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# Variability Discrimination in Humans and Animals

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## *Implications for Adaptive Action*

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*Both humans and animals live in a rich world of events. Some events repeat themselves, whereas others constantly change. The authors propose that discriminating this stability, sameness, and uniformity from change, differentness, and diversity is fundamental to adaptive action. Evidence from many areas of behavioral science indicates that the discrimination of and preference for stimulus variability affects both human and animal action. Recent comparative research with humans and animals illustrates a promising approach to the study of these issues. Discovering and understanding the behavioral and neural processes related to stimulus variability and its consequences for behavior offer distinctive challenges and important new opportunities for psychologists and neuroscientists.*

**S**tability and change. People must discriminate and respond to both if they are to survive and reproduce. But, trying to serve these two conflicting masters is particularly challenging. Ian Malcolm, the protagonist of Michael Crichton's best-selling science fiction novel, *The Lost World*, proposed that

complex systems seem to strike a balance between the need for order and the imperative to change. Complex systems tend to locate themselves at a place we call "the edge of chaos." We imagine the edge of chaos as a place where there is enough innovation to keep a living system vibrant, and enough stability to keep it from collapsing into anarchy. (Crichton, 1996, p. 4)

Despite its unorthodox provenance, this intriguing analysis of stability (sameness) and change (differentness) should not be dismissed as mere science fiction.

Discriminating stability, sameness, and uniformity from change, differentness, and diversity is basic to many advanced intellectual and artistic activities, such as language, mathematics, analogical reasoning, social behavior, music, sculpture, and painting. Too little variety suggests a lack of creativity, produces ennui, and sparks a craving for greater stimulation ("diversive curiosity"—Berlyne, 1954; Loewenstein, 1994; "sensation seeking"—Zuckerman, 1994), but too much variety suggests a lack of coherence, produces overstimulation, and engenders a longing for things familiar, predictable, or regular. Many of the struggles of the mentally ill may take place along this dimension (e.g., Ganzevles & Haenen, 1995; Gschwandtner, Aston,

Renaud, & Fuhr, 2001). As well, drug abuse may involve individuals' efforts to move toward an optimal degree of stimulation that alternately rises to a more exhilarating level (via stimulants) or that falls to a less hectic level (via depressants). Indeed, evolution itself acts through the selection of naturally occurring variation, both within and between populations of organisms, to create the vast biodiversity—and the resulting variations in behavior—that people see around them.

For any individual animal, adaptively detecting and reacting to environmental variation is critical to its ultimate success; in fact, recent research has found that both humans and animals perceive, discriminate, and produce constancy and variability in many different settings (Nickerson, 2002). For instance, the males of some bird species sing highly complex and variable songs during breeding season. In such cases, females preferentially mate with those males that have the largest and most variable song repertoires (Hiebert, Stoddard, & Arcese, 1989; McGregor, Krebs, & Perrins, 1981; Searcy, 1984), perhaps because such complex song stores provide a reliable genetic marker of mate quality. Thus, the production of song variability by males and its perception by females (Searcy, Podos, Peters, & Nowicki, 1995) may play an important role in the reproductive survival of these species.

Despite the past and present importance of variability in the ontogeny and phylogeny of behavior, the keen interest of experimental psychologists in precise stimulus control—where variation is deliberately minimized and repeatability is highly valued—has resulted in rather little direct attention being paid by this community to understanding stimulus and response variability as factors in adaptive behavior. As such, determining how stimulus vari-

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ability is processed and ascertaining its role in controlling the behavior of people and animals is only just beginning. A similar evaluation of the importance of response variability has also recently emerged. As Neuringer (2004, this issue) has observed, discovering and understanding the behavioral and neural processes related to variability and its consequences for behavior offer distinctive challenges and important new opportunities for psychologists and neuroscientists.

In this article, we review research on how humans and animals process and respond to stimulus variation and constancy, complementary twins of fundamental importance to understanding behavior. The impact of these factors on different levels and facets of behavior is wide ranging and profound. At the molecular level, for instance, the immune system's major task involves making a cellular identification of self (same as me) versus nonself (different from me), whereas at more molar levels, same-different judgments about objects help to integrate the ever-changing stream of daily events into a coherent and stable reality. William James (1910) even suggested that the recognition and integration of the "sense of sameness is the very keel and backbone of consciousness" (p. 240). To restrict the scope of our review to manageable proportions, we focus on just two fundamental aspects of behavior: preference and discrimination and their relations to stimulus variety. The first part of our article looks at factors that modify the preference for variety; the second part reviews our own and others' research on how variety and constancy are discriminated by humans and other species.

## **Variation and Behavioral Preference**

The precise level of variety that one prefers differs across individuals and development (Munsinger & Kessen,

1966b). As knowledge is gained and regularities are detected, people tend to crave greater variety, thus keeping them close to the edge of chaos, a theoretical location where the greatest amount of learning presumably transpires. Piaget (1952) recognized the need to be near this edge with his dual concepts of *assimilation* and *accommodation*; familiar patterns are readily assimilated and require little change by the organism, whereas less familiar patterns require accommodation and modification of prior knowledge to capture these new patterns. These complementary behavioral processes must be kept in balance: "Always and everywhere adaptation is only accomplished when it results in a stable system, that is to say, when there is equilibrium between accommodation and assimilation" (Piaget, 1952, p. 7). In maintaining this balance, both individual differences (personality, age, and knowledge) and environmental contingencies can affect the level of preferred variety.

## **Individual Differences**

People know that environmental variability exists. Their reaction to variability is, well, varied. When they like variability, they use terms with positive connotations, such as *varied*, *assorted*, *diverse*, and *sundry*; but, when they do not like variability, they use terms with negative connotations, such as *inconsistent*, *unstable*, *chaotic*, and *unpredictable*. A similar dichotomy is observed when people speak of the lack of variability: *consistent*, *stable*, *steady*, *reliable*, and *predictable* versus *boring*, *monotonous*, *rigid*, *repetitive*, and *mundane*. Sometimes variability is highly desired; sometimes it is not. What determines this preference?

Some of the individual differences in the desire for variety can be captured by psychometric evaluation. Zuckerman (1979) developed his Sensation Seeking Scale to measure differences in optimal levels of stimulation and arousal by focusing on behavioral variability. Raju (1980) developed a similar scale but targeted a consumer's optimal stimulation level. This work revealed three primary factors that captured individual differences: the desire for the unfamiliar, the desire for alternation among familiar options, and the desire for information (Loewenstein, 1994). These treatments focused on preferences for variety as a personality trait.

In contrast, Munsinger and Kessen (Munsinger, 1966; Munsinger & Kessen, 1966a, 1966b, 1966c) examined variability preference as a function of knowledge. These authors proposed that people are most likely to learn when they are presented with a level of *cognitive uncertainty* that is just beyond their level of ability. This proposal parallels that of Piaget (1952) in suggesting that a person "looks neither at what is too familiar, because he is in a way surfeited with it, nor at that which is too new, because this does not correspond to anything in his schemata" (p. 68). This desire for an intermediate degree of cognitive uncertainty was underscored by Munsinger and Kessen when they observed that people preferred intermediate degrees of variability in stimuli, whether those stimuli were visual figures of various complexity (Munsinger & Kessen,



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1966b) or strings of letters and/or words (Munsinger & Kessen, 1964, 1966a). Furthermore, a person's ability to categorize and recall these stimuli was much poorer beyond his or her preferred level of variability.

The above factors are vitally important in educational settings. One of the essential roles of a teacher or mentor is to monitor, provide, and adjust the difficulty and variety of material to best advance and motivate a student's progress. Knowledge of the student's capacity for variety and uncertainty is a key component to properly selecting the next educational challenge.

### ***Environmental Contingencies***

Although reactions to variability may differ among individuals, a single individual's reactions may also differ across situations. Sometimes one likes variability; sometimes one does not. In addition to the desire to seek out variability at the edge of one's ability to comprehend information, environmental contingencies also dictate the utility of variety and consistency.

For example, Simonson and Winer (1992) explored people's preferences for variety in shopping behavior. These authors hypothesized that people might seek variety in some circumstances but seek consistency in others. In the study, people were given the opportunity to buy a variety of yogurts that differed in flavor and brand. Interestingly, Simonson and Winer found that people showed a preference for a variety of flavors but a preference for a consistency of brand. Furthermore, this pattern of preference occurred regardless of whether the items were organized by flavor or brand. Buying preferences also depended on the number of items purchased, with buyers preferring more flavor variety when purchasing large quantities of items and exhibiting more flavor consistency when buying

small quantities. Finally, when purchasing many things simultaneously, the buyers preferred flavor variety, but when purchasing many things sequentially, the buyers preferred flavor consistency.

These observations should not be surprising. Brand tends to be associated with quality and price; a buyer is expected to prefer a consistent level of each. Flavor preferences, however, are more likely to vary from day to day; one progressively tires of eating strawberry yogurt everyday and comes to crave something different. Top chefs are rewarded for providing the right amount of variety in their menus to keep the palette interested. Variety matters more when preferences are uncertain because of the adaptability it affords; added flexibility in the face of uncertainty appears to be a key factor in store choice (Kahn & Lehmann, 1991).

The certainty and variability that are associated with the quality and price of various items and options affect the choices and preferences of both humans and animals. This relationship can be seen when animals are faced with the environmental demands of choosing and securing their next meal. For the majority of animals, foraging for food is a continuous string of choices about where to eat, what to eat, and its relative benefits versus its costs to survival. Most of the time, these choices have differing degrees of variability associated with them. Some habitats or food items, for example, might consistently produce small amounts of food energy, as when shorebirds probe for small invertebrates buried in a sandy beach; other habitats or food items may produce occasional but very large bonanzas such as a washed-up crab located among the rocky crags. Thus, for any species with a mixed diet, the variability in the frequency of encounter, the ease of handling, and the nutritional payoff associated with each food type can afford an important and ongoing series of choices among variable or constant outcomes. So, do animals tend to prefer certain and constant small rewards over variable and uncertain large ones or vice versa?

These kinds of optimal foraging decisions have been framed in ways similar to those used to understand human economics (Stephens & Krebs, 1986). In both field and laboratory situations, where the long-term energy returns are roughly equivalent, animals and humans are generally risk averse, preferring consistent and stable rewards over riskier and more variable rewards. Nevertheless, several factors can alter this strategic choice.

One such factor is the value of the variable option (Hastjarjo, Silberberg, & Hursh, 1990); an animal will tolerate increased variability for a sufficiently large return. Another factor is an animal's internal state. If an animal is in a positive energy state (i.e., it is already obtaining sufficient food to meet its daily requirements), then being risk averse is an adaptive and safe strategy. But, as an animal moves toward an increasingly negative energy state, its preference shifts to becoming increasingly risk prone by gambling more often on the larger but more variable alternative, a choice that might better avoid starvation (e.g., Caraco, 1981; Caraco, Martindale, & Whittam, 1980). Finally, when the delay to food is varied instead of the



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amount of food, an animal becomes more risk prone and will choose the more variable-delayed outcome in comparison with a constantly delayed outcome (Bateson & Kacelnik, 1997).

The similarities of these findings to many aspects of human economic behavior are striking and reflect the shared assumptions of optimal foraging theories and accounts of expected utility. Although it is intuitively more adaptive to choose the guaranteed safe outcome, in some settings the more variable can be the preferred option. Further, it has become increasingly clear that human decision making in such risky and probabilistic settings is even more complicated than the above theories suggest. Daniel Kahneman's recent Nobel Prize was awarded in a large part for his (and Amos Tversky's) studies of human reasoning in such probabilistic and variable-choice situations (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992).

Finally, even in the fine arts, stimulus variability has important effects on human preference. In both the composition and performance of music, the degree of variation and repetition is critical to its perception and enjoyment. Although the main melody of a piece of music forms its core, developing and playing variations on this theme are time-honored ways to bring continuous interest to a score. Building and changing the melodic, harmonic, and rhythmic variations in a piece of music is a primary role of the composer. Indeed, one trend in Western music is the increasing use made by composers of such variations to challenge their listeners. Even musical styles are defined by the degree of variability that is tolerated, from the comfortable and predictable structures of country music to the more challenging improvisations of free jazz. Besides musical structure, variations in musical expression are also vital to human musicality. Music is rarely performed ex-

actly the same way by musicians; minute variations in timing, articulation, and loudness are essential to live performances. Without such variations, computerized music may be perceived as overly mechanical. Great music involves the successful balance and tension between expected constancy and unexpected variability.

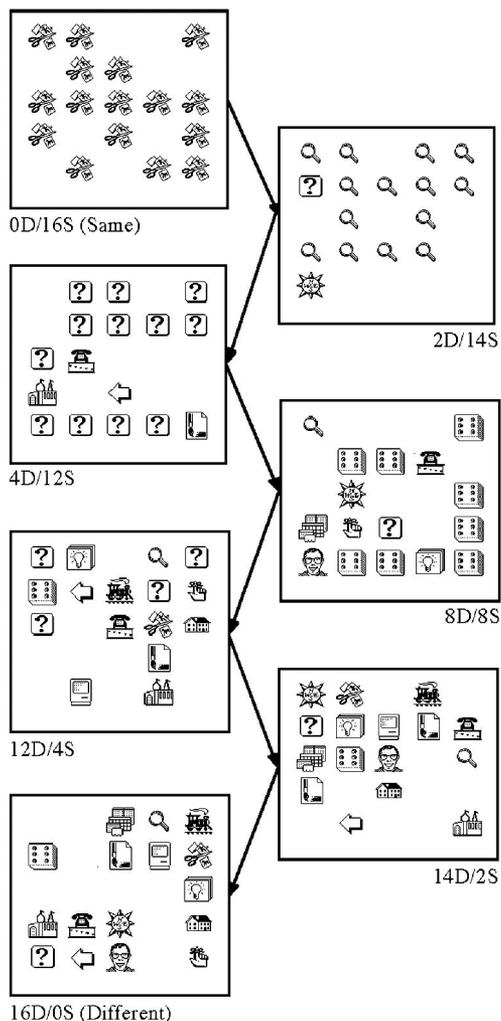
Although much remains to be clarified, the above evidence and observations point to the important effects of stimulus variability and uniformity on human and animal preference. Of course, for such preferences to exist, individual humans and animals must be sensitive in some manner to different degrees of stimulus variability. How such discriminations and preferences arise is still an open question. For instance, responding to variability may be a byproduct of sensitivity to the range of values, variance in nervous system responding producing variable behavior, or other unknown sources. Regardless, preferences for variability demand some mechanism for discriminating variability. Because it is on the latter issue of discrimination that considerable empirical and theoretical progress has recently been made, the next section reviews studies of variability discrimination in humans and animals.

## Discrimination of Variability

Where there is variety, there is information. Because sensitivity to variability is likely to be critical to survival, the intriguing possibility arises that the cognitive and neural substrates of variability discrimination are common to a wide range of organisms. Over the past 10 years, our laboratories have studied how animals and humans discriminate and locate stimulus variety and difference in complex visual stimuli. In particular, animal research facilitates our understanding of the cognitive and neural substrates of variability discrimination and localization—without the participation and complications of human language. By “controlling” for language, animal research allows us to identify the mechanisms of variability detection, to understand its evolution, and to see if and how language builds on or modifies these basic mechanisms.

In our discrimination tasks, the organism makes one response to report *same* when stimuli are identical to one another, and it makes a second response to report *different* when they are not. Using this same–different discrimination task with stimuli like those depicted in Figure 1, Wasserman, Young, and their colleagues have found that pigeons (Young & Wasserman, 1997), baboons (Wasserman, Fagot, & Young, 2001), and humans (Young & Wasserman, 2001) respond to variability in similar and lawful ways. Using the same task with stimuli like those depicted in Figure 2, Cook and his colleagues have found that pigeons can both discriminate and locate areas of difference (i.e., find the odd area or item) across a wide range of visual stimuli (Cook, 2002; Cook, Cavoto, & Cavoto, 1995; Cook, Katz, & Cavoto, 1997; Cook, Katz, & Kelly, 1999; Cook & Wixted, 1997). In both cases, the organisms appear to be processing and discriminating the variety or difference in such displays from the repetitive identity of the elements.

**Figure 1**  
Examples of the Icon Arrays Used in Young and Wasserman (1997)



Note. The  $mD/nS$  notation designates a display including  $m$  different icons and  $n$  same icons. From "Entropy Detection by Pigeons: Response to Mixed Visual Displays After Same-Different Discrimination Training," by M. E. Young and E. A. Wasserman, 1997, *Journal of Experimental Psychology: Animal Behavior Processes*, 23, p. 163. Copyright 1997 by the American Psychological Association. Reprinted with permission.

### Entropy as a Measure of Categorical Variability

In our initial studies, we sought to understand the discrimination of variability across the entire spectrum from low (everything identical) to high (everything different). Do people (Young & Wasserman, 2001, 2003), pigeons (Young & Wasserman, 1997), and baboons (Wasserman, Fagot, & Young, 2001) judge variability as a function of the number of different types of items in a collection, the frequency of the most common item, the frequency of the least common item, or is there a more complex function

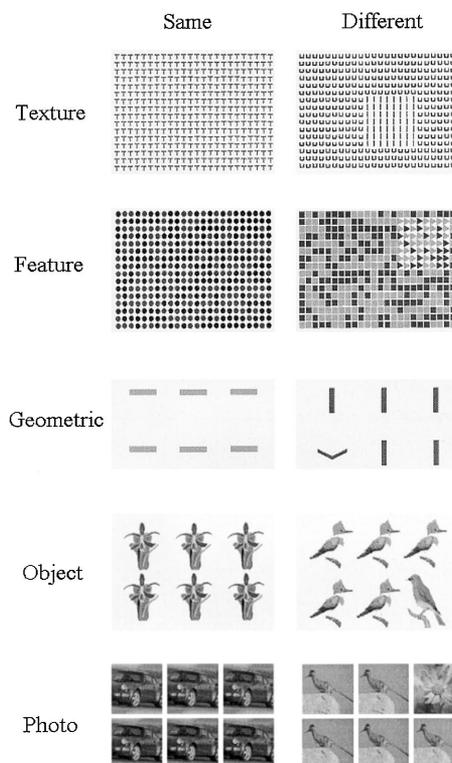
that better describes the stimulus features that control performance? Surprisingly, an existing measure of categorical variability, *entropy*, provided the best descriptor of performance for all three species, as shown in Figure 3. Entropy quantifies the amount of variety in a categorical variable. The same and different arrays represent the endpoints of the entropy dimension: The same arrays have no entropy, whereas the different arrays have maximal entropy for 16 observed categories.

To compute entropy, we use the following equation (Shannon & Weaver, 1949):

$$H(A) = - \sum_{a \in A} p_a \log_2 p_a \quad (1)$$

where  $H(A)$  is the entropy of Categorical Variable  $A$ ,  $a$  is a category of  $A$ , and  $p_a$  is the proportion of observed values

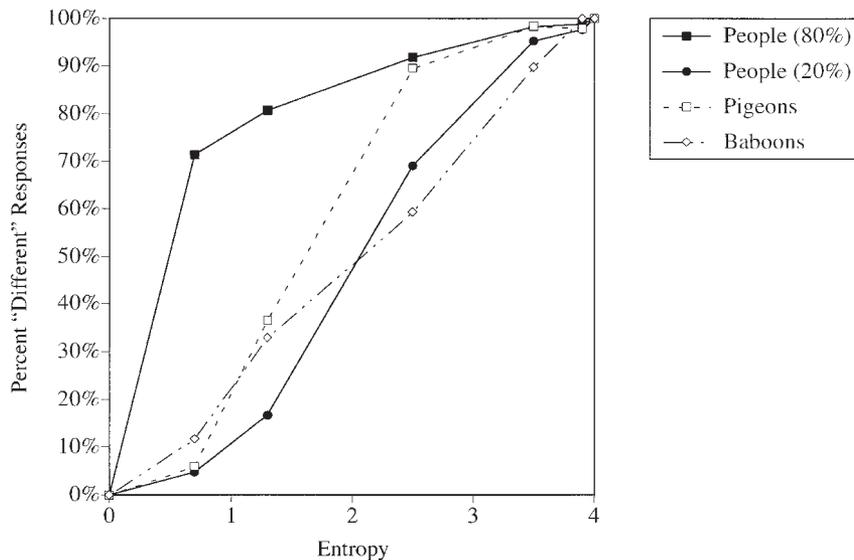
**Figure 2**  
Representative Examples of the Display Types Tested in Cook, Katz, and Cavoto (1997) and Cook, Katz, and Kelly (1999)



Note. The left column shows examples of same displays for each display type (the example for the feature display type depicts a shape-same display). The right column shows examples of different displays for each display type. The examples for the texture, feature, and geometric display types depict shape-different displays, but color differences were also tested. From "Pigeon Same-Different Concept Learning With Multiple Stimulus Classes," by R. G. Cook, J. S. Katz, and B. R. Cavoto, 1997, *Journal of Experimental Psychology: Animal Behavior Processes*, 23, p. 417. Copyright 1997 by the American Psychological Association. Adapted with permission.

**Figure 3**

Mean Percentage of Different Responses as a Function of Entropy for People, Pigeons, and Baboons



Note. People's performance exhibited two distinctly different performance profiles that are shown separately. The figure shows the means and standard errors of the percentage of different responses after standardizing performance to a minimum score of 0% for same displays and 100% for different displays.

within that category. When a display has 16 identical icons, there is only one category with a probability of occurrence of 1.0. Because  $\log_2(1.0) = 0.0$ , the entropy of the same displays is 0.0. The different displays consist of 1 of each of 16 icons or categories, yielding an entropy of  $-\log_2(.0625) \times 16$ , or 4.0.

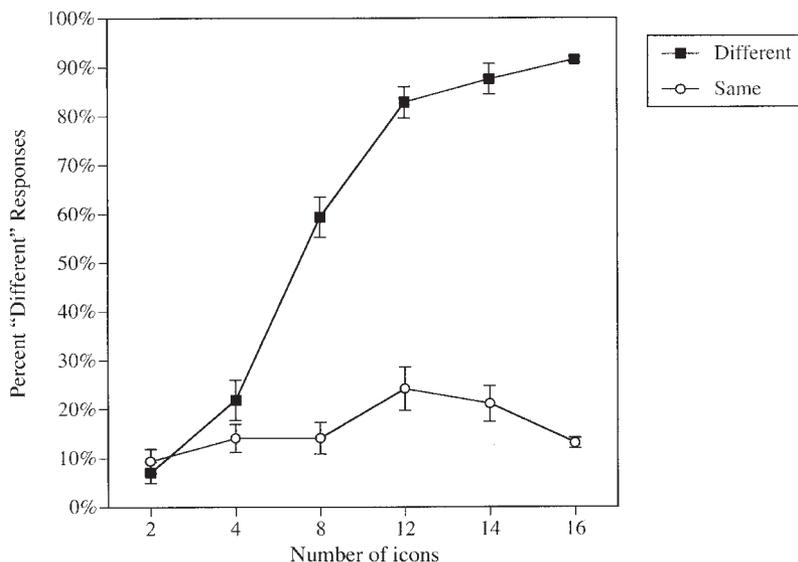
The pigeons and the baboons showed systematic control by the degree of entropy present in the display. Further, a minority of people (20%) also exhibited a continuous response profile very similar to that exhibited by pigeons and baboons, suggesting their decisions too were controlled by the variability or entropy within the display. On the other hand, most people (80%) exhibited a categorical distinction between those displays with any degree of variability (entropy greater than 0) and those with no variability (entropy equal to 0). Thus, people seem to show two distinctly different response profiles: some exhibiting control by the continuous variable of entropy and others responding categorically to the same and different properties of the display. None of the individual-difference characteristics that we examined (handedness, ACT scores, gender, GPA, or age) accounted for the observed behavioral differences among humans.

Our research also revealed that the number of items in a collection of stimuli can alter its perceived variety, as predicted by entropy (Wasserman, Young, & Fagot, 2001; Young & Wasserman, 2001; Young, Wasserman, & Garner, 1997). When a collection involved identical items (entropy of 0), increasing the number of items (e.g., from 2 to 16 identical items) had no discernible effect on the speed

or accuracy of the discrimination. But, when a collection involved all different items, increasing the number of items (e.g., from 2 to 16 different items) had a significant effect on the speed and accuracy of the discrimination. Interestingly, both pigeons and baboons found it very difficult to discriminate collections of 2 identical items from 2 different items, but they had no difficulty making the same discrimination based on 16 items (Figure 4 illustrates the effect in pigeons). Computing entropy in these two situations reveals that the 2-item task required distinguishing between displays with an entropy of 0 (same displays) and displays with an entropy of 1 (a relatively small difference in entropy), whereas the 16-item task required a distinction between entropies of 0 and 4 (a significantly larger disparity in entropy). Most people's choice accuracy was far less affected by the number of items than was that of our pigeons and baboons; but, even then, people's choice speed showed the same asymmetric effect (a larger impact of item number on different than on same trials; Young & Wasserman, 2001). A key difference between our animal and human results may be that our own species' linguistic experience with the labels *same* and *different* focuses attention on the categorical rather than the continuous aspects of the variety in these displays.

Interestingly, it appears that pigeons too can respond to stimulus variety in different ways depending on their past experience. In research involving a same-different discrimination (Cook et al., 1995, 1997), pigeons were trained to discriminate variation-difference as provided by

**Figure 4**  
Results of Experiment 1 of Young, Wasserman, and Garner (1997)



Note. The figure shows the mean percentage of different responses as a function of the number of icons in the display (2, 4, 8, 12, 14, or 16) and the type of display (same or different). From "Effects of Number of Items on the Pigeon's Discrimination of Same From Different Visual Displays," by M. E. Young, E. A. Wasserman, and K. L. Garner, 1997, *Journal of Experimental Psychology: Animal Behavior Processes*, 23, p. 494. Copyright 1997 by the American Psychological Association. Adapted with permission.

a single odd item or area in a wide variety of display types (see Figure 2). These displays ranged from large arrays of small colored shape elements to small arrays of large colored shapes, objects, or photographs, but they all contained a defined area or item that was defined by its oddity relative to the remainder of the display. As such, these pigeons experienced much smaller entropy differences between their same and different displays than the pigeons in the previously described procedures of Young and Wasserman (1997), because only a few different types of objects constituted a display (contrast the different displays in Figure 1 with those in Figure 2). Despite this much smaller difference in entropy, these pigeons also learned and transferred this oddity same-different discrimination to novel displays of each type.

The key question that brought our two laboratories together was whether these oddity-based results might also be captured by entropy. At the moment, the answer seems to be no (see review by Cook & Wasserman, in press). In one critical manipulation, Cook et al. (1997) varied the number of common elements in the visual displays, thereby changing the entropy of the displays. Following same-different training with  $3 \times 2$  arrays (vertical columns  $\times$  horizontal rows) of pictures involving one odd and five common elements (different trials) or six common elements (same trials), the pigeons were tested with  $2 \times 2$  arrays (one odd and three common elements or four common elements) and  $3 \times 1$  arrays (one odd and two

common elements or three common elements). In response to these trials, correct responding steadily fell on different trials as the number of display elements was reduced; there was little effect on the same trials. The decline on different trials is crucial because an entropy account predicts the diametrically opposite result: namely, that accuracy should rise. This prediction follows because decreasing the number of common items in an oddity display increases the entropy of the display.

Thus, it appears that Cook et al.'s (1997) pigeons may have learned something different about variety than did Young and Wasserman's (1997) pigeons, despite their otherwise similar training. Cook et al.'s (1997) pigeons are likely to have attended to the relative oddity of the target difference and to have used it to guide their choices. The disparate results from our two laboratories imply that pigeons, like humans, can process different aspects of stimulus variability depending on the demands of the task and the organization and number of elements in the display. When they are presented with a great deal of variety, pigeons can easily process the entropy of the display; but, when the overall amount of variety is markedly reduced, this may permit or promote other features of variety, such as stimulus oddity, to control performance. Besides the potential effects of language and past experience, what other factors may alter the processing and experience of variety by humans and animals?

## Organization Matters

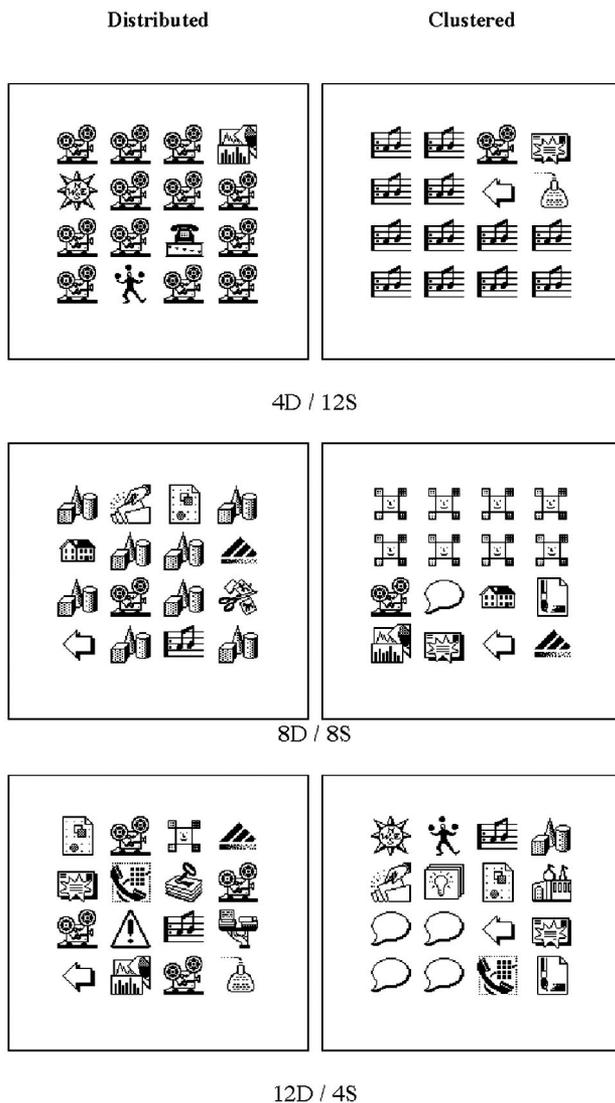
In our earlier work, the spatial location of each item in a display was randomly determined. More recently, we manipulated the spatial organization of the items to see whether their relative placement would alter the perception of variety (see Figure 5). Although the effect of spatial organization was not large (i.e., entropy was still the dom-

inant controlling feature), in both pigeons (Wasserman, Young, & Nolan, 2000) and people (Young, Ellefson, & Wasserman, 2001) spatial organization mattered. When the identical items in a display were clustered (and, as a consequence, the different items in the display were also clustered), the display was judged to have less variability than when the items were distributed. This result suggests that people and pigeons are less likely to discriminate and respond that two things are identical to one another when other, different items separate them.

Spatial organization is perhaps even more critical to oddity tasks. Given that identifying the odd item in a collection requires a judgment of relative difference, the location and salience of an item within a collection could determine its oddity and its ease of detection. For example, both people (Treisman & Gelade, 1980) and pigeons (Cook, 1992) often experience a form of parallel visual search called *pop out*, in which odd items or targets stick out from the surrounding items because of their unique dimensional features (e.g., it is easy to find a blue *U* in a field of red *Us* and *Ts*). However, when the search target does not possess a unique feature, it does not pop out, thus requiring a time-consuming search (e.g., it is difficult to find a blue *U* in a field of blue *Ts* and red *Us*). The reason why such targets are hard to find is that they require combining information from multiple dimensions. This extra processing prevents the stimuli from being perceptually grouped and easily located by the dimensionally tuned channels of our visual system, channels that can easily be recruited to detect the dimensionally or spatially odd features of a display.

Given the effects of spatial organization on discrimination, it is not surprising that marketing researchers have studied methods of organizing product on store shelves. One major goal of a store owner is to maximize perceived variety (Hoch, Bradlow, & Wansink, 1999). The use of distinctive motifs and logos increases the perceived number of options in a store aisle, while their homogeneity and relative oddity simultaneously allow the buyer to quickly identify and target a particular brand. Likewise, if people have ever been frustrated by the disorganization of the soup aisle (Why not put the cans in alphabetical order?), then they know that marketers leverage their knowledge of perception and cognition to maximize judgments of variety and contact with their products by forcing people to engage in a slow serial search of the product. User interface and Web designers can also leverage the research on this type of stimulus discrimination in order to make interface components more salient. Similarly, in advertisements, capturing attention with an oddball event of some sort is a classic device for garnering interest and making a product more memorable. Here, the critical principle is to make the crucial information more salient by its visual (motion or dimensional uniqueness) and spatial placement (central) within the display. By making an object more outstanding in terms of its appearance in comparison with the surroundings, a well-designed interface or advertisement can increase the chances that the object will catch the eye of its viewer.

**Figure 5**  
Examples of the Distributed Versus Clustered 4D/12S, 8D/8S, and 12D/12S Displays Used in Wasserman et al. (2000)



Note. D = different; S = same. From "Entropy Detection by Pigeons: Response to Mixed Visual Displays After Same-Different Discrimination Training," by E. A. Wasserman, M. E. Young, and B. C. Nolan, 2000, *Journal of Experimental Psychology: Animal Behavior Processes*, 26, p. 135. Copyright 1997 by the American Psychological Association. Reprinted with permission.

The same perceptual and conceptual principles apply to communication and signaling in the animal world and may explain the colorful and distinctive “advertising” of courtship displays in many species. The human need to separate oneself from the crowd, while not being viewed as too different or peculiar, has certainly influenced human mate selection for thousands of years; exploring how such variability-based decisions affect our behaviors may be a fruitful one in the developing field of evolutionary psychology.

### **Degrees of Similarity**

Our earliest work made the simplifying assumption that the items in a display were either identical or not; the degree of difference was ignored, except to ensure that items from different classes were different enough. Subsequent research has addressed the influence of item similarity on the discrimination of variability by manipulating the relative similarity of the items in a display.

A recent study by Young and Ellefson (2003) has shown that human variability discrimination is affected by the similarity of the items in the displays (for a related finding with pigeons in the domain of visual search, see Cook, Cavoto, & Cavoto, 1996). Not surprisingly, when displays with identical entropies comprised either small or large perceptual differences, people judged the former to have less variability and the latter to have more variability. This result suggests that people integrate categorical and continuous variability into a single judgment: It is not simply whether the displayed items are different (a categorical judgment) but how different they are from one another (a continuous judgment).

The observed effects of similarity on variability discrimination sharpens our intuition that having the local grocer carry more kinds of spaghetti is not as desirable as having them carry more kinds of pasta (unless most shoppers only like spaghetti). In future research, we plan to investigate the joint effects of similarity and organization on behavior. A given collection of items of varying degrees of similarity might be judged to be less variable if local comparisons involve very similar items and to be more variable if local comparisons involve very different items. Thus, organizing a collection so that the most similar items are distant from one another might increase the perceived variety of that collection.

Although these and other ongoing studies continue to disclose the nature and complexity of the processes that underlie variability discrimination (as captured by a recent computational model of these processes; Young, Ellefson, & Wasserman, 2003), entropy still provides a convenient rule of thumb for anyone who wishes to apply this knowledge to everyday tasks. When entropy differences are relatively large, it is most likely that the differences in judged variability will likewise be large, unless the items are very similar to one another.

### **Sequential Variability**

So far, we have discussed the discrimination of variability for simultaneously presented arrays of items. It is never-

theless possible that species like pigeons might be successful at detecting variability in an array of simultaneously presented icons but be incapable of detecting variability in a list of successively presented items. Perceiving variability in a simultaneous display makes no memory demands and may directly leverage the perceptual system’s ability to determine whether two or more items are the same as or different from one another; this situation is analogous to judging the variety of items on a store shelf. Perceiving variability in a list of successive items creates memory demands (only one of the items is present at any moment) and relies on a cognitive system that can compare the current item with others from the past, a situation analogous to judging the variety of items purchased over repeated visits to the same store. Because of the greater demands on memory, the discrimination of list variability may be far more difficult than the discrimination of array variability.

Young, Wasserman, and Dalrymple (1997) successfully trained pigeons to discriminate lists of 16 identical icons from lists of 16 nonidentical icons, where some lists involved no variability and different lists involved maximal variability. The pigeons were later tested (Young, Wasserman, Hilfers, & Dalrymple, 1999) with novel lists containing mixtures of same and different icons in various temporal locations within the list (e.g., *aaaabbbbccccdddd* or *abcdabcdabcdabcd*) or different numbers of same and different items. The results revealed that increasing the number of icon types led to more different responses, as did temporally distributing those different types of icons. Because entropy predicts that variability is a function of the number and mixture of icon types but that the temporal organization of the icons should have no effect, these results suggest that entropy (as previously applied to simultaneous arrays) cannot provide a complete account of successive same–different discrimination behavior.

A second experiment revealed that the number of items has a different effect on variability discrimination when the task involves list of items. Experiment 2A of Young et al. (1999) tested pigeons with same and different lists of either 2, 4, 8, 12, or 14 items. Here, increasing the number of list items raised discrimination accuracy on both same and different trials. This result has an important implication: The systematic effect of list length on same lists as well as different lists suggests a factor beyond entropy.

The above series of studies indicates that variety can be detected and discriminated across successive stimulus presentations by pigeons. Further, when using procedures in which each list item either does or does not differ from the next, the results look similar to those obtained with simultaneous arrays in which every item is either different from or identical to the other. These results suggest that exposing pigeons to displays entailing a great deal of variety leads them to attend to this factor and to be controlled by the entropy among the items. At the moment, it is not clear whether this holds true for all types of experiences.

For example, Cook, Kelly, and Katz (2003) recently conducted related experiments using another kind of list presentation procedure. In it, pigeons were shown either a sequence of same (aaaaaa) or alternating (ababab) photographic stimuli. Pigeons soon showed that they could discriminate these two types of sequences by exhibiting high rates of pecking during sequences of identical pictures (these trials were reinforced) and low rates of pecking during sequences of nonidentical pictures (these trials were not reinforced). Following acquisition, the pigeons showed successful transfer to novel stimuli. So, in this procedure, pigeons learned to make a same–different discrimination based on only two different items; indeed, pigeons were found to need only one stimulus transition to begin responding at different rates to the two types of sequences. This finding suggests that stimulus change can be detected quite quickly.

All of this work with successive stimuli has involved pigeons; no comparable studies are available on the discrimination of sequential variability in people or in other species (although there are studies of sequential randomness, a list can be variable without being random; Nickerson, 2002). Given the practical importance of perceived variability in situations involving sequentially presented programs on television, photographs of travel destinations, and songs on the radio, future work should try to determine the ways in which the results involving pigeons transfer to other species and domains. Given such knowledge about how people discriminate and remember sequential variety, one could more accurately balance the need for repetition (to increase familiarity) with the danger of overexposure in marketing new songs or television shows. Likewise, maximizing perceived variability or stability could be used to produce more stimulating environments and/or more relaxing ones.

## Concluding Comments

In 1785, the English poet, William Cowper, wrote that “variety’s the very spice of life.” This famous saying may often be true, but it might not prove to be very helpful in predicting and controlling behavior, generally. What is variety? How might we detect it? In what ways does variety affect our behavior? How is it processed? Are humans the only creatures sensitive to it? And, what is the psychological and biological significance of detecting and responding to variety? We hope that our prior discussion begins to answer some of these fundamental questions. We close with some additional comments that we hope will prove helpful.

Mathematics clearly helps us to define variety. From this perspective, variety is tantamount to the amount of information in a collection of events; the more different kinds of events, the greater the variety. Specifically, we have found that the mathematical concept of entropy (see Equation 1) can be usefully deployed to scale stimulus variety and its influence on both human and animal behavior in some situations.

Detecting stimulus variety is a complex behavioral process that involves at least the following activities: per-

ceiving, discriminating, comparing, and deciding. Detecting variety in sets of detailed displays, like those pictured in Figure 1, entails our discriminating 2 or more of the 16 items. We must then compare some or all of those items to appreciate their relation to one another. Finally, we must decide on the precise degree of variety that is present in the display by integrating these relations across either space or time. If the individual items are presented serially, then memory also comes into play during this integration; for instance, to discriminate a musical melody, one must remember and compare the relative pitches of the prior notes.

Clearly, humans and animals survive in a world of sameness and differentness. Adaptive action requires recognizing and responding to both. Sameness may indeed be special, as suggested by the large psychological gap in pigeon’s and people’s responding to homogeneous displays and to displays with any different items at all (Young & Wasserman, 2002). As well, James (1890) appreciated the crucial importance of the complementary sense of change–differentness–diversity. “We go through the world, carrying on the two functions abreast, discovering differences in the like, and likenesses in the different” (p. 529).

Disclosing and understanding the behavioral processes related to stimulus variability offer unique challenges and important new opportunities for psychological scientists. The integration of multiple spatial and temporal events must be appreciated as well as the properties of the specific individual stimuli themselves. The rich interplay among these and other factors like the species, sex, age, and prior experience of the organism as well as the situational and motivational conditions of training and testing truly ups the ante in our efforts to comprehend the stimulus control of adaptive action (Fetterman, 1996). Our review also highlights the need to integrate research in variability discrimination (the focus of the second portion of our article) with variability preference (the focus of the first portion of our article). Preference presupposes discrimination. Yet, the mere fact that an organism discriminates different levels of environmental variability does not mean that it will exhibit a preference for one level over another. To understand variability preferences, one must take both motivation and reinforcement into account.

In addition to our own work on stimulus variability, there is a rich and growing body of research on behavioral variability (see Neuringer, 2004, for a review and discussion). Can humans increase behavioral variability? What are the consequences of doing so? Our own work on the discrimination of stimulus variability interestingly applies to the assessment of behavioral variability in others. Because creativity is often associated with behavioral variability, assessments of creativity may be heavily influenced by the variability of the observed behaviors that others have produced. Behavior sometimes leaves a record—a manuscript, a painting, a symphony, or a remembered event—that constitutes a stimulus to be judged. Is the stimulus staid and predictable or is it creative and novel? Research on creativity and choice can be supplemented by new investigations of the relationship between research on the

production of behavioral variability and the discrimination of that produced variability.

We also see special opportunities to extend the behavioral study of variability discrimination into the biological realm. This study may contribute to researchers' understanding of the dynamics and plasticity of motivated behavior, where dopaminergic brain circuits appear to play an important part in reward-seeking and addictive behaviors (Ikemoto & Panksepp, 1999; Martin-Soelch et al., 2001). Research has recently shown that predictability modulates humans' cortical and subcortical responses to rewarding gustatory stimuli; indeed, different brain systems respond differently to predictable and unpredictable patterns of reward—unpredictable patterns possibly enhancing dopaminergic activation (Berns, McClure, Pagnoni, & Montague, 2001).

How predictability exerts its influence on brain and behavior is far from clear. But, one could speculate that nicotine and opiate addictions involve the same neural systems that enhance the effectiveness of unpredictable gustatory rewards. Variability per se may be reinforcing because, like stimulants and opiates, dopamine is prodigiously produced in certain brain systems.

But, drugs might not only be taken because they engender varied or disordered psychological states; drugs might also be taken because they engender stable or ordered psychological states. After all, people abuse both stimulants and depressants. Drugs might thus be reinforcing under different circumstances for different people to create either stability or change; people do surely engage in a wide range of behaviors in their efforts to cope with life on the "edge of chaos." Evaluating these and other speculations could be aided by a fuller understanding of the behavioral and neural effects of same versus different and predictable versus unpredictable patterns of stimulation (Huettel, Mack, & McCarthy, 2002).

Much like animals foraging for food, scientists forage a variable landscape of research opportunities in their attempt to find morsels that may nourish the future of our species. Through our continuing pursuit of the research paradigms introduced here, we hope to advance our understanding of stimulus variability by merging the methods of psychological science, information theory, and neuroscience.

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