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Categorization changes object perception

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Abstract

Most models of object recognition assume that shape is the primary dimension of recognition and that color and texture play only a secondary role. One reason for this could be that color and texture are generally less diagnostic for recognition and so it would be comparatively more difficult to find evidence of their usage. Another, but as yet unexplored reason for their secondary role, is that color and texture differences are not as well perceived at short exposures of stimuli. We report two experiments that address the *perception* (as opposed to the *usage*) of dimensions over the time course of visual processing.

Introduction

No one would ever doubt that orange, the color, characterizes oranges, the fruit. In fact, orange peel, the texture, is also characteristic of oranges, particularly if a basket contains other fruits such as peaches and apricots. However, to most object recognition theories, the roundish shape of an orange is the primary dimension of its recognition, while its typical color and texture are only secondary information. Obviously, this argument is not restricted to oranges and fruit; it applies to the recognition of all common objects, including cars, chairs, houses, faces and so forth. The primacy of shape is the founding assumption of most object recognition and object categorization theories (Tversky and Hemenway, 1984; see also Biederman, 1987; Biederman & Ju, 1988).

Why are shape cues so special for object recognition? One side of this question is familiar to categorization research: Special cues are those that solve a particular recognition problem; they are *diagnostic* in this task. For example, shape might be special because one of its determinants is part organization: Objects with common parts tend to have a common shape. In fact, Tversky and Hemenway argued that "... the natural breaks among basic-level categories are between clusters of parts" (1984, p. 186). According to Biederman (1987), the higher diagnosticity of parts explains the primacy of shape in everyday, basic-level recognition.

However, none of the studies which argued for the primacy of shape over other dimensions distinguished between dimension *perception* and dimension *diagnosticity*. We will say that a dimension is perceived when its information (e.g., shape, color or texture differences) is distinguishable. For example, *texture* would generally be perceived for recognition if visual processes could always notice differences in texture. Of course, the perception of a dimension is a condition *sine qua non* for its usage: No experiment could ever show a usage of color (or texture) if color differences were simply not perceived. However, dimensional information could be perceived, but not used, for example because this information is not diagnostic for the task at hand. This paper addresses the issue of determinants of dimension perception for object recognition: Is it fixed, or does it change with categorization experience?

Evidence for the Usage of other Information than Shape in Object and Scene Recognition

We will here call "object categorization" the typical task in which participants see object pictures that they then name. Biederman and Ju's (1988) showed that naturally colored objects and black and white line-drawings were categorized equally fast. Even though low intensity, non-masked photographs were recognized faster than their black-and-white drawing counterparts, Biederman and Ju (1988) concluded that shape was the reliable information most needed, and used. However, a careful control of stimulation conditions in Brodie et al. (1991) (particularly shading and contrast) revealed a significant advantage of colored pictures. Ostergaard and Davidoff (1985) also showed that color reduced categorization time. More recently, Davidoff and Ostergaard (1988) replicated the categorization advantage of colored stimuli, but failed to show that color influenced higher-level categorical judgments (such as living/non-living things).

None of these studies, however, distinguished between dimension perception and dimension usage. Categorization performance only reveals dimension usage, which assumes dimension perception. However, in most studies, the main determinant of dimension usage (i.e., its diagnosticity for the task at hand) was not controlled. Furthermore, besides Brodie et al. (1991), control of stimulation conditions was generally neglected. For these reasons, it is not at all surprising that the evidence for color usage in recognition varies from across experiments.

Oliva and Schyns (1996) controlled color diagnosticity in speeded scene recognition. They used two types of categories: natural scenes for which color was diagnostic (e.g., *field, desert, beach*) and artifact scenes for which color was not diagnostic (e.g., *room, city, highway*). For each of these categories, three types of stimuli were produced: naturally colored, abnormally colored and gray levels. Results showed that participants who recognized the scenes at very brief exposures were faster with normally colored stimuli of natural categories. Hence, Oliva and Schyns (1996) concluded that color only helped when it was diagnostic of a categorization. The abnormal colors controlled that the effect was simply a segmentation advantage for colored vis-à-vis gray-level stimuli. Tanaka and Bunosky (1996) also found such diagnostic advantage for colored objects.

In summary, it appears that color is used when it is diagnostic of a categorization. To our knowledge, texture has not been studied, but we might reasonably expect that its diagnosticity would also determine its usage. However, the previous results do not permit any conclusion as to the actual perception of these dimensions over the time course of visual processing. Our studies tap into this issue.

Ground Rules for the Study of Dimension Perception

If recognition tasks change the usage of object cues, then it is better not to use recognition tasks to study the perception of dimensional information. An alternative task requires participants to judge whether two simultaneously presented stimuli are *physically identical.* Stimulus pairs could either be effectively identical, or differ along one, or more dimensions. Prior to the task, participants would be instructed that three dimensions (here, shape, color and texture) compose each object and that a single dimensional change unambiguously indicates that two objects are physically different. Exposures could vary from very brief (e.g., 30 ms) to very long (e.g., 1 s) to track perception of dimensions over the time course of recognition. The following ground rules detail why we believe that such design is well-suited to study dimension perception.

- **Conditions of Presentation:** The *simultaneous* presentation of two stimuli on the screen warrants that participants can rely on the displayed information to establish their physical identity.
- **Stimuli:** The computer synthesis of 3D objects composed of a specific shape, color and texture enables a tight control of the physical similarity between stimuli.
- **Instructions:** Participants would know the dimensional composition of each object, and they would also know the possible ways in which objects differ. Participants would be shown each stimulus that they would later need to distinguish. Thus, it could not be argued that participants do not know which information to seek out in the visual input.
- **Task:** Judgments of physical identity are very constrained and are assumed to tap into the perceptual encodings of stimulus dimensions--at least more so than categorizations, unconstrained same/different judgments, or sequential assessments of physical identity which are arguably less free of high-level cognitive influences (see Schyns *et al.*, in press). Physical identity forces participants to look for any difference that they can perceive between two objects.
- **Data:** Participants who would judge as identical two stimuli that were physically different would indicate that they could not perceive this dimensional difference. Systematic testing of dimensional differences at different presentation times of the stimulus pairs would then allow to track the respective perceptions of these dimensions over the time course of visual processing.
- **Calibration:** Calibration within dimensions, and overall information across dimensions are here crucial issues. Stimuli are perfectly calibrated whenever any two successive points within a dimension are equally distinguishable. The average confusability of points between dimensions should also be equalized. Otherwise, the perceptual primacy of a dimension could simply be equated with the lower overall confusability of its values. Unfortunately, it is close to impossible to control within- and between-dimension confusability with natural objects. Furthermore, we wish to entertain the possibility that the natural distributions of dimensional points promotes the relative confusability of naturally distributed dimensions. However, we take issue with the idea that this is the only factor explaining the perception of information. Thus, our experiments will test the effect of diagnosticity on dimension perception.

These ground rules were applied to the design of two experiments investigating categorization influences on the perception of shape, color and texture. Experiment 1 assessed baseline performance. Stimulus pairs were presented for different durations (30, 120 and 1000 ms), and we gathered physical identity judgments of objects which varied either along the shape, color or texture dimension, or on all three dimensions. Experiment 2 tested whether categorization experience could change the baseline perception of trained dimensional points.

Experiment 1

Experiment 1 was designed to assess the baseline perceptual availabilities of shape, color and texture information in object processing. Objects were three-dimensional (3D) computer synthesized fruits (banana, lemon, orange, pear, apple) and vegetables (carrot, cucumber, mushroom, potato, tomato) crafted so as to look as natural as possible (see Figure 1). A physical identity task as just described required participants to establish whether two simultaneously presented fruits were strictly identical. The fruit pairs could either be identical along all three dimensions composing the objects (shape, color and texture), or they differed on one, or three dimensions (see Figure 2). Object pairs were presented for either 30 ms, 120 ms, or 1000 ms in different participant groups. If shape, color and texture information is simultaneously available for object processing, then different exposures to the same object pairs should not affect the perception of their similarities and differences. Alternatively, if dimensional information is subject to a differential availability over the time course of visual processing, we might expect people to perceive identical pairs quite differently.

Participants

45 Glasgow University students with normal or corrected vision were paid to participate in the experiment.

Stimuli

Stimuli were computer synthesized 3D shapes of fruits and vegetables composed of three dimensions: shape, color and texture. Five NATURAL fruits and five NATURAL vegetables constituted the original stimulus set from which all other stimuli were derived (see Figure 1). Stimuli preserved their "natural" height relationship--heights varied between 2.5 cm to 9 cm and widths between 3 cm to 14 cm on the display, corresponding to about 6 x 6 degrees of visual angle. Several transformations were applied to the original objects to construct two sets of new fruits and vegetables. In the one-dimensional change set (1DIM), the value of one of the three dimensions (shape, color or texture) was swapped with the of another object (e.g., a yellow lemon would become red). For each object, and for each dimension, we introduced two such changes of values, see Figure 2. In total, 60 new stimuli were created (10 objects * 3 dimensions * 2 dimensional changes).

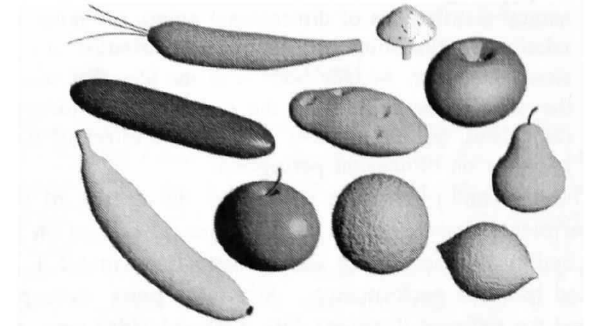

Figure 1: Fruits and vegetables constituting the original stimulus set

One problem with our stimuli is that the higher confusability of a dimension could arise from the choice of the tested NATURAL values. We crafted 30 supplementary stimuli (that we call EXTREMES) as controls. Each one of them was created by replacing the NATURAL value of a dimension (*e.g.*, the orange peel texture of an orange) with an "extreme" value. EXTREMES were designed to appear as different as possible to the NATURAL values of the stimulus set. For instance, the colors of the rainbow replaced the NATURAL colors of fruits and vegetables; a zebra texture replaced NATURAL textures; a combination of geometric primitives replaced the smooth shapes (see Figure 2). These values were thought to be equidistant from the dimensional values composing the ensemble of NATURAL stimuli--*e.g.*, any NATURAL color is equidistant from the colors of the rainbow. The rationale was that similar patterns of results for EXTREMES and NATURAL values could demonstrate that the relative primacies of dimensions depends upon the that the intrinsic structure of information along this dimension, not just the confusability within a set of NATURAL values.

Three-dimensional transformations (3DIM) were also applied to the stimuli. In this case, all three dimensions composing an object were swapped with those of another object. To illustrate, a lemon could become a red potato shape with the texture of a carrot. Note that these stimuli did not need to correspond to a NATURAL fruit or a NATURAL vegetable; 3DIM objects were included in the design as unambiguously different trials in the physical identity task. For each of the 10 original objects, we computed five different 3DIM objects. In total, Experiment 1 used 150 distinct stimuli (10 originals + 60 1DIM + 30 EXTREMES + 50 3DIM).

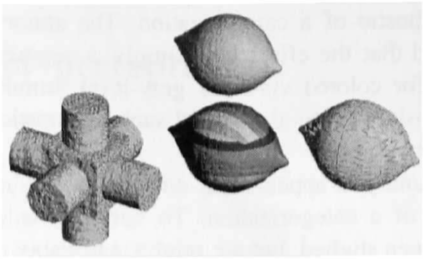

Figure 2: Examples of stimuli created with extreme dimensions.

Procedure

Before starting the experiment, participants were shown the 10 original stimuli. They were asked to name the objects and to explicitly list the reasons why the objects presented belonged to the named category (*e.g.* "it is an orange because it is round, orange and it has a orange peel texture"). This precaution was taken to ensure that participants were aware of all three dimensions present in each object. When participants missed noticing one or more dimension(s), the experimenter pointed out the forgotten dimension(s) to ensure that participants did see it and could subsequently distinguish it.

In a trial, two objects were simultaneously presented on the screen for a duration of 30, 120 or 1000 ms, depending on the experimental group. The two objects were either physically identical (SAME trials), differed along one dimension (1DIM trials, including the EXTREMES), either shape, color or texture, or along the three dimensions (3DIM trials). Participants' task was to determine as quickly and as accurately as possible whether the two objects were *physically identical.* A difference along one dimension was enough to say that the stimuli were different since to respond "same" the two stimuli had to be identical along three dimensions. The experiment included four blocks, each composed of 70 trials. The order of the blocks was counterbalanced across participants, and the order of trials within blocks was randomized. Each block lasted for about five minutes.

Results and Discussion

A d' measure, which includes both Hit (H) rate (saying that two stimuli are different when they are different) and False Alarm (FA) rate (saying that two stimuli are different when they are identical), was used as our dependent variable. A high d' is a sure sign of good discrimination performance (its maximum value is 5), but the simplicity of the task (the objects were simultaneously presented on the computer monitor) was such that we expected a performance close to saturation whenever dimensional information was readily available for visual processing.

Table 1: D's of Experiment 1 for each dimension and presentation time.

	Shape	Color	Texture
30 ms	2.85	2.20	1.26
120 ms	3.21	2.94	1.84
1000 ms	4.36	4.24	3.88

For each dimension in the 1DIM condition, we computed separate d's to investigate whether participants discriminated certain dimensional differences better than others. A two-way ANOVA revealed significant main effects of exposures (30, 120, 1000 ms), $F(2, 42) = 35.63$, $p < .001$, types of dimensional difference (shape, color, texture

1DIM), $F(2, 84) = 110.03$, $p < .001$, and a significant interaction between these factors, $F(4, 84) = 9.72$, $p < .001$. Further analysis revealed that differences in the perception of dimensional values were true for exposures of 30 ms, $F(2, 84) = 67.38$, $p < .001$, 120 ms, $F(2, 84) = 55.06$, $p < .001$ and 1000 ms, $F(2, 84) = 7.02$, $p < .01$. At 30 ms exposures, the physical identity of textures was harder to assess than the physical identity of colors (d' = 1.259 vs. 2.202), which were themselves less accurate than shape judgments (d' = 2.845). At 120 and 1000 ms exposures, shapes and colors were systematically easier to discriminate than textures (see Table 1). Even with very long, 1000 ms exposures, texture was still harder to discriminate, but because performance was close to saturation we will not dwell too much on this difference. These initial data reveal (1) that the perceived physical identity of a given pair of distal objects changes with prolonged exposures to the stimuli, suggesting that some cues are perceptually available before others, and (2) that the order of availabilities seems to be shape before color and texture. The perception of texture improves with longer exposures, but it never really reaches the perception of the other two dimensions.

Our design controlled extreme dimensional changes to assess whether the lower availability of texture and color arose from the subset of tested NATURAL values or the intrinsic structure of textural information for perception. Were drastic (*i.e.*, EXTREME) textural and color differences still harder to perceive than drastic shape changes? If they were not--*i.e.*, if EXTREME shape, color and textural differences were as easy to perceive --then higher confusability of the NATURAL samples of colors and textures could explain the reported difference of perception across dimensions.

Discriminations of 1DIM EXTREME differences were compared to 1DIM NATURAL differences (see Figure 3). A three-way ANOVA revealed significant main effects of dimension (shape, color, texture), $F(2, 84) = 76.94$, $p < .001$, EXTREME vs. NATURAL, $F(1, 42) = 34.45$, $p < .001$, and exposure time (30, 120, 1000 ms), $F(2, 42) = 29.22$, $p < .001$. We decomposed a significant triple interaction, $F(4, 84) = 2.6$, $p < .05$ to examine significant simple interactions between shape, color, texture and NATURAL vs. EXTREME values for 30 ms, $F(2, 84) = 3.18$, $p < .05$, and 120 ms, $F(2, 84) = 5.07$, $p < .01$, exposures, but not for 1000 ms, because it was not significant, $F(2, 84) = 2.51$, *ns*.

Differences were found in the perception of EXTREME dimensional values that mirrored those of NATURAL values at exposures of 30 ms, $F(2, 86) = 12.64$, $p < .001$, and 120 ms, $F(2, 86) = 4.72$, $p < .05$. EXTREME shapes and colors were also easier to discriminate than EXTREME textures at 30 ms, and 120 ms (Tukey, all $p < .05$). Thus, NATURAL and EXTREME discriminations followed a similar trend suggesting that the intrinsic structure of textural information (not just the NATURAL samples we tested) is less immediately perceivable than shape and color. However, EXTREME colors and textures were more discriminable than their NATURAL counterparts at 30 and 120 ms. Nevertheless, and because we are here interested in relative, not absolute, availabilities, EXTREME colors and textures differences were still harder to perceive than EXTREME shapes differences.

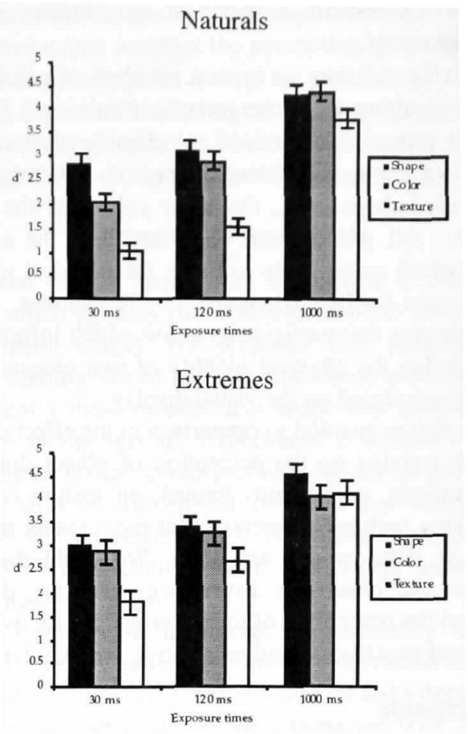

Figure 3: D's for the NATURAL and EXTREME values for each dimension and presentation time.

In summary of Experiment 1, time of exposure changes the perception of the three dimensions composing objects. Of all dimensions, texture appears to be rarely available for processing at very short presentation times, even when the difference in texture is as extreme as can be. Nevertheless, with longer exposures, the availability of this dimension increases.

Experiment 2

Experiment 1 suggests that the untrained eye is not particularly adept at perceiving the color and textural differences of very briefly presented objects. Even drastic differences along these dimensions were still more difficult to perceive than shape differences. One general problem that arises is whether this limitation is fixed (e.g., because perceptual systems are wired in a way that they cannot process some information sufficiently fast), or whether it can change (Schyns *et al*, in press).

This issue taps into the origin of the higher perceptual salience of shape over color and texture. We noted earlier that expertise with a category, or the diagnosticity of a dimension, could sometimes change the perception of object cues. The primacy of shape cues reported in Experiment 1 could originate in such acquired perceptual salience of shape over color and textural cues--for example, because the psychological distances between shape cues are on average higher than those of other dimensions. The acquisition of perceptual expertise with a dimension could, however, reduce the confusability of its values, speed up the availability of its information and increase its overall salience to the expert observer. If this were true, the global salience of a dimension would not be solely determined by the intrinsic confusability of its information, but also by the diagnosticity of this dimension for the expert observer.

Experiment 2 was set up as a problem of perceptual expertise resulting from categorization training. Three participant groups were trained to classify abstract objects categories using a different diagnostic dimension. One group used shape cues, the other color and the last one texture. All groups were then tested on the same task which asked participants to judge the physical identity of object pairs (as in Experiment 1). Remember that this tasks ensures that participants know which information to use to judge the physical identity of two objects simultaneously presented on the visual display.

This design enabled a comparison of the effect of categorization training on the perception of object dimensions. For example, participants trained, on texture could start perceiving textural differences that participants trained on shape or color would not see. We could then assess whether the observer's experience with the dimension changed the perception of this information, its availability for visual processing, and its relative primacy for recognition.

Participants

45 Glasgow University students with normal or corrected vision were paid to participate in the experiment.

Stimuli

Stimuli were computer synthesized 3D objects composed of three dimensions: shape, color and texture (see Figure 4). To create the stimuli, we selected ten different values for each dimension, with the constraint that they would be as different as possible from one another. Experimental stimuli were created by crossing values along the three dimensions.

Figure 4: Examples of 1 category defined by a texture.

Procedure

In an initial training phase, three experimental groups (SHAPE, COLOR and TEXTURE) were assigned to a different dimension classification task. In each group, participants were required to learn 10 different categories. Four distinct objects composed each category. On their diagnostic dimension, they shared the same value across the exemplars of the category, while the values of the two other dimensions were randomly chosen. As there were 10 different values per dimension, we defined 10 categories per experimental group, for a total of 40 training stimuli.

It is important to stress that the same ensemble of 40 stimuli was differently carved into 10 categories, depending on which dimension (SHAPE, COLOR or TEXTURE) was diagnostic in that group. The fact that participants saw the same stimuli but grouped them differently ensures that any observed difference in the perceptual availability of a dimension does not result from a differential exposure to the values of the other dimension.

Initial training phase. In the initial training phase, the 10 categories received a different arbitrary name (possible names were *feb, dur, mol, pin, bod, top, glo, jap, cal,* and *rac*). Participants in the SHAPE, COLOR and TEXTURE groups were instructed to learn the category name going with each stimulus. A learning trial consisted of the presentation of a category name, for 1000 ms, immediately followed by a category exemplar, for 30 ms, followed by a mask composed of colored patches for 30 ms. A keypress (the space-bar) on the computer keyboard would initiate the next learning trial. Participants were instructed that they should keep learning the pairings until they felt they knew the 10 categories.

Initial testing phase. Following the initial training phase, participants were tested on their knowledge of the 10 categories. To ensure that participants knew the cues defining the categories (not just their exemplars), new objects were tested--*i.e.*, participants had not seen them before. In a trial, a category name would appear on the screen for 1000 ms, immediately followed by a new exemplar for 30 ms, and a 30 ms mask. Participants were asked to indicate whether or not the category name and the object matched by pressing the appropriate keys on the computer keyboard. This phase composed of 40 trials tested all 10 categories with a balanced number of "yes" and "no" responses. A 90% correct response criterion was required before participants could enter the second testing phase. Participants who did not reach the criterion went back to the initial learning phase.

Second testing phase. The second testing phase familiarized participants with the perceptually taxing procedure of the physical identity task. In a trial, participants saw a category name immediately followed by two stimuli presented simultaneously on the screen for 30 ms, followed by a 30 ms mask. Only one of the two stimuli was a category member, and participants' task was to indicate (via the appropriate keypress) the portion of the screen (left or right) on which the exemplar of the named category appeared. Two different blocks of 40 such trials, with a balanced assignment of category members to the left and right screen portions, composed the second testing phase. Again, a 90% accuracy criterion was required before participants could proceed to the final testing. Otherwise, they would go back to the initial training phase.

Final testing phase. The physical identity task was the final test. The other testing phases insured (1) that participants could identify all values of the learned dimension, and (2) that this identification was possible even when two stimuli were simultaneously (and briefly) presented. The physical identity task was similar to Experiment 1. Object pairs were presented for 30 ms, followed by a 30 ms mask, and participants were asked to judge the physical identity of the displayed objects. The stimuli used in this task included all the stimuli used in the learning phase and in the previous testing phases. As in Experiment 1, participants were told that physically identical objects were those that shared identical shapes, colors and textures, and that a single difference along any of these dimensions was sufficient to judge them different. The task comprised three blocks of 90 such trials. The order of blocks and trials was randomized across participants. The experiment took about 60 minutes to complete.

Results and Discussion

As in Experiment 1, a d' sensitivity measure which combines Hit (H) rate (saying that two stimuli are different when they are effectively different) and False Alarm (FA) rate (saying that two stimuli are different when they are physically identical) was used to analyze participants' response in the physical identity task. A two-way ANOVA revealed no difference between the groups (SHAPE, COLOR, TEXTURE training), $F(2, 42) < 1$, *ns*, a significant effect of dimensional difference (shape, color, texture), $F(2, 84) = 65.40$, $p < .001$, and a significant interaction between these factors, $F(4, 84) = 5.49$, $p < .001$ (see Table 2).

Table 2: D's in Experiment 2 for each dimension and experimental group.

	Shape	Color	Texture
SHAPE-group	3.757	3.605	2.158
COLOR-group	3.601	3.574	2.804
TEXTURE-group	3.491	3.671	2.936

All groups were similarly adept at noticing shape, $F(2, 42) < 1$, *ns*, and color differences, $F(2, 42) < 1$, *ns*, irrespectively of the dimension they had been trained on. However, performance was here close to ceiling and we therefore concentrate on texture, the dimension of interest in Experiment 2. Participants perceived textural information differently. TEXTURE and COLOR participants perceived textural differences equally well (d' = 2.97 and 2.8, respectively), and both better than SHAPE participants (d' = 2.16) (Tukey, all $p < .05$).

These data demonstrate that categorization expertise with a diagnostic dimension in the TEXTURE group enhances the discriminability, and therefore the perceptual availability of its points. This supports the idea that the perception of dimensional points flexibility changes with perceptual expertise. However, even when people were experts with textural information, its perception was still more restricted than that of shape and color, limiting the influence diagnosticity exerted on the perception of this dimension.

The data also reveal something unexpected: Participants trained on color discriminated textures as well as those trained on textures, even though the former were never explicitly required to categorize textures. It should be noted that color and texture are two characteristics of objects surfaces. Categorization training on one surface dimension (here, color) could set perceptual systems to tune to differences along another dimension (here, texture) that is also characteristic of the surface. The diagnosticity of specific dimensional values could then cause a general perceptual change; one that affects the global settings of perceptual systems, rather than the detection thresholds of a subset of learned dimensional values.

In sum, Experiment 2 set out to investigate whether the perceptual availability of object dimensions was fixed, or whether it could change with the diagnosticity of a dimension. The outcome was that the perception of textures was enhanced for participants trained on colors and textures. However, the overall salience of texture was still lower than that of shape and color, limiting the impact diagnosticity might have on the perception of dimensions.

General Discussion

The goal of this paper was to provide a framework whithin which to study dimension perception (as opposed to dimension usage). We proposed that judgments of physical identity would tap into dimension perception. In Experiment 1 these revealed that shape was available before color before texture. Experiment 2 showed that the perception of texture could partially depend on perceptual expertise with this dimension, but also that there was a "lower limit" on performance: Perceptual learning only enhanced discriminability, which was always worse with texture than with shape.

These results raise the interesting possibility that the extent to which a particular stimulus dimension is available for object, face and scene recognition tasks depends on the perceptual experience of the categorizer with this dimension. This is an interesting implication to pursue experimentally.

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