slow" group	66	153
Experiment 2a	"ignore…"		
Upright Trials	Labeled	34	65
	Not Labeled	47	81
Rotated Trials	Labeled	35	80
	Not Labeled	48	85
Experiment 2b	"find the…"		
Upright Trials	Labeled	37	70
	Not Labeled	39	70
Rotated Trials	Labeled	51	95
	Now Labeled	53	83

Subjects

Forty-eight subjects, 18-22 years old volunteered for the experiment in exchange for course credit. They were naïve to the task. Half the subjects participated in Experiment 2a and half in Experiment 2b.

Stimuli

Four distinct stimuli were used in the search trials: upright numbers:  and  ,and rotated numbers:  and . To assess the impact of auditory labels, a recording of the words "ignore" (Experiment 2a) and "find the" (Experiment 2b) was spliced with the words "two", "five", and a segment of white noise, creating 6 audio clips—Experiment 2a: "ignore five", "ignore two", "ignore [noise]." Experiment 2b: "find the five", "find the two", "find the [noise]". All auditory stimuli were adjusted to be of the same intensity and length (1000 ms).

Procedure

Procedure was identical to Experiment 1 with the following key differences. First, there were two types of trials: those involving upright numbers, and those involving rotated numbers. Upright and rotated trials were intermixed. Second, all participants were told to think of all symbols as the numerals 2 and 5. Third, prior to the appearance of each search display, participants heard a sound clip label the distractor identity on half the trials (e.g., "ignore 5")—the *label* condition, or a sound clip in which the distractor label was replaced by white noise ("ignore [noise]")—the *no-label* condition (Experiment 2a). Experiment 2b was identical except that target identity was named. Prior to each search trial, participants heard "find the 2 (5)" or "find the [noise]." The search display appeared 600 ms after the end of the sound-clip.

As in Experiment 1, target and distractor identities were blocked. Consequently, participants always knew ahead of time what the target and distractors were going to be—the linguistic label did not tell them anything they did not already know and thus could not guide search directly. As in Experiment 1, participants searched for a 2 among 5s and then for a 5 among 2s, with the order of the two parts counterbalanced. While target and distractor identities were blocked, orientation and labeling conditions were intermixed within each block.

This design created 24 types of trials: target present/absent × display size (4, 6, or 10) × orientation (upright or rotated) × *label* or *no-label*. Participants completed 10 blocks for a total of 240 trials searching for 2s and 240 searching for 5s. Each block began with 15 practice trials.

Experiment 2a Results

Search performance was analyzed using a within-subject ANOVA with display size, orientation (upright or rotated), and labeling (with-labels, without-labels) as within-subject variables. Analysis of errors revealed a significant effect of orientation, $F(1,23) = 13.82$, $p < .001$, with rotated numbers producing more errors (8%) compared to upright numbers (6%). Labeling did not significantly affect accuracy, $F(1,23) = 2.31$, $p > .13$.

Reaction time analyses included correct responses only and excluded RTs less than 150 ms and greater than 3 standard deviations above the mean. Analyses will focus on the target-present trials. First, consistent with the findings of Wang et al. (1994), RTs were longer on trials that involved searching for the rotated targets, $F(1, 23) = 42.12$, $p <.0005$. Unlike Wang et al's (1994), the display-size × orientation interaction here was not significant, $F(2, 23) < 1$, further confirming the facilitatory effect of treating perceptually unfamiliar objects as members of a familiar category.

There was no overall effect of labeling on RTs, $F(1, 23) = 2.02$, $p > .16$, but search slopes were reduced for labeled trials as revealed by a highly significant labeling × display-size interaction, $F(2, 23) = 5.76$, $p < .01$. There was also a significant orientation × labeling interaction, $F(1, 23) = 6.52$, $p < .025$ suggested that the effect of labels was mediated by orientation. Analyzing the upright and rotated trials separately clarified effect of labels. For the upright trials, hearing the distractors labeled with their category resulted in both faster overall search, $F(1, 23) = 8.1$, $p < .01$, and more efficient search (i.e., shallower slopes), $F(2, 23) = 3.27$, $p < .05$. On rotated trials, labels did not reduce overall search $F(1, 23) < 1$, but again produced shallower slopes, $F(2, 23) = 4.07$, $p < .025$ (Figure 2). It therefore appears that labels had a larger facilitating effect on upright compared to rotated trials. The target-absent trials mirrored these orientation × labeling interactions. Search was much slower, but not less efficient on rotated trials, and labeling produced more efficient search only on upright trials, $F(2, 23) = 3.63$, $p < .05$.

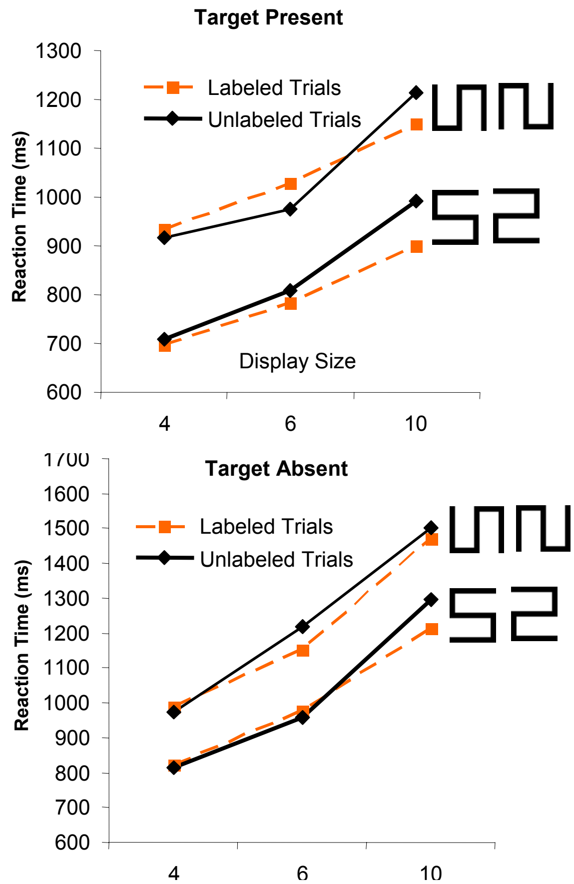


Figure 2 Experiment 2a search times for labeled vs. unlabeled upright and rotated trials. Labeling and orientation are intermixed (manipulated within each block).

Experiment 2b Results

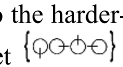
The overall pattern of performance was very similar to Experiment 2a, except that the effect of labeling was now limited to reducing overall search times and not on search slopes. Errors were again higher for the rotated trials (9%) compared to upright trials (5%), $F(1, 23) = 8.30$, $p < .01$. There were no other accuracy effects. Search on rotated trials was performed more slowly, $F(1, 23) = 64.43$, $p < .0005$, but not less efficiently, $(2, 23) = 2.14$, $p > .12$.

Labels had an overall effect of speeding search, $F(1, 24) = 5.15$, $p < .05$, but this effect was limited to the upright trials, $F(1, 23) = 5.59$, $p < .05$. Labels did not have a significant effect on rotated-trial performance, $F(1, 23) = 2.49$, $p > .13$.

Discussion

Although participants always knew the identity of targets and distractors, hearing the distractors (and to a lesser extent, the target), labeled by their basic-level names facilitated perceptual processing. This effect was most pronounced for the more typical (upright) stimuli, suggesting that it is specific to stimuli that most resemble members of the named category rather than being a general effect of hearing the name. While search times for the rotated stimuli were longer, efficiency was comparable (see Table 1), and similar to those in the number condition of Exp. 1. In contrast, Wang et al. (1994) found a twofold difference in search slopes between upright and rotated stimuli. So, while search for rotated numbers is minimally affected by on-line labeling, it is nevertheless influenced by having participants think of the unfamiliar symbols as rotated numbers.

General Discussion

Together, these experiments argue for a reassessment of theories of visual processing that do not take meaningfulness into account (Duncan & Humphreys, 1989; e.g., Treisman & Gelade, 1980). The argument that perceptual processing in visual search depends on more than visual similarity has been recently made by Rauschenberger & Yantis (2006) who argued that perceptual encoding depends on stimulus *redundancy*. For instance, not all combinations of a circle and a line are equally redundant. Combinations that create the letter Q are processed more efficiently. A Q, being a member of an implicit set of size 1, is highly redundant compared to the harder-to-process  —a member of a less redundant set  (Garner & Clement, 1963). Insofar as the redundancy framework is useful, it is clear that redundancy cannot be reduced to visual features, but must take meaningfulness into account. The present work shows that controlling for all perceptual variables, meaningfulness in its own right affects perceptual processing.

The dynamic nature of perceptual processing is further highlighted by Experiment 2. Even though the upright numerical stimuli were both meaningful and familiar, on-line presentation of labels further facilitated performance on the search task. What is a possible mechanism by which entirely redundant verbal information affects visual performance? Numerous studies have shown that attention has an object-based component (O'Craven, Downing, & Kanwisher, 1999; Shomstein & Behrmann, 2006). Category labels, through their associations with visual features typical of the named category, may facilitate the response of object-selective regions of cortex which in turn can guide attention to the members of the named category, possibly in parallel and throughout the visual scene.

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