AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology: Animal Learning and Cognition

ISSN: 2329-8456

2021, Vol. 47, No. 1, 4–13
http://dx.doi.org/10.1037/xan0000276

Some Unresolved Issues in Perceptual Learning

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Perceptual learning has been studied extensively using a procedure in which subjects (involving both humans and nonhuman animals) are exposed to two similar stimuli (to be referred to as AX and BX, where A and B represent distinctive features and X the features they hold in common), prior to a test of their ability to discriminate between AX and BX. Performance on the discrimination is found to be enhanced by this procedure, particularly if the preexposure arrangement involves intermixed presentations of AX and BX (a regime that might be expected to facilitate comparison of the stimuli). This perceptual learning effect has generated a range of theoretical interpretations that have focused, for the most part, on how exposure to a stimulus (or feature of a stimulus) can change its effectiveness, by which is meant its ability to command processing and to control responding. But a consensus is difficult to achieve, given that some aspects of what must be explained remain uncertain. Three issues are discussed here: Does appropriate exposure to the stimuli reduce the effectiveness of the common, X, elements? Does exposure enhance the effectiveness of the unique (A and B) elements? Are any such effects enhanced by the opportunity to compare the stimuli? It will require further experimental work to answer these questions, but raising them may promote this and thus facilitate achieving a satisfactory theoretical analysis.

Keywords: perceptual learning, discrimination, generalization, stimulus preexposure

Many examples of perceptual learning (even including the development of special skills by experts in a variety of areas—radiographers, wine tasters, chicken sexers, and so on) are a consequence, at least in part, of explicit discrimination training in which different events are associated with different outcomes. In experimental studies with animals, these outcomes could be reward for making one response to one stimulus and a different response to another. For human participants, the reward will be supplied by knowledge of results—by looking at the label to see that the wine just tasted was indeed merlot rather than cabernet sauvignon. The issues to be considered here, however, concern the processes whereby mere exposure to similar stimuli can facilitate subsequent discrimination between them. Gibson (e.g., 1969, p. 140) was insistent that perceptual learning could occur in these circumstances and that the ability to detect distinctive features of similar stimuli was not dependent on reinforcement or feedback (except insofar as reduction in uncertainty constituted some form of reinforcement; see also Mackintosh, 2009).

An early example of perceptual learning as a result of mere exposure (employing an experimental procedure that has been much used since) comes from an experiment with rats, reported by Mackintosh, Kaye, and Bennett (1991, Experiment 1). Over a period of 12 days, thirsty rats were given 10-min trials of access to water flavored with sucrose and lemon on some days and, on alternate days, to water flavored with saline and lemon. The presence of lemon in both served to make the flavors more similar and hence more difficult to discriminate. (These compound stimuli may thus be represented as AX and BX, where A and B stand for the unique features of each and X for the various features, which will include the taste of lemon, that they hold in common.) Drinking was not without consequence of course (it reduced thirst), but the different flavors did not have different consequences. Discrimination was assessed by establishing a conditioned response to one of the compounds and by testing for generalization of this response to the other. Mackintosh et al. found that prior exposure to the stimuli reduced the extent of such generalization; that is, it facilitated discrimination.

The details of the procedure are quite different, but a study by Wang and Mitchell (2011) provides an example of an experiment with human subjects that shows at least a formal correspondence to the work done with animals. (Whether the learning processes engaged by a procedure of this sort match those that at work in the animal experiments has been extensively discussed—see, e.g., Mitchell & Hall, 2014—and the issue will arise again as we proceed with this review.) Wang and Mitchell used visual stimuli of the sort shown in Figure 1—complex checkerboards having the same background pattern but each with a small, distinctive, added shape. In the terminology used above, the background constitutes the common component, X, and the shapes the distinguishing features, A and B. Participants received initial exposure in which AX and BX were presented in alternation, 60 times each; each

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This article was prompted by comments and discussion at the Perceptual Learning Workshop, University of Exeter, United Kingdom, June 17–18, 2019. My thanks to the organizers and participants.

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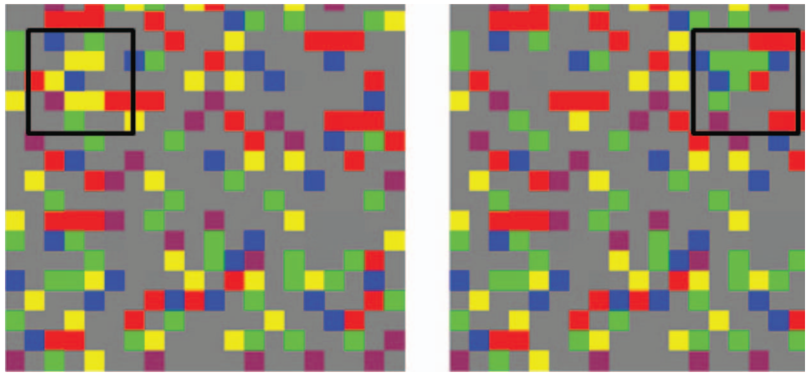

Figure 1. Checkerboard stimuli as used in the experiments by Wang and Mitchell (2011). They have common background on which a distinctive feature (outlined in black in this figure, for the purposes of illustration) was superimposed. Each feature had a simple distinctive shape and was of a uniform color. See the online article for the color version of this figure.

presentation lasted 480 ms, with an interval between trials of 2 s. Discrimination was tested by way of a same/different test, which showed that the participants were better able to discriminate the preexposed AX and BX than novel stimuli, CY and DY (stimuli with different distinctive features, C and D, superimposed on a different common background, Y).

There has been no shortage of experimental work using variants of the experimental procedures just described and intended to elucidate the nature of perceptual learning. (This is reviewed by Hall, 2001, and by Mitchell & Hall, 2014, who focus on work published since 2000.) Equally, there has been no shortage of attempts to supply an explanatory theory of the mechanisms involved: see, for example, Artigas and Prados (2014); Mundy, Honey, and Dwyer (2007); Hall (2003); McLaren and Mackintosh (2000); see also reviews by Hall (2017) and Goldstone (1998). Each of these theoretical endeavors has had some explanatory successes, but equally, all have had some failures. That the various theories can survive despite these failures is a consequence, in part, of the fact that the empirical evidence bearing on some of the critical issues is indecisive. The theorist (and I do not excuse myself here) is able to persist with his or her account by focusing on the empirical findings that support it and ignoring (or, more kindly, putting aside for later consideration) findings that do not. To make further progress, it will be useful, as a first step, to identify these issues and to review the discrepant findings, and this is the primary purpose of what follows. In some cases, a resolution may emerge; in others, it will not, but we may hope that identifying the problem will encourage the research needed to resolve it.

Loss of Effectiveness by Common Stimulus Features?

Background

We are concerned with the learning involved in becoming able to tell apart rather similar, and usually quite complex, stimuli. To continue with the terminology introduced above, the issue is how to tell apart AX and BX, where A and B represent unique identifying features of the stimuli and X those (perhaps many) features that the stimuli hold in common. Discrimination between AX and BX is achieved when behavior is controlled by the unique features (A and B) as opposed to the common (X) features. This formulation immediately leads to a suggestion for a mechanism that could be responsible for enhanced discrimination after mere exposure to AX and BX. Exposure to a stimulus will change its effectiveness (its ability to command processing and to control responding) in various ways: It will be less able to evoke its normal response (habituation), and it will be less ready to serve as a conditioned stimulus (CS) or an unconditioned stimulus (US) in associative learning (the latent inhibition and US-preexposure effects). These effects may be taken to reflect a reduction in some aspect of the attention paid to the stimulus. Now exposure to AX and BX will affect all three aspects of these stimuli (i.e., A, B, and X). It will be noted, however, that the X elements will receive twice as much exposure as the distinguishing features (A and B), so that the X elements could be rendered quite ineffective, while A and B still retain some power to command attention. In such circumstances, discrimination between AX and BX could be superior to that shown by subjects given no prior exposure, for whom the nondiscriminating X elements could command attention, to the detriment of attention to the critical A and B features. Just such an analysis is central to the account of perceptual learning proposed by McLaren and Mackintosh (2000), although other attentional processes have been developed to deal with other aspects of perceptual learning effects (see McLaren, Wills, & Graham, 2010).

The possible role of latent inhibition of common stimulus elements in generating a perceptual learning effect is well demonstrated experimentally. Using the procedure described above, Mackintosh et al. (1991, Experiment 2) gave rats exposure to the X element (lemon) alone, prior to testing generalization between sucrose-lemon and saline-lemon (AX and BX). Generalization was found to be substantially reduced (i.e., discrimination was enhanced). But to develop such an account further, it is necessary to address the fact that the effects of preexposure depend importantly on the way in which presentations of AX and BX are scheduled. It has been known for some time (from experiments with domestic chicks by Honey, Bateson, & Horn, 1994, and with rats by Symonds & Hall, 1995) that discrimination is superior after preexposure in which AX and BX are presented in alternation than when

AX and BX occur on separate blocks of trials.[1] In this procedure, the total amount of exposure to the X elements is the same in the intermixed and blocked conditions, giving no grounds for supposing that latent inhibition to X is responsible for the difference between them. One possible response to this finding is to postulate that change in the effectiveness of X is not determined solely by the amount of exposure—that the process responsible for loss of effectiveness is enhanced by the intermixed arrangement. But before taking this step and elaborating hypotheses as to why this should be so, it would be prudent to look at the experimental evidence. Do direct tests of the properties of the X stimulus show that change occurs more readily after intermixed than after blocked exposure to AX and BX? It is accepted that these different procedures will have different effects on the properties of the unique elements, A and B, than on the X elements so that their relative standing is likely to change. Our concern here is solely with changes in the absolute properties of X.

Experiments

This question was first investigated in experiments by Bennett and Mackintosh (1999) and by Mondragón and Hall (2002), with rats as the subjects and a version of the flavor-aversion learning procedure introduced by Mackintosh et al. (1991). In both studies, different groups of rats were given either intermixed or blocked exposure to compound flavors, AX and BX, the procedures being those that produce the standard perceptual learning effect (reduced generalization between AX and BX after intermixed exposure). In these experiments, the effects of preexposure on the properties of the X element were assessed by using it as the CS in a flavor-aversion conditioning procedure. It may be assumed that a reduction in the effectiveness of X would retard the acquisition of conditioned strength. In neither experiment, however, was there any difference between the groups in the course of acquisition of the aversion.[2]

Although there was no difference between the preexposure conditions in their acquisition of the aversion by X, there was an indication of a difference between the groups in the experiment by Mondragón and Hall (2002) in that the aversion was better maintained in the blocked condition over the course of a series of nonreinforced test trials. This hint prompted a series of studies (conducted in the York laboratory by C. A. J. Blair in 2004) summarized in Hall (2020). These used the preexposure procedures of the earlier experiment but tested the properties of X more directly. One set of experiments assessed the magnitude of the unconditioned response governed by the X stimulus. This might be expected to decline (habituation will occur) in both preexposure conditions but could do so more readily in the intermixed condition if that produces a more significant reduction in the effectiveness of X. No difference between the groups was obtained, however. A second set of experiments used a different test procedure (referred to as a superimposition test) that has been used successfully to detect change in stimulus effectiveness after other forms of stimulus preexposure (see Blair, Wilkinson, & Hall, 2004). This assessed the ability of the preexposed X stimulus to interfere with the response controlled by a separately trained CS. Again, there was no difference between subjects given intermixed preexposure and those given blocked preexposure to AX and BX. Finally, a third set of studies returned to simple conditioning in which X was paired with an aversive US. This established an aversion to X that extinguished with repeated nonreinforced presentations—but in no case was there any difference according to whether preexposure had been intermixed or blocked.

A similar study using rats and a flavor-aversion procedure, as well as pointing to the same conclusion, is offered by Rodríguez and Alonso (2004). It differed from that just discussed in that the preexposure phase consisted of presentations of AX and X alone (rather than of AX and BX), but this procedure is effective in producing a perceptual learning effect—that is, generalization to AX after conditioning with X as the CS was reduced when presentations of AX and X were intermixed during preexposure, compared with the performance shown when preexposure to AX and X used the blocked arrangement. Critically, for our present purposes, there was no difference between the preexposure conditions in the readiness with which X acquired strength during the conditioning phase of the study (see also Rodríguez & Alonso, 2008).

This collection of null results begins to look convincing and to point toward the conclusion that the two forms of preexposure do not differ in the extent to which they modify the properties of common, X, elements. Doubts are raised, however, by two studies reported by Artigas and Prados (2014, 2017). The first uses a flavor-aversion learning technique and the second an appetitive conditioning procedure with rats, but the experimental design is the same in both cases. As before, rats were given either intermixed or blocked exposure to the compounds AX and BX. They then received conditioning to X presented, in this case, in compound with a novel stimulus (i.e., NX was the trained CS). Stimulus X was then tested, again in compound with another novel stimulus (call it N′X). In both experiments, the subjects given intermixed preexposure showed a weaker response on the test, a result that was interpreted as indicating that intermixed exposure had reduced the effectiveness of X. An alternative interpretation is, however, possible.

Although we are debating the effects of preexposure on stimulus X, there is no debate about the effect on the unique features A and B. Here intermixed presentations of AX and BX increase the effectiveness of A and B (in comparison with the effects of blocked preexposure; see, e.g., Blair et al., 2004). A consequence of this is that, if there is generalization from A and B to the novel stimuli (N and N′), these latter stimuli are likely to be more salient after intermixed than after blocked preexposure. (Such generalization is quite likely—in the Artigas & Prados, 2017, study, e.g., A, B, N, and N′ were all pure tones, whereas X was a white noise.) In these circumstances, for animals in the intermixed condition, the

[1] The superiority of the intermixed procedure accords with the intuition that a procedure in which the subjects will be readily able to compare the two stimuli will facilitate perceptual learning. This topic is taken up in a later section of this article.

[2] Bennett and Mackintosh (1999) included a condition in which AX and BX were presented concurrently and found no reduction in the effectiveness of X. Rather, conditioning to X proceeded readily after this treatment, compared with a standard intermixed procedure in which 24 hr intervened between stimulus presentations. This effect was confirmed by Rodríguez and Alonso (2008). Both sets of authors attributed the effect to attenuation of latent inhibition of X, suggesting that this would be a consequence of the marked change of context from preexposure to conditioning that would be a consequence of the concurrent preexposure procedure.

salient N stimulus will be able to overshadow X during conditioning, and N′ will be able to interfere with expression of learning. The reduced level of performance to X would thus not reflect an effect of the preexposure regime on X itself but rather would be a by-product of the well-established effect of different schedules of preexposure on the unique features. These complications mean that we cannot rely on the results of Artigas and Prados (2014, 2017) to demonstrate that the effectiveness of X is reduced after intermixed exposure to AX and BX. There is, however, a study by Mondragón and Murphy (2010, Experiment 3) that, like Artigas and Prados (2017), uses rats, auditory cues, and an appetitive conditioning procedure but uses a simpler design and thus avoids the complications just noted. In this experiment, the rats were simply given intermixed or blocked exposure to AX and BX (A and B being tones; X, white noise) prior to conditioning with X as the CS. Although the groups did not differ in acquisition, a difference emerged over a series of tests with X given in extinction, with X controlling a lesser response in the intermixed condition. Mondragón and Murphy concluded that the effectiveness of X had been reduced in the intermixed condition.

Some support for this conclusion comes from a study, using quite different procedures, reported by de Zilva and Mitchell (2012). Human subjects were trained with stimulus displays consisting of 12 shapes, one of which was critical for discrimination, the rest being common to all displays. Three examples of the displays are shown in Figure 2. (The boxes around the distinctive features, A and B, are for illustration only. The bottom panel of the figure illustrates how the position of the distinctive element—in this case, A—can shift from one trial to another. The common features are, confusingly, referred to as W in this study.) Exposure to such stimuli was followed by a recognition memory test in which individual shapes that had formed the background (the W stimuli) were presented, and subjects were asked if this shape had been seen previously. Accurate responding on this test was lower when AW and BW had been presented in an intermixed fashion during preexposure than when a blocked arrangement had been used. Assuming that the ability to recognize such a stimulus is determined (at least in part) by what we have referred to, when discussing the animal studies, as its effective salience, then the conclusion is that the common element is less effective here after intermixed than after blocked preexposure.

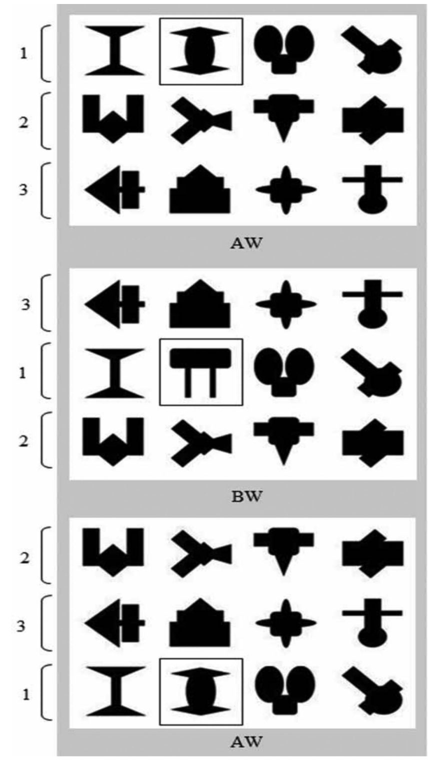

Figure 2. Three of the stimulus displays used by de Zilva and Mitchell (2012). The boxes around the distinctive features (A and B) are for illustrative purposes only. The vertical positions of the lines of figures changed from one trial to another. The top (AW) display shows one possible arrangement (denoted 1, 2, 3); other arrangements are shown for the two lower displays.

Summary

Although the bulk of the experimental work has failed to find the effect, there are persistent hints that the effectiveness of a common feature X may be reduced more substantially by intermixed exposure to AX and BX than by blocked exposure. If confirmed, this could constitute a mechanism contributing to the perceptual learning effect, and our theories would need to be expanded to accommodate it.

The effect demonstrated in the study by de Zilva and Mitchell (2012), although potentially of importance with some stimulus displays, may not require a major theoretical rethink. For displays of the sort shown in Figure 2, it is evident that a tendency to orient toward and fixate on the distinctive stimulus feature would reduce the amount of exposure subjects receive to the common (W) elements. Recognition memory scores for these elements could therefore be reduced as secondary consequence of whatever perceptual process has enhanced the attention paid to the unique elements. Although perhaps not impossible, it is harder to construct an analysis of this sort to provide a satisfactory explanation for the apparent loss of effectiveness by the common element in the experiment by Mondragón and Murphy (2010), where that element was an auditory cue (a white noise) presented in compound with other auditory cues (tones). It would be worthwhile to attempt to replicate this effect; if it can be confirmed, we might have to acknowledge the role of a process that specifically reduces the effectiveness of nondiscriminating features of stimuli. We would also need to determine why the effect should be obtained in this experimental paradigm and not in the flavor-aversion learning procedure. This would clearly have implications for our theories, which have drawn freely on results from both paradigms on the assumption that both are tapping the same underlying processes.

Enhanced Effectiveness of Unique Stimulus Features?

Background

Theoretical accounts of the perceptual learning effect terms of changes in the effective salience of various aspects of the stimuli have been offered by McLaren and Mackintosh (2000) and by Hall (2003) (see also Hall & Rodríguez, 2019). Both accounts suppose that exposure to a stimulus will tend to reduce its effectiveness, and, as we have noted, this in itself can be enough to explain why preexposed stimuli may be better discriminated than novel stimuli. Exposure to AX and BX will reduce the effective salience of all the stimulus elements, but especially of X, the feature that, if perceptually dominant, will hinder any discrimination. Even if A and B have lost salience during preexposure, discrimination will still be superior if X is much less effective than for subjects confronted with AX and BX as novel stimuli.

The implication of this interpretation is that the perceptual learning effect is obtained despite the fact that the effective salience of the unique elements is less than what it was when these elements were novel. Other interpretations (see, e.g., Mitchell, Nash, & Hall, 2008) allow the possibility that appropriate exposure to stimuli might actually enhance the effectiveness of the stimuli above the level they governed when novel.

Experiments

It has proved surprisingly difficult to devise an experimental procedure that allows a clear answer to this question. An example of the issues that arise is provided in a study reported by Wang and Mitchell (2011), presented earlier as an example of the procedures used in work on perceptual learning in humans. As we have noted, in one of their experiments, they gave initial intermixed exposure to AX and BX (stimuli like those shown in Figure 1), followed by same/different test with these stimuli. Performance on this test was superior to that shown on a same/different test with novel displays CY and DY (these abbreviations denoting novel features on a novel background). During this test, the direction of the subject's eye gaze was monitored, and it was found that more time was spent looking at the features A and B than was spent looking at C and D. Although these findings are suggestive, Wang and Mitchell were cautious about drawing the conclusion that the effectiveness of A and B in controlling this aspect of attention had been increased above the level controlled by equivalent novel stimuli (C and D). Their interpretation was that C and D were likely to be more salient in absolute terms but that the presence of a novel (Y) background would be enough to attract attention away from them and generate the result obtained.

There are, however, three further studies of perceptual learning in human subjects— by Wang, Lavis, Hall, and Mitchell (2012); Jones and Dwyer (2013); and Moreno-Fernández, Salleh, and Prados (2015)—that avoid problems of this sort. All three use similar procedures, and together they have generated all possible results.

The stimuli used in the study by Wang et al. (2012) were like those depicted in Figure 1. After initial exposure to AX and BX, presented on an intermixed schedule, the subjects were given a same/different test. In this test, two stimuli were presented one after the other (e.g., AX then AX, or AX then BX), and the subject had to say whether the two were same or different. Performance on this discrimination was better when the stimuli were AX and BX than when the test was given with stimuli having novel features (i.e., CX and DX). With this test procedure, given that the same common (X) elements are present for both sets of stimuli, a difference between performance with AX/BX and CX/DX must rest with the properties of the unique features. Performance was found to be better when these were A and B (i.e., preexposed) than when they were C and D (i.e., novel). This result seems to indicate that the perceptual learning effect generated by intermixed exposure to AX and BX is achieved by raising the effective salience of the unique features so that it exceeds that of equivalent novel stimuli. But a further experiment by Wang et al. designed to deal with a complication introduced by using stimuli of this type (in which the distinctive feature is located in a particular part of the display), challenges this.

In the experiment just described, A and B were presented each in a particular quadrant of the display (e.g., top-left, bottom-right). C and D, in the test phase, occurred in the other quadrants. If subjects learned, during the preexposure phase, to fixate selectively on the quadrants used for A and B, then that would be enough to explain the test results. This is not to dismiss the importance of learning to look in the right place with complex visual displays—this is a plausible, and potentially important, contributor to perceptual learning effects obtained with such stimuli. But it remains important to determine if there is any effect over and above this. Wang et al. (2012) addressed this issue in a further experiment in which, after training with AX and BX as in the previous experiment, tests were given with A and B presented in what may be termed the "unattended" locations as well as in their original ("attended") locations. The novel features C and D were also tested in both the attended and unattended locations. This test showed that for stimuli presented in the unattended locations, performance with the novel features, C and D, was superior to that shown to the preexposed A and B. Thus, when the contribution of selective looking is catered for, we find that novel features are somewhat more effective than the features given preexposure.

The study by Jones and Dwyer (2013) raises doubts about the generality of this conclusion. This used stimuli and procedures very like those used by Wang et al. (2012). All subjects received intermixed preexposure to AX and BX followed by a same/different test to confirm the basic effect (that performance was superior with AX and BX than with the novel displays CX and DX, in which different unique features were presented in different locations on the X background). Half of these subjects also received tests with AX and BX, but with the features A and B presented in locations different from those used in training; the remaining subjects were tested with novel features in these locations. In this test, discrimination performance with A and B was no better than with the novel features. A second experiment, using a more complex experimental design that allowed a within-subject test of the theoretically important comparisons, confirmed that test performance was determined by the location of the unique features and was quite unaffected whether or not the feature had been present in training. There was no evidence for an advantage of novel over pretrained features as was obtained by Wang et al. (2012).

The experiments by Moreno-Fernández et al. (2015) again used checkerboard stimuli with distinctive features that could appear in different locations. The preexposure procedure the relevant experiment consisted of intermixed presentations of AX and of X alone. (As we have already noted, this procedure generates a perceptual learning effect, resulting in enhanced performance on a subsequent discrimination between AX and X, compared with the performance shown when preexposure to AX and X has used the blocked arrangement.) After this training, Moreno-Fernández et al. tested the ability of their subjects to discriminate between AX and X, both when A was in the same location in the display as was used during preexposure and when it was presented in a different location. They also included an equivalent set of tests with a novel stimulus feature, N (i.e., the subjects were required to discriminate between NX and X, both when N was in the "attended" location and when it was in the other location). They found that intermixed preexposure facilitated test performance with A as the critical feature, whether it was presented in the original or a different location (confirming that the subjects had learned something about the feature itself and not simply about its location). Critically, they also found that performance on tests with the A feature was superior to that shown when the test was given with N. Their conclusion was that intermixed preexposure had enhanced the salience of feature A, making it even more effective than a novel feature.

Summary and a Further Question

It is somewhat disconcerting that three such similar studies should generate these differing results. From one point of view, that by Jones and Dwyer (2013), is less troubling than the others. If we can accept that something (yet to be determined) about the details of the procedure, or of the stimuli used, resulted in the subjects learning only about the location of the unique features and not about their content, then their null result remains just that. But for the other experiments, in which subjects did learn something about the nature of the unique features, there is a direct contradiction, with one suggesting that these features have less salience than novel features and the other that their salience is enhanced. Although similar in principle, there are, of course, many procedural differences between these two studies, and there is a difference in the basic design in that one looked at the effects of training with AX and BX, the other with AX and X. It is in factors such as these that the source of the differing results must lie. This is an issue of theoretical importance and demands further study; perhaps it would be advantageous to investigate it using stimuli in which the features are not distinguished by their spatial location (e.g., by using auditory or olfactory stimuli), thus eliminating one of the factors that complicates the experiments just discussed.

The further question raised by these experiments concerns the role of selective looking in experiments of this sort. It is clear that, for displays in which distinctive features are presented, each in a particular location, subjects can come to concentrate on those locations. As we have already noted, learning to look in the right place is a valid mechanism for enhancing discrimination—that is, for generating a perceptual learning effect. For human subjects given the instruction to look for differences between the displays, detecting the feature will be rewarding to a certain extent, and the tendency to direct the gaze to the appropriate place will be reinforced (see Mackintosh, 2009); indeed, in some circumstances, the perceptual learning effect may not be obtained at all in the absence of such instructions (Recio et al., 2016).

Before pursuing this issue further, it will be useful to note that (instruction-induced) reinforcement of the tendency to concentrate on a particular location cannot be the sole source of perceptual learning effects demonstrated for human subjects exposed to complex visual displays. McLaren and his colleagues (e.g., McLaren, 1997; McLaren, Leevers, & Mackintosh, 1994) have demonstrated effects in subjects given minimal instructions and trained with stimuli having no distinctive localized unique feature. Figure 3 shows examples of the displays used in a study reported by McLaren et al. (2010). These are prototypes used to generate a range of exemplars in which a proportion of the elements were changed: For each exemplar, six or so of the horizontal lines were changed, being replaced with a randomly generated set of black and with squares. There was thus no simple, localized feature that distinguished stimuli based on one prototype from those based on the other. Nonetheless, initial training with a range of exemplars (a categorization task in which subjects were required to assign exemplars to Type I or Type II) produced positive transfer to a final discrimination test in which the two prototypes were presented side by side, and the subjects were reinforced for choosing one rather than the other.

We return now to the case in which the displays have a unique feature in a particular place and in which, at least after intermixed exposure to a pair of displays, subjects show evidence of having learned something about not only the location but also the "content" of the feature presented in that location. The issue that remains to be resolved here concerns which of content and location is the chicken and which is the egg. One possibility is that, from the outset, subjects adopt a strategy of fixating a certain section of the display, chosen initially perhaps at random, and are reinforced for looking at that point when in it turns out that its properties change from one presentation to the next. Such a strategy would facilitate performance in the same/different test phases of the experiments considered above. Encoding and retention of infor-

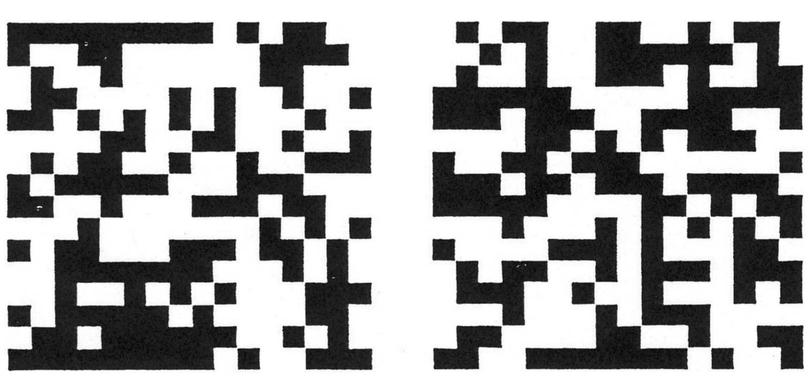

Figure 3. Examples of the stimuli used in the experiment described by McLaren et al. (2010).

mation about the feature that is present at the attended location would be possible but incidental and secondary to this process. The alternative possibility is that intermixed preexposure serves to maintain or enhance the effective salience of all aspects of the unique feature, with location being just one aspect, along with color, shape, and so on. That location should come to dominate performance as training continues would be testimony to the power of reinforcement to establish a response pattern (preferential inspection of particular parts of the display) that allows an easy solution to the task in hand. But the question of the mechanisms by which intermixed exposure has its effects initially would remain. It is important to resolve this issue, to decide between these alternatives, given the extent to which displays of the sort shown in Figure 1 have been used in the analysis of perceptual learning (see Mitchell & Hall, 2014).

Comparison

Background

Honey et al. (1994) introduced the intermixed training procedure, assessing its effects against the control in which the same stimuli were experienced on separate blocks of trials, explicitly to investigate the effects of a preexposure procedure in which the subjects were given the opportunity to compare the stimuli. The assumption was that the intermixed arrangement would promote the occurrence of comparison in a way that the blocked procedure would not. They attributed the suggestion that comparison plays an important role in perceptual learning to Gibson (1969), and indeed, her influential differentiation account of perceptual learning includes the suggestion that distinctive features can be extracted as a result of exposure to a range of similar events or displays (Gibson, 1969, p. 108). But Gibson offered no formal analysis of what is involved in comparison, saying little more than that simultaneous presentation of two stimuli will allow "differentiation . . . and the discovery of contrasts and feature differences" (p. 145); also, this process can operate if the stimuli are presented successively provided an "image" of the first is stored for comparison with the second.

The effectiveness of the intermixed procedure in facilitating later discrimination between the preexposed stimuli is firmly established. What remains to be determined is whether this effectiveness derives from a process of comparison and, if it does, what mechanisms underlie this process. The experimental evidence so far available is no more than suggestive, and these issues are not yet resolved.

Experiments

An obvious implication of the idea that the critical feature of the intermixed schedule is that it allows comparison is that the effectiveness of this schedule would be increased if the stimulus presentations were more closely spaced. That is, we may assume that the comparison process will require the memory (Gibson's "image") of one stimulus to be intact and operative when the second stimulus arrives, and this is more likely when the first has been experienced only recently.

Close presentation: Animal studies. Honey and Bateson (1996) took up the notion in a further study of domestic chicks given exposure to visual cues but found no straightforward support for it. They found that reducing the interval between presentations of the stimuli from 28 to 14 s had quite the opposite effect; that is, discrimination was worse after exposure at the shorter interval. Nonetheless, they did not discard the idea that comparison might be important. Their suggested explanation was that two opposing mechanisms might be at work here. Reducing the interval between stimulus presentations might well facilitate comparison, but it could also lead to the formation of a direct excitatory association between the (distinctive features of the) two stimuli. If one is able to activate the representation of the other, this will tend to retard performance on a task requiring different responses to them. It is possible, Honey and Bateson suggested, that this negative effect might be enough to outweigh the advantage that the possibility of more effective comparison would bring.

As a consequence, the focus of subsequent research, which has largely made use of rats trained with flavors as the stimuli, shifted to attempting to assess the validity of this interpretation. Bennett and Mackintosh (1999) found a positive effect of preexposure when the two flavors were presented daily with an interval of 4 hr between them, and although it was not enhanced (as a straightforward application of the notion of comparison might expect), this effect was still obtained when the interval was reduced to a minute or so. The perceptual learning effect was reversed, however (i.e., there was stronger better generalization after intermixed preexposure), when the two flavors were presented concurrently, or in very rapid alternation, with just a few seconds between them. Bennett and Mackintosh concluded that the effects obtained in the latter case were a consequence of very short-term sensory adaptation effects. The likelihood of such effects was reduced in a similar study by Recio, Iliescu, and de Brugada (2019) again using flavor stimuli with rats. They inserted a 5-min interval between stimulus presentations and filled this with access to water, thus reducing the likelihood of the short-term adaptation of concern to Bennett and Mackintosh (1999). Nonetheless, rats given four sessions of this form of exposure showed enhanced generalization between the two stimuli, an outcome Recio et al. attributed to the associative mechanism postulated by Honey and Bateson (1996).[3]

Enhanced generalization was also obtained in the experiments reported by Alonso and Hall (1999) in which the subjects were given concurrent exposure to the compound flavors AX and BX. This study attempted to test directly the suggestion that this failure to obtain a perceptual learning effect was a consequence of the formation of an excitatory association between the features A and B. In this experiment, rats were given an extra phase of training, following the initial exposure phase, in which A and B were presented separately. This should allow extinction of any excitatory associations between A and B, established previously, but despite this, the reverse of a perceptual learning effect was still obtained. This result cannot be decisive—as Alonso and Hall acknowledge, it may be simply that the extinction training was insufficient given to eliminate the A–B association—but it offers

[3] By contrast, rats given 12 sessions of this exposure showed less generalization (i.e., a perceptual learning effect). Why extended training should have this effect remains to be explained. Unfortunately, however, we cannot know that the opportunity for comparison offered by this procedure was of importance, as there were no subjects given the (normal) arrangement with several hours separating stimulus presentations.

no support for the hypothesis proposed by Honey and Bateson (1996).

The only secure conclusion to be drawn from these experiments is that close spacing of the stimuli has not been shown to enhance the perceptual learning effect and that the source of the reversed effect that can be observed in these circumstances could arise from sensory or associative interactions between the unique features A and B. To test the hypothesis that close presentation of the stimuli will promote the perceptual learning effect (i.e., enhance discrimination between AX and BX), it is necessary to eliminate these complications. This was the aim of a series of experiments by Rodríguez and Alonso (2008) and Rodríguez, Blair, and Hall (2008).

These experiments made use of the fact that a perceptual learning effect can be obtained when preexposure is given to intermixed presentations of a stimulus having a distinctive feature (AX) and of the background to that display (i.e., to X alone). This outcome is to be expected given our interpretation of the role of comparison—feature A might be expected to "stand out" in the AX stimulus if subjects have recently previously experienced X on its own. In the experiments by Rodríguez and Alonso (2008) and Rodríguez et al. (2008), some rats were given exposure to AX and X presented hours apart (the standard intermixed procedure), others received concurrent presentations with two drinking tubes side by side, and (in Rodríguez et al., 2008, Experiment 3) a control condition received separate blocks of trials with all AX trials preceding the X trials or vice versa. The effect of these treatments on the properties of the unique feature A was tested in a variety of ways. These concurred in showing the standard perceptual learning effect—that A was effectively more salient after intermixed than after blocked exposure. The new finding was that concurrent preexposure generated just the same outcome as the standard intermixed procedure. Thus, when the preexposure procedure excludes the possibility of an interaction between unique features of the two stimuli (i.e., between A and B of AX and BX, as in the experiments described earlier), a perceptual learning effect is obtained with concurrent as with more widely spaced preexposure. And the effect is of exactly the same magnitude, implying that the opportunity for close comparison is of no relevance in this procedure.

Distractor effects. If experiments with nonhuman animals have produced no clear evidence of a role for comparison, the picture is different when the subjects are people. In experiments with this species, it has been customary to present (visual) displays at intervals of a second or less and even, in the procedure used by Mundy et al. (2007), concurrently, side by side. This procedure is very effective in enhancing performance on a subsequent discrimination task. (See also Angulo, Alonso, Di Stasi, & Catena, 2019.) Mundy et al. specifically attributed the effect they observed to a process of comparison that depends on a short-term memory (STM) of the first stimulus (AX) being active when the second (BX) arrives. More specifically, they identified this with a short-term adaptation (or habituation) effect. Exposure to AX will produce a short-lasting habituation to the features displayed so that, critically, the unique feature B of the BX display will stand out and receive full processing on the next trial. (Mitchell et al., 2008, offer a similar, but slightly different, interpretation of this general notion).

Dwyer, Mundy, and Honey (2011) provided a test of this interpretation by examining the effect of a "distractor," an irrelevant visual cue, inserted in the interval between the presentation of AX and that of BX. Such a cue might be expected to negate the effects of the AX presentation and thus reduce the magnitude of the perceptual learning effect. In fact, the cue turned out to be genuinely distracting, in that it produced a lowering of test performance quite generally. Critically, however, its effect was most marked when it occurred in the interval between AX and BX rather than at some other point in the preexposure sequence, thus supporting the hypothesis that led to the experiment.

The effectiveness of the distractor procedure confirms the intuition that comparison of the stimuli plays an important part in (human) perceptual learning. It seems, therefore, to drive a wedge between these studies and the effects obtained with animal subjects, where, as we have seen, evidence for a comparison process is not strong. It is of special interest, therefore, that recent experiments by Recio, Iliescu, and de Brugada (2018) have provided some evidence of a distractor effect using rats trained in a flavor-aversion procedure. In the first of their experiments, rats were given preexposure with closely spaced presentations of the compound flavors AX and BX, the 5-min gap between the stimuli being filled simply by access to water. Some rats were given an intermixed arrangement in which different flavors were presented on each trial (e.g., AX/water/BX); others got some trials in which both were AX and other trials on which both were BX (a version of the blocked arrangement). The ability of the unique feature to interfere with the response controlled by a separately trained CS was used to assess its effective salience. This showed that the effective salience of the feature was greater in the subjects given the intermixed procedure—the standard perceptual learning effect. In a second experiment, further rats were given the same treatment except that a novel and salient distractor flavor was presented in the 5-min gap, in the place of water. With this procedure, the perceptual learning effect was not evident; that is, there was no difference between the subjects given the intermixed and those given the blocked exposure procedure. It is not easy to reconcile this result with those of the animal experiments described previously, but the implication is that in some circumstances (yet to be determined), it is possible to obtain a comparison effect in animals akin to that observed with human participants.

Summary

Although the word has been widely used in this context, it was never likely that *comparison,* as we generally understand it, could be responsible for the effects obtained from experiments with rats given alternating presentations of the stimuli spaced many hours apart. Theories of the perceptual learning produced by this procedure (e.g., Hall, 2003; Hall & Rodríguez, 2019; McLaren & Mackintosh, 2000) have therefore interpreted the effects generated by this procedure in terms of longer-term associative learning processes—for example, an association between A and X after an AX presentation could allow associative activation of A when BX is presented hours later.

Comparison as we know it, implying the presence of a STM of one event during experience of the other, seems to be demonstrated as being a factor in human perceptual learning. This leads to a set of issues that need to be resolved. These may be summarized simply as: Why is it so difficult to obtain a parallel effect in animal subjects? Answering this seemingly simple question would speak to an important basic issue. Recent work on perceptual learning has been built on studies using broadly similar methods with both human and animal subjects. The assumption (debated at some length and supported by Mitchell & Hall, 2014) has been that the same mechanism will be at work in rats and humans. A proper answer to the question just posed may require us to rethink this assumption.

Conclusions

Advance in our understanding of a psychological issue proceeds on two fronts—the collection of empirical findings and the construction of theoretical accounts. It would be absurd to suggest that one should pause its advance while the other sorts itself out: The two fronts are complementary—our experiments generate the facts that the theory tries to explain; our theory generates predictions that we test empirically. But perhaps in some cases, an imbalance between fact and theory can arise that is large enough to make it worth the effort of attempting to correct.

Perceptual learning may be a case in point. Theorists (e.g., Hall, 2003, to name but one) have developed accounts (in Hall's case, of learning processes that modulate the effective salience of various aspects of stimuli) that go beyond the available evidence. Consider the procedure that has been much studied and is the focus of discussion here—the enhanced discrimination between AX and BX after preexposure to intermixed presentations of these stimuli. Hall's account proposes the following: (a) that this procedure maintains the effective salience of the features A and B at a level higher than that produced by control procedure, and it does not suppose that the salience of these features is raised above their starting level; (b) that the positive effects of such preexposure do not depend on change in the effective salience of the common X features; and (c) that no special mechanism of comparison is involved in producing the observed effects.

All of these propositions are in doubt, if for different reasons in each case. Thus, for proposition (a), apparently very similar experimental studies have produced quite differing outcomes. To resolve this requires an analysis of the fine details of the procedures used in the various experiments. This could reveal that variables, routinely considered to be of trivial importance, are critical in determining perceptual learning effects. Proposition (b) is supported by the bulk of the evidence; further work could usefully focus on replicating and analyzing the effect seen in the discrepant results. The discrepancy in this case raises the possibility that different mechanisms are at work in experiments using flavors as the stimuli and those using auditory and visual cues. The generality of proposition (c) is undermined by the apparently clear demonstration of distractor effects, at least in human perceptual learning procedures. If such effects depend on a comparison process, then theoretical work needs to be done to specify the exact nature of this process, and further experimental work is required to establish what is the case for animal conditioning procedures (and thus to assess whether the same general explanatory account can apply to rats and to humans).

Finally, although I have picked out the problems of Hall's (2003) account for special mention in this context, it is only fair to add that other theories face similar or parallel problems.

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Received July 16, 2020
Revision received September 4, 2020
Accepted September 7, 2020 ■