
**The Quarterly Journal of Experimental Psychology**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100704

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First Published on: 19 May 2009

**To cite this Article** Schmidt, Joseph and Zelinsky, Gregory J.(2009)'Search guidance is proportional to the categorical specificity of a target cue',The Quarterly Journal of Experimental Psychology,62:10,1904 — 1914

**To link to this Article: DOI:** 10.1080/17470210902853530

**URL:** http://dx.doi.org/10.1080/17470210902853530

THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2009, 62 (10), 1904–1914

Psychology Press
Taylor & Francis Group

# Short article

# Search guidance is proportional to the categorical specificity of a target cue

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Visual search studies typically assume the availability of precise target information to guide search, often a picture of the exact target. However, search targets in the real world are often defined categorically and with varying degrees of visual specificity. In five target preview conditions we manipulated the availability of target visual information in a search task for common real-world objects. Previews were: a picture of the target, an abstract textual description of the target, a precise textual description, an abstract + colour textual description, or a precise + colour textual description. Guidance generally increased as information was added to the target preview. We conclude that the information used for search guidance need not be limited to a picture of the target. Although generally less precise, to the extent that visual information can be extracted from a target label and loaded into working memory, this information too can be used to guide search.

*Keywords*: Guided search; Eye movements; Categorical search; Semantic cues; Realistic objects.



Think back to the last time that you looked for your keys, or a pen to jot down a note, or a friend that you were to meet at the airport. Were you holding in your mind's eye a picture of the target as you were conducting these searches? Many theories of visual search, particularly those that rely on target–distractor similarity to guide the search process (e.g., Duncan & Humphreys, 1989), make this assumption. For example, Wolfe's (1994) guided search theory holds that top-down knowledge of the target, represented as weights on feature maps, can preattentively guide search efficiently to the target. Search theories designed to work with realistic objects in scenes rely even more on knowledge of the target's properties (e.g., Zelinsky, 2008), represented as a high-dimensional vector of features. Of course, as this representation becomes increasingly detailed what emerges is a sort of iconic or pictorial representation of the target (Rao, Zelinsky, Hayhoe, & Ballard, 2002).

Although these theories are useful in explaining the substantial evidence for guidance in the search

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This work was supported by National Institute of Mental Health (NIMH) Grant 2 R01 MH063748-06A1 and National Science Foundation (NSF) Grant IIS-0527585 to G.J.Z. We thank Samantha Brotzen, Shreena Bindra, and Zainab Karimjee for help with data collection.



http://www.psypress.com/qjep
DOI:10.1080/17470210902853530

literature (see Chen & Zelinsky, 2006, and Wolfe, 1994, for reviews), it is rarely the case that we have clear knowledge of a target's visual features. Unless your friend had the foresight to send you a list defining her visual features (e.g., the colour of her coat; will she be wearing sunglasses or a hat?), you probably won't know her exact appearance when you are looking for her at the airport. Moreover, a search process that is overly feature-specific is likely to be undesirable in the real world. Including the colour "blue" in your search for a pen might cause you to miss the red pen located right in front of you. Many search tasks are even categorical; often we need to find any pen or person, not a specific one. Under these conditions, the target visual features are necessarily less exact and will only be useful to the extent that they describe an entire object class. The purpose of this study is to explore how the textual description of a target affects the visual search for real-world objects. Is search still guided to categorically defined targets, and, if so, how is this guidance affected by the inclusion of visual details in the text label designating the target?

The study of categorical search dates back at least to work by Jonides and Gleitman (1972), who showed that search performance depended on whether a target was defined as an "oh" or a zero. Although subsequent work demonstrated that this effect disappeared when feature similarity between the target category and distractors was controlled (Duncan, 1983), this early debate highlighted the importance of categorical search and the role of feature similarity relationships in determining categorical search effects.

More recent work has focused less on the question of how target membership in a category affects search and more on how visual features are represented from target cues. For example, people searching for an oriented bar do not use the exact orientation from the target preview, adopting instead a more categorical representation, such as left leaning or steep (Wolfe, Friedman-Hill, Stewart, & O'Connell, 1992). Dahan and Tanenhaus (2005) also observed that people searching for an outstretched snake tended to fixate distractors that looked like typical snakes (e.g., a curled rope) over distractors that were not snake-like in appearance. However, this preference was asymmetrical; when looking for a rope people only mildly preferred to look at the snake. This asymmetry suggests that guidance was not due to visual similarity to a specific template, but rather visual similarity to the target category.

Recently the focus has shifted yet again to the consequences of mismatches between target previews and targets in the search display (Vickery, King, & Jiang, 2005; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). These studies generally report that search efficiency is best for pictorially previewed targets, but decreases with increasing mismatch between the preview and search views. Search is least efficient when the preview is eliminated, and targets are cued using a text label. However, these studies repeated targets, thereby introducing the potential for priming or interference effects, and they quantified efficiency using exclusively manual measures. Subsequent work using an eye movement paradigm and excluding object repetition confirmed that search guidance is superior with a pictorial preview, but importantly also found above-chance guidance to categorically defined targets (Yang & Zelinsky, 2006). Eye movement guidance has also been reported in scenes for the pedestrian target category (Ehinger, Hidalgo-Sotelo, Torralba, & Oliva, in press).

None of these studies, however, manipulated the specificity of target information in the text label. To date the only search study to use such a manipulation found that search guidance is unaffected by the specificity of a text cue; the search for "fruit" was as efficient as the search for "pear" (Foulsham & Underwood, 2007). However, this study used a relatively small number of target categories. There was only a single abstract target category (fruit) and four specific target categories (apple, lemon, orange, and pear), all of which repeated several times. Such repetition may have allowed specific templates to be learned for the abstract target category, thereby negating any advantage of the specific target cue by making the "fruit" search easier than what it otherwise would be.

Perhaps the work most related to the present study comes from outside the search literature. Intraub (1981) manipulated the informativeness of a target cue in the context of a rapid serial visual presentation (RSVP) task. Participants were asked to detect a target under varying degrees of target specificity, including the specific name of the target (e.g., "giraffe"), the superordinate category to which it belonged ("animals"), and a condition providing negative category information ("not an animal"). She found faster responses and better detection as information was added to the target cue, suggesting that the recognition process can quickly convert a text description into visual information and use it in a speeded judgement.

Our study builds on this work, extending it to two relationships between search guidance and categorical targets. First, is search guidance possible with nonpictorial, semantically defined targets? Search is known to be inefficient with such targets, but do they generate a signal that can be used to guide overt search? If so, above-chance guidance should be found to these targets, even when they are designated by fairly abstract cues. Second, does guidance increase with the precision of this semantic information? Such an increase might indicate that more precise semantic descriptions can be used to create more precise visual target representations. To the extent that this occurs, we expect that the addition of shape and colour information to the target label would increase guidance relative to an abstract cue condition, although guidance is still likely to be best from a pictorial target preview.

## Method

### *Participants*

A total of 65 students from Stony Brook University participated for course credit. All had normal or corrected-to-normal vision and were native English speakers, by self-report.

### *Stimuli and apparatus*

Stimuli consisted of a target cue and a search display (Figure 1). Target cues were either a picture of the target or a text label describing the target, both presented centrally and subtending 3°. Search displays consisted of four distractors and one target (Hemera objects), which were arranged into a circle having a 9° radius relative to central fixation. Objects were positioned by first placing the target at a random point on the circle's circumference, then placing each distractor at 72° increments along the circle relative to the target's location. Each object subtended ~2°. A small (0.17°) + or × character was inserted next to the target in the search array. Over trials, half of the targets appeared with a + and the other half with a × . These characters were manually placed as close to the target as possible, either touching or within 2 pixels. Positioning around the target was random, with the constraint that they were legible and easy to segment, while still being difficult to discriminate unless directly fixated.

Eye position was sampled at 500 Hz using an EyeLink II eye-tracker with default saccade detection settings. Calibrations were not accepted until the average spatial error was less than 0.49°, and the maximum error was less than 0.99°. Head position and viewing distance were fixed at 72 cm using a chinrest. Judgements were made by pressing the left and right index finger triggers of a game pad controller; trials were initiated with a button operated by the right thumb.

### *Design and procedure*

There were five target cue conditions, consisting of either a pictorial preview or a semantic description (presented as text) that varied in specificity. These were: *pictorial*—a picture of the target; *abstract*—an imprecise categorical text label describing the target; *precise*—a more specific text label emphasizing additional shape details other than colour; *abstract + colour*—a colour descriptor was added to the abstract condition labels; and *precise + colour*—the same colour descriptor as that in the abstract + colour condition was added to the precise condition labels (see Figure 1; for a complete list of categories see the Appendix). Target cue was a between-subjects variable, and each condition had 70 experimental trials. Search displays

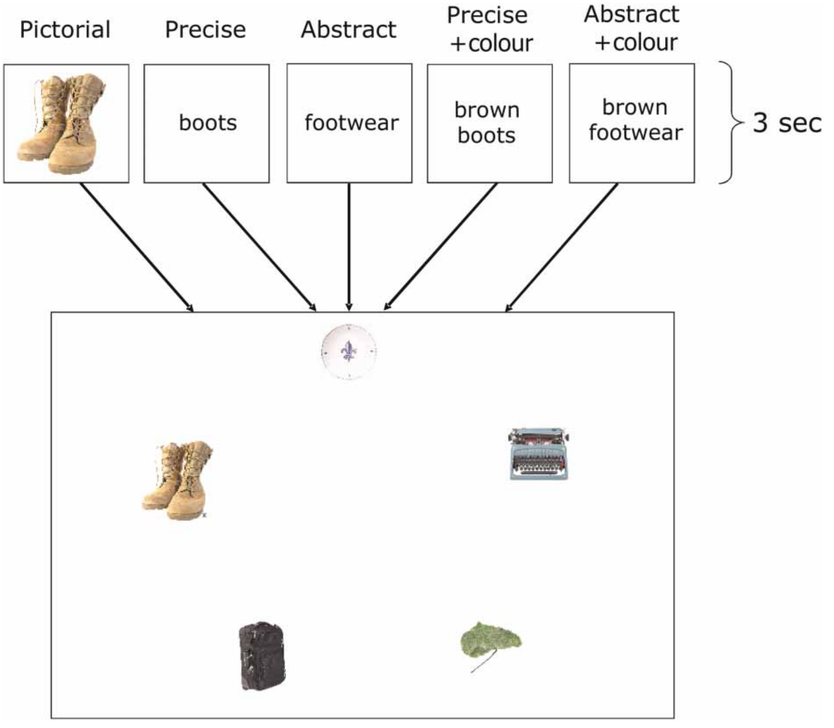


**Figure 1.** *Illustrations of the target cue conditions and a representative search trial. To view a colour version of this figure, please see the online issue of the Journal.*



were identical across all conditions, enabling us to observe a pure effect of cue on search behaviour.

Targets and distractors never repeated, and a different target category was used on each trial. Moreover, we attempted to prevent categorical overlap between the precise and abstract conditions over trials. These steps were taken to minimize the potential for priming and bias. If "apple" was the target on trial $n$, a participant cued with "fruit" on trial $n + x$ might be biased to search for an apple based on their previous exposure to this item. Target categories (at all levels of specificity) were also prevented from overlapping with distractors, and categorical overlap was even minimized among the distractors by using 47 different broad distractor categories.

Trials began with participants fixating a central point and pressing a button. In addition to starting the trial, this served to "drift correct" the eye-tracker to account for any movement since calibration. The fixation point was then replaced by the target cue, which was displayed for 3 seconds to ensure that participants had enough time to read even the longest text labels. The search display immediately followed the cue, which remained until the discrimination judgement. A target was present on every trial, and participants were instructed to first acquire the target, as quickly and accurately as possible, then to indicate the presence of a + or × by pressing the left or right triggers, respectively. The experimental trials and four practice trials were performed in a single block, and the entire experiment lasted approximately 30 minutes.

## Results and discussion

In order to gauge search guidance we analysed initial saccade direction and the number of distractor objects fixated before the target, as well as the manual measures of reaction time (RT) and error rates. Although several comparisons were planned between our cueing conditions, we will use the more conservative post hoc least significant difference (LSD) test when reporting statistical results, unless otherwise noted. For clarity, we first discuss comparisons between the pictorial, precise, and abstract conditions, followed by a separate discussion of the colour conditions.

Error rates and RTs are shown in Table 1. Errors were less than 5%, indicating that participants were able to correctly identify the + and × characters. These trials were excluded from further analyses. RTs showed a clear effect of target cue; pictorial (1,418 ms) < precise (1,763 ms) < abstract (2,088 ms), both *p*s < .03, which was confirmed by one-way analysis of variance (ANOVA), $F(4, 64) = 8.44$, $p < .001$. This analysis provides initial support for our hypothesis that search efficiency increases as visual information is added to the target cue. However, as a measure of search guidance, RT differences are ambiguous; it is unclear whether shorter responses are due to the faster rejection of distractors or true guidance toward the target.

If RTs are one of the coarsest measures of guidance, the direction of the initial saccade during search is one of the most stringent. To calculate initial saccade direction each display was cut into five equal-sized 72° slices, one for each object. If the first eye movement fell within the target slice it was counted as an eye movement toward the target. By chance, 1/5 or 20% of these initial saccades would be directed at the target; a significantly greater preference to fixate targets would indicate greater guidance.

**Table 1.** *Reaction times and errors by target cue condition*

| *Cue* | *Reaction time (ms)* | *Errors* |
|---|---|---|
| Pictorial | 1,418 (60.3) | 3.5 (0.3) |
| Precise | 1,764 (79.6) | 2.6 (0.5) |
| Abstract | 2,088 (74.4) | 4.2 (0.6) |
| Precise + colour | 1,983 (125) | 2.3 (0.3) |
| Abstract + colour | 2,067 (168.8) | 3.9 (0.6) |

*Note:* Reaction times reflect only correct trials. Values in parentheses indicate standard error of the mean (*SEM*).

Figure 2 shows that the percentage of initial saccades to the target decreased as visual information was removed from the target cue (pictorial > precise > abstract), $F(4, 64) = 6.73$, $p < .001$. Post hoc tests confirmed that differences between the precise and abstract conditions were significant ($p < .04$), as were differences between the pictorial and precise conditions ($p < .005$). For all conditions we also found a higher percentage of initial saccades to the target than what would be expected by chance, even when the target cue was abstract, $t(12) \geq 29.85$, $p < .001$. The latencies of the initial saccades averaged only 202 ms and did not differ between cue condition, $F(4, 64) < 1$. These patterns indicate a very rapid use of text information to guide search to real-world objects and confirm our hypothesis that guidance increases with the amount of semantically defined visual information available from the target cue.

Initial saccade direction captures early evidence for search guidance, but fails to capture guidance emerging later during search. To better characterize guidance throughout search we analysed the number of distractors fixated before the target, defined as gaze landing within 4.2° of an object's centre. Given five-object displays, a participant might fixate two distractors before the target based on chance alone. Finding fewer than two distractors fixated before the target would therefore provide evidence for search guidance.

Figure 3 shows the average number of distractors fixated during search before initial fixation on the target. Consistent with the initial saccade direction analysis, we again found a pattern of increasing guidance with additional information in the target cue, $F(4, 64) = 30.10$, $p < .001$. Post hoc tests again revealed significant differences between the precise and abstract conditions ($p < .01$), as well as differences between the pictorial and precise conditions ($p < .001$). Distractors were also fixated much less than what would be expected by chance, $t(12) \geq 5.12$, $p < .001$. Together, these results suggest that guidance was not limited to an initial bias in the direction of the target, but rather was a pronounced effect persisting throughout a search trial.

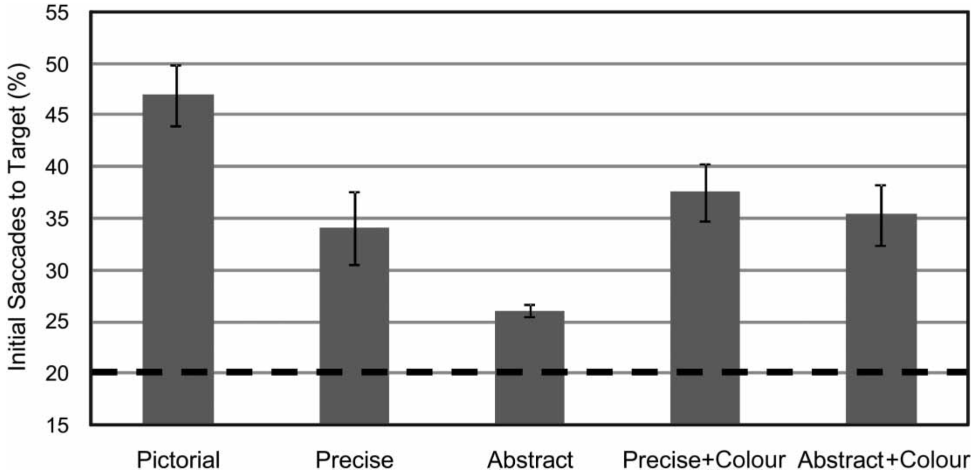


**Figure 2.** *Percentage of initial saccades directed to the target on correct trials. The dashed line indicates chance; error bars indicate standard error.*

The previous analyses demonstrated an increase in search guidance when primarily shape-related visual details were added to the target description. However, colour is also an important feature for guiding search, probably more so than shape (e.g., Motter & Belky, 1998). To determine how the inclusion of text-based colour information affects guidance we now consider the two conditions in which a colour name was added to the target cue.

Errors in the two colour conditions were also infrequent, and RTs in both were significantly

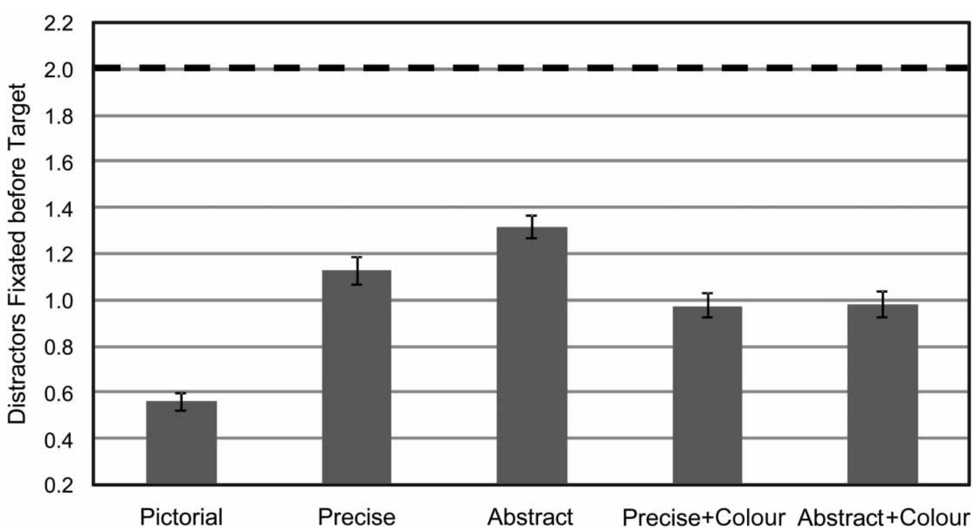


**Figure 3.** *Average number of distractors fixated before the target (without replacement) for correct trials. The dashed line indicates chance; error bars indicate standard error.*

slower than those in the pictorial condition (both $p$s $< .001$; Table 1). The two colour conditions also did not reliably differ from each other ($p > .1$). As well, we did not find a reliable RT benefit when a colour term was added to the non-colour target label; the abstract + colour condition was not significantly faster than the abstract condition ($p > .1$), and RTs in the precise + colour condition were in fact somewhat longer than those in the precise condition, although not significantly so ($p = .09$). Adding text-based colour information therefore did not result in faster RTs in our task, although one must keep in mind that colour-related benefits in manual search efficiency might be masked by variability in the discrimination judgement.

To better characterize the effect of colour on search guidance we again turn to oculomotor measures. If adding a colour term to the target label improves guidance, more initial saccades should be directed to the target, and fewer distractors should be fixated before the target in the colour conditions than in their no-colour counterparts. Consistent with these predictions Figures 2 and 3 show significantly better guidance in the colour conditions than in the abstract condition for both measures, although guidance was still strongest in the pictorial condition (all $p$s $< .05$). Compared to the precise condition there were also fewer distractors fixated before the target in both the precise + colour and abstract + colour conditions (both $p$s $< .05$). These differences suggest that the addition of colour information improves guidance even over the considerable level already observed in the precise condition. However, this benefit relative to the precise condition did not extend to initial saccade direction ($p > .1$), suggesting that colour information may not be immediately available to the search process when the target cue is a relatively detailed textual description. Interestingly, guidance did not meaningfully differ between the two colour conditions ($p > .1$). Perhaps adding a colour term eliminated guidance differences between the precise and abstract conditions by imposing a ceiling on the level of guidance that is possible using a text-based target cue. This ceiling effect may also explain the relatively small and delayed guidance benefit observed in the precise + colour condition relative to the precise condition.

## GENERAL DISCUSSION

There are two clear take-away messages from this study. First, search can be guided to textually defined targets, but not all text-based target descriptions yield equivalent levels of guidance. Guidance generally increases as visual information is added to the target's textual description; it is not an all-or-none process. This is exemplified by the greater guidance observed in the precise condition than in the abstract condition. Our evidence for graded categorical guidance, however, probably depends on the specifics of our task; had we not minimized overlap between the target and distractor categories, or had allowed abstract targets to repeat, these differences in categorical guidance may not have been as great (e.g., Foulsham & Underwood, 2007). Second, although guidance generally improves with the addition of visual details, there is a limit on the amount of guidance that can be expected from a textually defined target. Even with our most precise target label, guidance from a text cue was still far less than guidance from a pictorial target preview. Early evidence suggests that this limit may correspond to the guidance level observed in our colour conditions, as guidance differences between the abstract and precise conditions were eliminated by adding a colour term to the target label. This is also consistent with the important role that colour is known to play in guiding search (Motter & Belky, 1998); our work suggests that this importance applies to colour information more broadly, regardless of whether it is supplied by a target preview or a text label.

Our finding that guidance is graded, proportional to the information available from a target cue, has implications for real-world applications of search, such as screening baggage for concealed weapons (McCarley, Kramer, Wickens, Vidoni, & Boot, 2004). Our data suggest that screeners asked to find *any* weapon should be quite inefficient at their task, due partly to the abstract target description (see also Wolfe, Horowitz, & Kenner, 2005). However, adopting an overly precise target description carries the opposite risk; one might mistakenly conclude that a target is absent, when in fact it is present but not in the precise form expected by the searcher. A useful compromise might be to have multiple screeners each searching for a different target (see also Menneer, Barrett, Phillips, Donnelly, & Cave, 2007), or a single screener conducting a series of relatively precise target searches (e.g., knife, then gun, etc). More generally, our findings suggest that care must be taken in tailoring a target label to a specific search task, to maximize guidance to the intended target.

Our data also have important implications for theories of search, particularly as they relate to categorically defined targets. Models of search often assume knowledge of a target's specific features, which takes the form of a template that can be matched to the search scene (e.g., Duncan & Humphreys, 1989; Wolfe, 1994; Zelinsky, 2008). To the extent that this match is successful, search will be guided efficiently to the target. The problem is that most real-world searches take place under conditions of high mismatch to a target template. An extreme example of this is categorical search, where a template might differ from the actual target on an untold number of feature dimensions. The fact that search is still guided under these conditions, albeit not as efficiently as when the target's appearance is perfectly specified using a preview (Yang & Zelinsky, 2006), is consistent with the graded expression of guidance reported in this article.

We speculate that when participants are provided with a text label describing a target they attempt to self-generate a target template to guide their search, much as they do when they are provided with a pictorial target preview. When the target label is fairly detailed, as in our precise condition, a useful template might be constructed to efficiently guide search. Of course this template would not be as detailed as when the target was actually previewed, and this probably explains the guidance difference observed between our pictorial and precise cue conditions. When the target label is less detailed, as in our abstract condition, participants still attempt to construct a guiding template, but there would necessarily be more room for error in this description, resulting in less guidance. We therefore believe that search guidance improves as information becomes available to better predict the target's appearance, but that the actual process of comparing this template to the search scene is not fundamentally different from what is assumed by appearance-based models of search (e.g., Zelinsky, 2008).

Although generally consistent with existing search theory, our work challenges models of search to better describe this process of self-generating templates from imprecise target cues. Most models assume that templates are constructed via the application of visual filters to the target image (e.g., Zelinsky, 2008), but this assumption is obviously violated when the target is specified using a text label. One clear finding from this study is that, to the extent that visual information can be extracted from a target label and used to construct a working-memory representation, this variety of self-generated template can also guide search. However, only two existing models can accommodate such target templates, one by using machine-learning techniques to extract discriminative visual features from training samples of a target class (Zhang, Yang, Samaras, & Zelinsky, 2006) and another by using keywords interacting with knowledge in a long-term memory network to bias specific target features (Navalpakkam & Itti, 2005). By using text labels to describe targets at varying degrees of specificity and demonstrating the effect of this manipulation on search guidance, we are providing the essential data that will be needed to constrain this new breed of search theory.

Original manuscript received 4 November 2008
Accepted revision received 17 February 2009
First published online 19 May 2009

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# APPENDIX

## Target categories by cue condition

| *Abstract* | *Abstract + colour* | *Precise* | *Precise + colour* |
|---|---|---|---|
| school supply | silver school supply | ruler | silver ruler |
| patio item | red patio item | barbecue grill | red barbecue grill |
| reptile | green reptile | snake | green snake |
| rug | red rug | throw rug | red throw rug |
| laundry supply | blue laundry supply | laundry basket | blue laundry basket |
| watch | gold watch | pocket watch | gold pocket watch |
| carbonated beverage | red carbonated beverage | soda can | red soda can |
| fruit | green fruit | apple | green apple |
| key | gold key | antique key | antique gold key |
| bus | red bus | double decker bus | red double decker bus |
| power tool | red power tool | drill | red drill |
| cleaning tool | green cleaning tool | broom | green broom |
| dessert | brown and black dessert | chocolate cake | brown and black chocolate cake |
| bell | blue bell | glass bell | blue glass bell |
| clock | white clock | alarm clock | white alarm clock |
| office furniture | white office furniture | desk | white desk |
| vase | purple vase | glass vase | purple glass vase |
| hygiene product | purple and white hygiene product | toothbrush | purple and white toothbrush |
| computer | silver computer | laptop | silver laptop |
| book | blue book | spiral notebook | blue spiral notebook |
| medicine | gray medicine | pills | gray pills |
| hat | black hat | top hat | black top hat |
| pillow | white pillow | throw pillow | white throw pillow |
| locomotive | black locomotive | steam powered train | black steam powered train |
| bird | brown bird | duck | brown duck |
| painting supply | red painting supply | paintbrush | red paintbrush |
| gloves | blue and white gloves | work gloves | blue and white work gloves |
| dog | black and tan dog | german shepherd | black and tan german shepherd |
| balloon | blue balloon | birthday balloon | blue birthday balloon |
| building | red and white building | lighthouse | red and white lighthouse |
| telephone | black telephone | rotary telephone | black rotary telephone |
| helmet | red helmet | football helmet | red football helmet |
| pepper | yellow pepper | chilli pepper | yellow chilli pepper |
| camping gear | blue camping gear | tent | blue tent |
| briefcase | brown briefcase | leather briefcase | brown leather briefcase |
| chair | brown chair | rocking chair | brown rocking chair |
| woodwind instrument | gold woodwind instrument | saxophone | gold saxophone |
| kettle | silver kettle | tea kettle | silver tea kettle |
| ball | green ball | billiard ball | green billiard ball |
| rodent | tan rodent | hamster | tan hamster |
| writing instrument | blue writing instrument | pen | blue pen |
| baseball equipment | black baseball equipment | baseball bat | black baseball bat |
| kitchen appliance | white kitchen appliance | blender | white blender |
| guitar | red guitar | electric guitar | red electric guitar |
| chocolate | brown chocolate | chocolate bar | brown chocolate bar |
| cookie | brown cookie | tree shaped cookie | brown tree shaped cookie |
| bread product | tan bread product | bagel | tan bagel |

(*Continued overleaf*)

**Appendix** (*Continued*)

| *Abstract* | *Abstract + colour* | *Precise* | *Precise + colour* |
|---|---|---|---|
| barrel | green barrel | wooden barrel | green wooden barrel |
| footwear | brown footwear | boots | brown boots |
| insect | green insect | beetle | green beetle |
| gardening tool | green gardening tool | hose | green hose |
| gun | brown gun | hunting rifle | brown hunting rifle |
| medical examination tool | blue medical examination tool | stethoscope | blue stethoscope |
| lizard | gray lizard | crocodile | gray crocodile |
| weightlifting equipment | silver weightlifting equipment | dumbbells | silver dumbbells |
| jar | black jar | ceramic jar | black ceramic jar |
| construction vehicle | yellow construction vehicle | bulldozer | yellow bulldozer |
| knife | silver knife | dagger | silver dagger |
| money | gold money | coin | gold coin |
| basket | red basket | Easter basket | red Easter basket |
| mirror | gold mirror | hand held mirror | gold hand held mirror |
| alcoholic beverage | red alcoholic beverage | glass of wine | glass of red wine |
| surgical supply | silver surgical supply | scalpel | silver scalpel |
| boat | red boat | canoe | red canoe |
| cooking item | black cooking item | frying pan | black frying pan |
| baby furniture | green baby furniture | crib | green crib |
| fan | white fan | rotating fan | white rotating fan |
| glasses | black glasses | sunglasses | black sunglasses |
| bowl | yellow bowl | dog bowl | yellow dog bowl |
| farm animal | white farm animal | lamb | white lamb |