Research Article

The Training and Transfer of Real-World Perceptual Expertise

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ABSTRACT—*A hallmark of perceptual expertise is that experts classify objects at a more specific, subordinate level of abstraction than novices. To what extent does subordinate-level learning contribute to the transfer of perceptual expertise to novel exemplars and novel categories? In this study, participants learned to classify 10 varieties of wading birds and 10 varieties of owls at either the subordinate, species (e.g., "great blue crown heron," "eastern screech owl") or the family ("wading bird," "owl") level of abstraction. During training, the amount of visual exposure was equated such that participants received an equal number of learning trials for wading birds and owls. Pre- and posttraining performance was measured in a same/different discrimination task in which participants judged whether pairs of bird stimuli belonged to the same or different species. Participants trained in species-level discrimination demonstrated greater transfer to novel exemplars and novel species categories than participants trained in family-level discrimination. These findings suggest that perceptual categorization, not perceptual exposure per se, is important for the development and generalization of visual expertise.*

An obvious difference between experts and novices is that experts have greater exposure to objects from their domain of expertise than do novices. Dedicated bird-watchers go on "birding" trips during which they encounter large numbers and a diverse variety of bird species. Similarly, car aficionados make it a point to attend car shows where they see the latest makes and models of automobiles. Although an expert has more opportunities to "see" objects of expertise than a novice does, an expert also recognizes these objects at a different level of abstraction. Novices tend to categorize objects first at the basic level (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), whereas experts show a preference to identify objects at a level that is more specific, or subordinate to the basic level (Johnson & Mervis, 1997; Tanaka & Taylor, 1991). For example, a bird novice will identify a feathered animal at the basic level of "bird," in contrast to the expert bird-watcher, who will identify the same animal more specifically as a subordinate-level "sparrow" or "chipping sparrow." This downward shift in the level at which an object is first identified has become one of the behavioral hallmarks of perceptual expertise (Gauthier & Tarr, 1997; Tanaka & Taylor, 1991).

If object categories provide a record of the perceiver's past, they also serve as a bridge to new object instances and new object categories (Solomon, Medin, & Lynch, 1999). Having a wealth of prior category knowledge, the owl expert, for example, should be able to identify common species of owls across a broader spectrum of viewing conditions than the novice. Similarly, the owl expert should be better able than the novice to distinguish never-before-encountered species of owls. Research indicates that experts are able to bootstrap new category learning onto old categories (Gauthier, Williams, Tarr, & Tanaka, 1998). Participants trained in the expert recognition of artificial objects (i.e., Greebles) learned the names of newly encountered Greebles in fewer training trials than novices (Gauthier et al., 1998). As an explanation for this advantage, it is plausible that the same perceptual operations that facilitate subordinate-level recognition were applied to the learning of new subordinate-level category representations. What is less clear is whether the transfer of perceptual expertise is broadly tuned to incorporate a wide range of object categories or narrowly focused to a more restricted class of categories.

In the current experiment, the perceptual basis of expertise and its transfer to novel object categories was investigated. Over multiple days of training, participants viewed pictures of owls and wading birds an equal number of times while categorizing one group at a general, family level (e.g., "owl") and the other

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group at the subordinate, species level (e.g., "green heron"). Pre- and posttraining perceptual performance was measured by a same/different discrimination task in which participants judged whether two sequentially presented bird pictures were members of the same or different species. The posttest discrimination measure included the images presented in the original training condition (old instances of old species), new images of the species of owls and wading birds classified during training (new instances of old species), and new species of owls and wading birds not seen during training (new instances of new species). If perceptual expertise is influenced by category training, participants should show better posttest discrimination of birds learned at the subordinate level than birds learned at the basic level. This enhanced discrimination should transfer to new images from both familiar subordinate-level categories and novel subordinate-level categories.

METHOD

Participants

Twenty-eight undergraduate students from Oberlin College participated in this experiment. All had normal or corrected-to-normal vision. Participants were trained individually and received course credit for their participation.

Stimuli

The stimuli consisted of 296 digitized photographs of owls and wading birds obtained from bird-identification field guides or ornithological Web sites on the Internet (see Fig. 1). The training set of 120 pictures was composed of 6 photographs of 10 species of owls (barn owl, barred owl, boreal owl, burrowing owl, eastern screech owl, elf owl, Eurasian eagle owl, flammulated owl, great gray owl, great horned owl) and 6 photographs of 10 species of wading birds (American bittern, black-crowned night heron, cattle egret, glossy ibis, great blue heron, great egret, green heron, least bittern, limpkin, little blue heron). The stimuli for the new-instances/old-species condition were 80 pictures, 4 new digitized photographs of each of the 10 species of owls and 10 species of wading birds learned during training. The stimuli for the new-instances/new-species condition were 96 pictures, 6 images of each of 8 novel species of owls (long-eared owl, northern hawk owl, northern pygmy owl, northern saw-whet owl, short-eared owl, snowy owl, spotted owl, whiskered screech owl) and 6 images of each of 8 novel species of wading birds (reddish egret, sandhill crane, snowy egret, tricolored heron, white ibis, whooping crane, wood stork, yellow-crowned night heron). The images were cropped and scaled to fit within a frame of 300 × 300 pixels and placed on a white background. Images subtended a visual angle of approximately 4.8° and 6.75° in the horizontal and vertical dimensions, respectively.

Procedure

The study was conducted over a period of 7 consecutive days. Half of the participants were assigned to the group that learned to classify owls at the subordinate level, and half were assigned

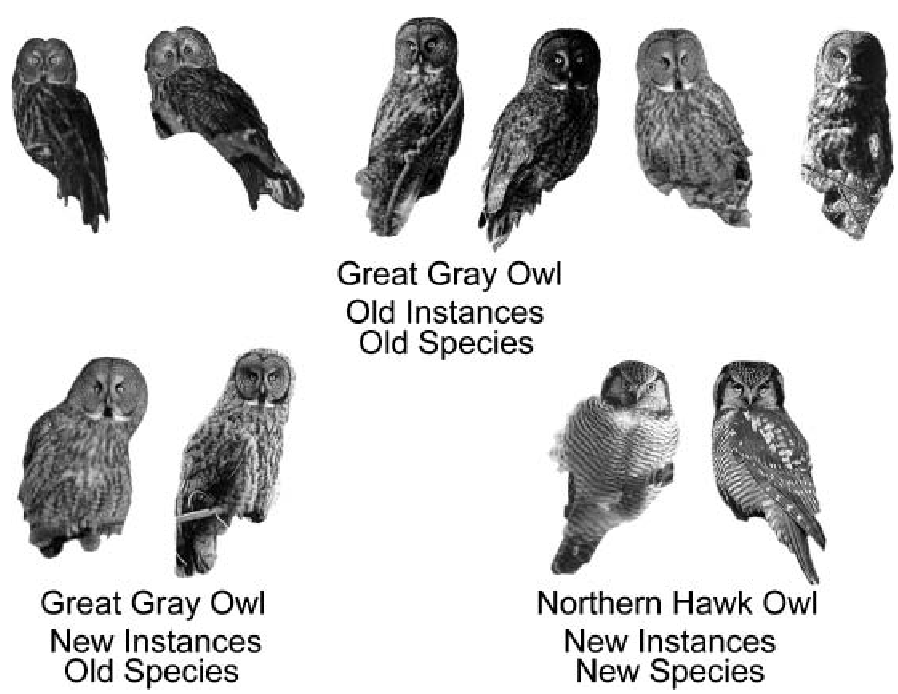

Fig. 1. Examples of the great gray owl used in the old-instances/old-species condition (top) and the new-instances/old-species condition (bottom left) and examples of the northern hawk owl employed in the new-instances/new-species condition (bottom right).

to the group that learned to classify wading birds at the subordinate level.

Pretraining Assessment

On the first day of the study, participants completed a preassessment sequential-matching task that has previously been shown to be sensitive to differences in perceptual expertise among real-world experts (Gauthier, Curran, Curby, & Collins, 2003). On each trial, a bird stimulus was presented for 150 ms on a computer monitor, followed by a 300-ms mask, and then a second bird stimulus for 150 ms. Participants responded "same" if the bird stimuli were members of the same species or "different" if they were from different species. For the *same* trials, the birds were two different images of the same species (e.g., two different images of eastern screech owls). For the *different* trials, the birds were images depicting two species from the same family (e.g., eastern screech owl and burrowing owl). The matching task involved two bird families (owls, wading birds), 10 species per family, two responses, and 6 trials for each combination of these variables, for a total of 240 trials.

Training

Immediately following the pretraining assessment on Day 1, participants were introduced to six species of owls (or wading birds) at the subordinate level and six species of wading birds (or owls) at the family level. At the beginning of each introduction block, participants were shown an owl or wading bird and its corresponding subordinate-level letter (e.g., "k" for eastern screech owl, "j" for burrowing owl) or family-level letter (i.e., "w" for wading bird, "o" for owl) on the keyboard. Following the introduction, participants were trained at subordinate and family category levels using naming, category verification, and object classification tasks, as employed in previous studies (Gauthier & Tarr, 1997; Gauthier et al., 1998).

For the keyboard naming task, participants viewed a 250-ms fixation point, followed by a randomly presented bird image. The task was to identify the stimulus at either the subordinate level or the family level by pressing the corresponding key (e.g., "k" for eastern screech owl, "w" for wading bird). The picture stimulus remained on the screen for 5,000 ms or until a keyboard response was made. If participants pressed the incorrect key, they were given feedback regarding the correct response. The naming task continued until participants identified the bird stimuli with the appropriate subordinate-level and family-level responses twice without error.

Following successful completion of the naming task, participants performed a category-verification task. On each trial, a fixation point was presented for 250 ms, followed by a 500-ms subordinate-level word label (e.g., "eastern screech owl") or family-level label (e.g., "wading bird") that was replaced by a picture stimulus. If the picture matched the label, participants were instructed to press the key marked "true"; otherwise, they were to press the key marked "false." For each block of training, there were 12 subordinate-level true trials (e.g., the label "eastern screech owl," followed by a picture of an eastern screech owl), 12 subordinate-level false trials (e.g., the label "eastern screech owl," followed by a picture of a burrowing owl), 12 family-level true trials (e.g., the label "wading bird," followed by a picture of a green heron), and 12 family-level false trials (e.g., the label "owl," followed by a picture of a green heron). On Days 3 through 6 of training, participants also performed a speeded version of the category-verification task in which responses were required before a 1-s deadline. For the normal and speeded versions, participants received auditory feedback on correct and incorrect responses.

On each trial in the object-classification task, participants saw a 250-ms fixation point, followed by a 500-ms subordinate-level word label (e.g., "eastern screech owl") or family-level label (e.g., "wading bird") that was replaced by two pictures, one on the left and one on the right. The task was to indicate which picture matched the word label by pressing the key marked "left" or "right." Each species of wading bird and owl was presented once. Participants received auditory feedback on correct and incorrect responses.

On Day 1 of training, participants learned to name, verify, and classify six owls and six wading birds at either the subordinate level or the family level. On Day 2 of training, participants named, verified, and classified four additional subordinate- and family-level species of owls and wading birds. On Days 3, 4, 5, and 6 of training, subordinate- and family-level learning was reinforced through the naming, category verification (normal and speeded), and object classification tasks.

Posttraining Assessment

On Day 7, participants were re-administered the sequential-matching task, in which two birds were judged as belonging to the same or different species. The general procedure was the same as for the pretraining assessment. The task was divided into three types of tests (see Fig. 1): old-instances/old-species, new-instances/old-species, and new-instances/new-species. The old-instances/old-species test was identical to the preassessment measure, with the exception that the number of tested images per species was changed from six to three. Thus, this test included the two bird families (owls, wading birds), 10 species, two responses (same, different), and 3 trials for each combination of these variables, for a total of 120 trials. The new-instances/old-species test measured perceptual discrimination of the same species of owls and wading birds learned in training, but with new images. This test evaluated two families of birds (owls, wading birds), 10 training species per family, two responses (same, different), and 3 trials for each combination of these variables, for a total of 120 trials. The new-instances/new-species test investigated the discrimination of 8 new species of owls and wading birds (see Stimuli) not seen or learned during training. This test included two bird families (owls, wading birds), 8 species per family, two responses (same, different), and

6 trials for each combination of these variables, for a total of 192 trials. The old-instances/old-species test was administered first, and then items from the new-instances/old-species and new-instances/new-species tests were randomly intermixed.

RESULTS

After the first day of training, 7 participants were eliminated from the study because they failed to learn the required six subordinate-level birds. Thus, a total of 21 participants remained in the study: 11 participants in the subordinate-level owl group and 10 participants in the subordinate-level wading-bird group. In the pretraining assessment, participants' ability to discriminate owls and wading birds at the species level was measured. The d' was 1.74 for owls and 1.79 for wading birds. Hence, before training began, participants exhibited no difference in their ability to differentiate the two families of birds at the species level, $p > .05$.

Training

Reaction times were computed for correct responses only. For the category-verification task, the subordinate-level categorizations became increasingly fast over the course of the 6 days of training (as shown in Table 1). Consistent with this interpretation, an analysis of variance (ANOVA) showed reliable main effects of category level (family, subordinate), $F(1, 15) = 69.93$, $p < .001$, and day of training (Day 2, Day 3, Day 4, Day 5, Day 6), $F(4, 60) = 48.01$, $p < .001$, as well as a significant interaction, $F(4, 60) = 17.42$, $p < .001$. Although reaction times for subordinate-level categorizations grew increasingly fast, they were still reliably slower than reaction times for basic-level categorization even at the end of six sessions of training, $p < .01$.

A similar pattern of results was found in the speeded verification task: Reaction times again became faster over the course of training (see Table 1). An ANOVA showed reliable main effects of category level (family, subordinate), $F(1, 19) = 60.76$, $p < .001$, and day of training (Day 3, Day 4, Day 5, Day 6), $F(3, 57) = 16.49$, $p < .001$, and a reliable interaction between category level and day of training, $F(3, 57) = 5.67$, $p < .01$. However, subordinate-level reaction times were still slower than basic-level reaction times even at the end of training, $p < .01$.

Similarly, the results from the classification task demonstrated that reaction times were faster for family-level than subordinate-level categorizations, $F(1, 19) = 101.72$, $p < .001$, and overall performance improved over the 6 days of training, $F(3, 57) = 12.99$, $p < .001$. There was greater improvement for the subordinate-level categorizations than the basic-level categorizations, $F(3, 57) = 24.47$, $p < .001$, but subordinate-level categorizations were still slower than basic-level categorizations at the end of training, $p < .01$.

TABLE 1
Reaction Times (in Milliseconds) for Basic- and Subordinate-Level Categorizations During Training

	Training session				
Task and level	Day 2	Day 3	Day 4	Day 5	Day 6
Verification					
Basic	942	767	715	667	664
Subordinate	1,389	1,054	883	781	746
Verification with deadline					
Basic	—	596	557	500	496
Subordinate	—	842	731	659	582
Classification					
Basic	—	647	621	630	637
Subordinate	—	1,095	906	851	839

Pre- Versus Posttraining Discrimination of Old Images

An initial analysis was performed to test whether posttraining discrimination of the training images was better than pretraining discrimination (see Table 2). An ANOVA was performed with training (pretraining, posttraining) and category level of training (basic, subordinate) as within-groups factors and expert type (wading birds, owls) as a between-groups factor. The ANOVA showed that the effects of training, $F(1, 19) = 279.58$, $MSE = 41.89$, and category level of training, $F(1, 19) = 172.80$, $MSE = 24.26$, were significant, $p < .001$. However, training interacted with category level, $F(1, 19) = 182.50$, $MSE = 16.21$, $p < .011$, such that subordinate-level training improved discrimination performance reliably more than basic-level training (as shown in Fig. 2). Nevertheless, basic-level training resulted in better discrimination than found prior to training, $p < .01$. The main effect of expert type was insignificant, as were the other interactions.

Transfer Conditions: Discrimination of New Exemplars and New Species

The transfer of discrimination to novel images was tested using an ANOVA with category level of training (basic, subordinate) and kind of transfer (new exemplars, new species) as within-groups factors and expert type (wading bird, owls) as a between-

TABLE 2
d' *Scores for the Training Images Before and After Subordinate- and Basic-Level Training*

	Training level			
	Subordinate		Basic	
Images	Pretraining	Posttraining	Pretraining	Posttraining
Wading birds	1.87	4.02	1.62	2.07
Owls	1.87	4.24	1.69	2.35
Mean	1.87	4.13	1.66	2.21

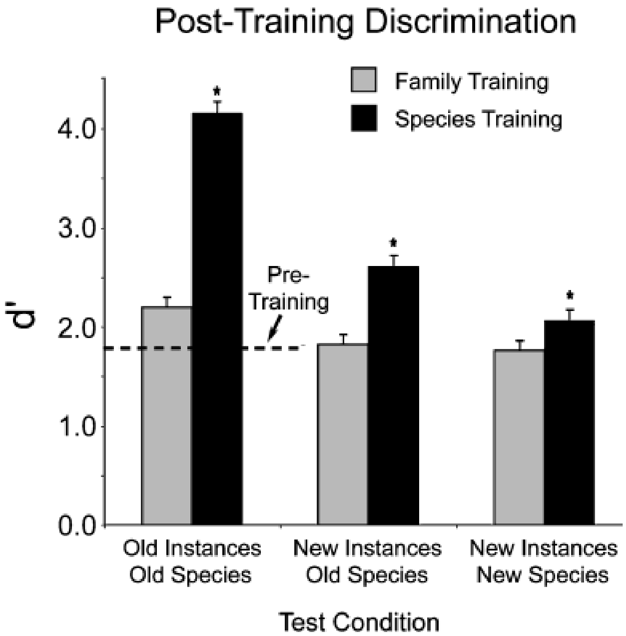

Fig. 2. Mean d' scores on the posttraining discrimination task in the old-instances/old-species, new-instances/old-species, and new-instances/new-species test conditions. Results are shown separately for participants who had received basic-level (family) training and subordinate-level (species) training with the family of birds tested. The dotted line indicates pre-training baseline performance in the old-instances/old-species condition. Asterisks indicate reliable differences between basic- and subordinate-level training. Error bars indicate standard errors of the means.

groups factor (see Table 3). Category level of training was significant, $F(1, 19) = 25.69$, $MSE = 5.99$, $p < .001$, indicating that subordinate-level training facilitated better discrimination of the new instances and new species than basic-level training did (as shown in Fig. 2). Kind of transfer was also significant, $F(1, 19) = 16.20$, $MSE = 1.84$, $p < .001$; images of new exemplars were better differentiated than images of new species. The significant Category Level × Kind of Transfer interaction, $F(1, 19) = 17.13$, $MSE = 1.06$, $p < .001$, demonstrated that the largest difference between subordinate-level and basic-level training involved the discrimination of new instances from familiar species. Direct comparisons showed subordinate-level training produced significantly better discrimination than basic-level training for both images of new exemplars, $F(1, 20) = 41.78$, $p < .0001$ (Greenhouse-Geisser), and images of new species, $F(1, 20) = 6.18$, $p < .02$ (Greenhouse-Geisser). The Category Level × Kind of Transfer × Expert Group interaction, $F(1, 19) = 20.55$, $MSE = 1.28$, $p < .001$, showed that subordinate-level training of wading birds produced better discrimination of new instances and new species of wading birds than basic-level training did, $p < .01$ (see Table 3). Although subordinate-level training of owls produced better discrimination of new instances of owls compared with basic-level training, $p < .01$, there was little difference between the two types of training on the discrimination of new species of owls, $p > .10$.

No other main effects or interactions were significant.

TABLE 3
d′ Scores for New Images After Subordinate- and Basic-Level Training

Training level	Wading bird images: New instances	Wading bird images: New species	Owl images: New instances	Owl images: New species
Basic	1.85	1.87	1.85	1.67
Subordinate	2.37	2.24	2.81	1.90

DISCUSSION

In their posttest performance on the same/different task, participants showed an improved ability to discriminate both training images that had been learned at the basic level and training images that had been learned at the subordinate level. That is, regardless of the category level used for training, repeated exposure to the same training stimuli improved participants' discrimination of the birds at the species level. However, compared with basic-level training, subordinate-level training produced greater posttest gains in the discrimination of familiar training images. This finding is not surprising given that subordinate-level learning required that participants differentiate the training images at the species level of classification.

One test of perceptual transfer showed that new images of previously learned species were better discriminated if training was at the subordinate level than if it was at the basic level. For example, participants who were trained to categorize a bird as an eastern screech owl were better able to discriminate never-before-seen images of eastern screech owls than participants who had learned to classify this bird at the basic level of "owl." Subordinate-level training promoted a perceptual strategy that was applicable to new category instances and not limited to the specific images used in training. A second test of perceptual transfer showed that subordinate-level knowledge also enhanced the discrimination of exemplars from completely unfamiliar bird species. For example, participants who learned to categorize wading birds, such as green herons, American bitterns, and limpkins, at the subordinate level were better able to differentiate completely novel species of wading birds, such as whooping cranes and snowy egrets, than were participants who learned to categorize wading birds at the basic level. These results indicate that subordinate-level training promoted two types of perceptual transfer: transfer to the recognition of new instances of existing category representations and transfer to the discrimination of new instances from novel species categories.

These results highlight an important distinction between simple perceptual exposure and perceptual experience. In this study, participants were exposed to owls and wading birds an equal number of times. Yet their cognitive experience of those perceptual events was profoundly influenced by the category level used in the training task (Schyns, 1998). Although past studies have shown that subordinate-level knowledge provides a reliable indicator of perceptual expertise, the current study demonstrates that subordinate-level training is also useful for facilitating the development of perceptual expertise. By virtue of its perceptual specificity, subordinate-level training requires that participants attend to properties of an object's shape and color at a level of detail that is more fine grained than is required for basic-level judgments (Jolicoeur, Gluck, & Kosslyn, 1984). Subordinate-level learning yields flexible object representations (Edelman & Bülthoff, 1992; Tarr & Pinker, 1990) that are robust enough to facilitate the discrimination of novel exemplars from familiar categories and morphologically similar categories. Beyond facilitating general perceptual abilities and attentional strategies, subordinate-level training selectively tuned participants' perceptions of color, shape, and texture cues that were specific to species in either the owl or the wading-bird family.

The basic-level (family) and subordinate-level (species) categorization strategies emphasized in this study parallel the strategies typically applied by novices and experts in the real world. Whereas bird novices tend to classify birds at the basic level of "bird," thereby ignoring detailed perceptual information, bird experts recognize birds at subordinate levels of abstraction and are keenly attuned to the visual features that distinguish different species of birds. Moreover, given their subordinate-level knowledge and experience, experts can readily incorporate new instances into their representations of existing object categories. Thus, the owl expert can identify a familiar species of owl across different exemplars and changes in viewpoints. Subordinate-level knowledge also provides a mechanism for acquiring new subordinate-level category representations. Cognizant about the perceptual features that distinguish familiar species of owls, the owl expert, for example, is sensitive to the visual features that signal a new, unfamiliar owl species. Thus, the expert holds an advantage over the novice not only with regard to the recognition of objects from familiar categories, but also with regard to acquiring new object categories in his or her specific domain of expertise.

The distinction between basic- and subordinate-level categorization and its role in perceptual expertise has also been explored at the neurophysiological level. An event-related potential (ERP) study demonstrated that when participants categorized objects at the subordinate levels of abstraction, an enhanced negative brain potential was produced approximately 170 ms after stimulus onset (N170) in the posterior recording sites (Tanaka, Luu, Weisbrod, & Kiefer, 1999). Similarly, bird, dog, and car experts displayed the enhanced N170 component when they categorized objects in their domain of expertise relative to when they categorized objects outside their domain of expertise (Gauthier et al., 2003; Tanaka & Curran, 2001). Categorical training of novel visual objects can produce similar N170 enhancement (Curran, Tanaka, & Weiskopf, 2002). Neuroimaging results have shown that the middle temporal region of the brain, the area referred to as the fusiform gyrus, is particularly activated during subordinate-level categorization (Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997). This same brain area is activated when laboratory-trained experts (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999) and real-world experts (Gauthier, Skudlarski, Gore, & Anderson, 2000) view objects in their domain of expertise. The converging neurological evidence indicates that specific brain processes are engaged during subordinate-level object categorization and that these same neural mechanisms are recruited for purposes of perceptual expertise.

The kind of perceptual expertise explored in the current study can be contrasted to other forms of perceptual learning. Whereas studies of perceptual expertise examine mechanisms underlying recognition of complex objects, experiments in perceptual learning focus on the discrimination of low-level visual properties, such as line orientation or color (Ahissar & Hochstein, 1997, 1998). Whereas perceptual expertise accrues over years of real-world experience (Johnson & Mervis, 1997; Tanaka & Taylor, 1991) or during concentrated training in the laboratory (Gauthier & Tarr, 1997; Gauthier et al., 1998), perceptual learning can be acquired quickly (Ahissar & Hochstein, 1997, 1998) and without awareness (Watanabe, Nanez, & Sasaki, 2001). Moreover, perceptual learning shows restricted transfer to the hyperspecific conditions of training (Ahissar & Hochstein, 1997, 1998), whereas perceptual expertise is characterized by its robustness and generalization to new contexts (Gauthier et al., 1998).

In conclusion, the current study demonstrates that frequent exposure to a particular class of stimuli alone is not sufficient to produce perceptual expertise. Rather, the acquisition of perceptual expertise depends on the rapid classification of objects at specific, subordinate levels. Perceptual experts are distinguished from novices not only in their ability to recognize familiar stimuli, but also in their ability to incorporate novel stimuli into established subordinate-level categories and to create new subordinate-level categories in their domain of expertise.

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