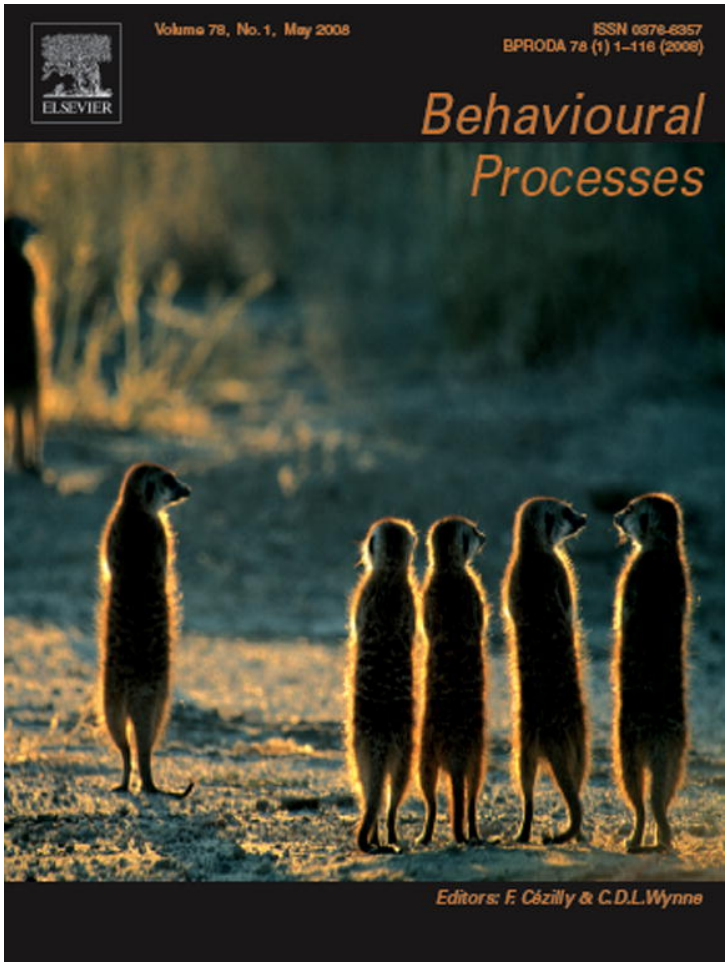

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Short report

The influence of comparison between similar stimuli on the effectiveness of their unique features

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Abstract

Four groups of rats received stimulus pre-exposure under conditions intended to produce different opportunities for stimulus comparison to occur. Groups AX/BX-L and AX/BX-S received alternating presentations of two compound flavors (AX and BX); the interval between these presentations was long (24 h) for group AX/BX-L, and short (5 min) for group AX/BX-S. Groups AX-L and AX-S matched groups AX/BX-L and AX/BX-S in their pre-exposure conditions except that they received presentations of water rather than presentations of BX. The effective salience of one of the unique stimulus features (A) was then assessed by using this flavor as a conditioned stimulus in a flavor-aversion procedure. It was found that aversion to A was learned about more readily after pre-exposure to AX and BX than after pre-exposure just to AX. However, there was no indication that the rate of conditioning to A was affected by the temporal interval between the presentations of AX and BX. These findings challenge the notion that stimulus comparison engages a process responsible for an increase in the salience of the unique stimulus features, but can be accommodated by the salience modulation mechanism proposed by Hall [Hall, G., 2003. Learned changes in the sensitivity of stimulus representations: associative and nonassociative mechanisms. Q. J. Exp. Psychol. 56, 43–55].

Keywords: Stimulus salience; Perceptual learning; Comparison; Temporal interval

Appropriately scheduled exposure to two similar stimuli can enhance their subsequent discriminability (i.e., reduce the extent to which generalization occurs between them). This phenomenon is known as *perceptual learning* (for a review, see Hall, 1991), and over the recent years has been studied in experiments using flavors as the stimuli. For instance, Symonds and Hall (1995; Experiment 2) gave rats pre-exposure to two flavor compounds, AX and BX (where A and B represent distinctive features of the stimuli and X represents an explicitly added common feature) in alternating trials (i.e., AX, BX, AX, BX. . .). Control subjects received an equivalent pre-exposure to the stimuli, but according to a different schedule, in which a block of AX trials preceded a block of BX trials (i.e., AX, AX, . . ., BX, BX. . .), or vice versa. For all subjects an aversion was then established to AX and generalization to BX was tested. It was found that rats given alternating pre-exposure showed less generalization (i.e., a better discrimination) between AX and BX than those that received blocked pre-exposure. This alternating versus blocked effect has been well-established in both animal (e.g., Bennett and Mackintosh, 1999; Honey et al., 1994; Mondragón and Hall, 2002) and human studies (e.g., Dwyer et al., 2004). However, the learning process responsible for it is still a matter for debate.

One possibility arises from Gibson's (1969) *differentiation* theory of perceptual learning. According to this, exposure to two similar stimuli (e.g., AX and BX) brings into play a *differentiation* process, which enhances the perceptual effectiveness or salience of the unique features of the stimuli (A and B) and decreases that of their common features (X). This sort of change in salience will enhance the perceptual dissimilarity of the stimuli, thus reducing generalization between them (i.e., enhancing their discriminability). Gibson (1969; p. 108) stated that differentiation is aided by situations that allow the opportunity to compare the to-be-discriminated stimuli. From this theoretical framework, it has been suggested that the critical factor in the alternating versus blocked effect might be that some form of comparison, and thus differentiation, will be more likely to occur when AX and BX are presented in alternation rather than in sepa-

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rate blocks of trials (e.g., Mondragón and Hall, 2002; Rodríguez and Alonso, 2004; Symonds and Hall, 1995).

Evidence consistent with this Gibsonian interpretation comes from a study by Mondragón and Hall (2002). They suggested that a simple test for the salience of a stimulus could be to assess the rate at which this is learned about when it is used as a conditioned stimulus (CS) in a conditioning procedure; the conditioned response (CR) will be acquired more readily the more effectively salient the CS. This logic was applied to a series of flavor-aversion experiments with rats. It was found that aversion to A was acquired more readily (indicating enhanced salience) after alternating pre-exposure to AX and BX than after blocked pre-exposure (Mondragón and Hall, 2002; Experiment 4; see also Blair et al., 2004; Experiment 4), and that this difference was reversed (indicating reduced salience) when X was used as the CS (Mondragón and Hall, 2002; Experiment 2). These results lend support to the proposal that alternating pre-exposure enhances the salience of the unique features of the stimuli. But they do not clearly demonstrate that such an effect is a consequence of stimulus comparison. The schedule used for alternating pre-exposure in the experiments just described involved a gap of several hours between successive trials. Comparison, as it is usually understood, would be more likely to occur when two stimuli are presented repeatedly in quick succession. Therefore, a role for comparison would be better demonstrated if it could be shown that enhancement in the salience of unique stimulus features occurs more readily under these (presumably) more favourable conditions. The study to be reported investigated this proposal.

As shown in Table 1, the experimental design involved four groups of rats. Two groups, AX/BX-L and AX/BX-S, received alternating presentations of AX and BX; the interval between these presentations was long (24 h) for group AX/BX-L, and short (5 min) for group AX/BX-S. The pre-exposure arrangements used in these two groups resulted in different temporal distributions of the AX trials (distribution "L" for group AX/BX-L and distribution "S" for group AX/BX-S). In order to explore the possible influence of this factor, two specific control groups were added to the design. These groups, AX-L and AX-S, matched respectively groups AX/BX-L and AX/BX-S in their pre-exposure conditions except that they received presentations of water rather than presentations of BX. Thus, a 2×2 factorial design, with number of pre-exposed stimuli (AX and BX vs. AX) and temporal distribution of AX trials (L vs. S) as factors, was produced. It is clear that stimulus comparison made possible by presenting both AX and BX during pre-exposure (in groups AX/BX-L and AX/BX-S) will not be possible if animals receive only presentations of AX (in groups AX-L and AX-S). The fact that previous experiments have revealed that alternating pre-exposure to a pair of stimuli reduces generalization between them (i.e., produces a perceptual learning effect) in a greater extent than pre-exposure to just one of them (e.g., Honey and Hall, 1989; Symonds and Hall, 1997), is consistent with this notion. In addition, a short interval between alternating presentations of the stimuli (in group AX/BX-S) should result in better opportunity for stimulus comparison to occur than a longer interval (in group AX/BX-L).

In order to assess the effects of these exposure conditions on the salience of the unique stimulus features, all groups subsequently received aversion conditioning trials with A as the CS. Two specific predictions were assessed. First, if comparison enhances the salience of the unique stimulus features then aversion to A should be acquired more readily for subjects pre-exposed to AX and BX than for those pre-exposed only to AX. And second, this effect should be more evident when the temporal interval between the AX and BX presentations is short than when it is longer. That is to say, it was expected that there would be an effect of the temporal distribution of the AX trials in the groups pre-exposed to AX and BX (since for them this factor picks up the two different intervals between the AX and BX presentations), but not in the groups pre-exposed only to AX.

1. Methods

1.1. Subjects and apparatus

The subjects were 32 experimentally naïve Wistar male rats with a mean ad lib weight of 357 g (range 309–412) at the start of the experiment. They were singly housed with continuous access to food in a room with a constant temperature (23 °C), humidity (50%) and a 12:12 h light: dark cycle with the light period beginning at 08:00.

Solutions were administered, in the home cages, at room temperature through 50-ml graduated cylinders. Two different stimuli were employed: AX and BX. For all the subjects AX was a solution of 0.2% (w/v) sugar (A) and 0.015% (w/v) citric acid (X) and BX was a solution of 0.05% (w/v) salt (B) and 0.015% (w/v) citric acid (X). Consumption was measured by weighing to the nearest .01 ml.

Table 1
Experimental design

Group	Pre-exposure	Conditioning	Extinction test
AX/BX-L	AX-W, W-BX, BX-W, W-AX, AX-W, W-BX, BX-W, W-AX	A+	A
AX/BX-S	W-W, AX-BX, W-W, BX-AX, W-W, AX-BX, W-W, BX-AX	A+	A
AX-L	AX-W, W-W, W-W, W-AX, AX-W, W-W, W-W, W-AX	A+	A
AX-S	W-W, AX-W, W-W, W-AX, W-W, AX-W, W-W, W-AX	A+	A

Note: A, B, and X refers to flavors, and W refers to water. During pre-exposure, stimuli separated by a script (-) were presented with an interval of 5 min, and those separated by a comma were presented with an interval of 24 h; + refers to the administration of LiCl.

1.2. Procedure

1.2.1. Water deprivation

The water deprivation regime was initiated by removing the standard water bottles overnight. On each of the following 3 days access to water was restricted to two daily sessions of 30 min, beginning at 11:00 (morning session) and 17:00 (afternoon session). Presentation of fluids continued to be given at these times daily throughout the experiment. The experimental sessions were conducted in the morning session. In the afternoon session all animals received free access to water for 30 min.

1.2.2. Pretraining

All animals received preliminary training during the morning sessions of the next 3 days. Each of these sessions consisted of two 2-min trials, with an interval of 5 min between them. On each trial, rats received access to a tube containing 50 ml of water.

1.2.3. Baseline

During the morning session of the next day, animals received access to a tube containing 50 ml of water for 30 min. Subjects were then randomly assigned to one of the four equal-sized experimental groups: AX/BX-L, AX/BX-S, AX-L, AX-S, being matched on the consumption in this session.

1.2.4. Pre-exposure

Subjects received four presentations of each of the compound stimuli (AX and BX) over the morning sessions of the next 8 days. Each pre-exposure session consisted of two 2-min trials, with an interval of 5 min between the offset of the first trial and the onset of the second. On each trial, rats received access to a tube containing 50 ml of the appropriate fluid: AX, BX or water (W). Specifically, the pre-exposure sequences for each group, described as 8 within-session pairs of trials, are described in Table 1.

1.2.5. Conditioning

After pre-exposure, all animals received two conditioning trials, one every other day, in the morning sessions over the next 4 days. Each trial consisted of a 30-min presentation of 9 ml of A followed immediately by an intraperitoneal injection of lithium chloride (LiCl) 0.3 M at 10 ml/kg of body weight. Each trial was followed by a recovery day on which the animals had free access to water for 30 min in the morning and in the afternoon sessions. After the second recovery day, a non-reinforced test trial was given in which all the subjects were given unrestricted access to A for 30 min in the morning session.

2. Results

Rats consumed about 2 ml of the fluid offered on each trial of pre-exposure. Group mean total consumption of AX over the course of pre-exposure was 2.3, 2.5, 2.8, and 2.4 ml for groups AX/BX-L, AX/BX-S, AX-L, and AX-S, respectively. Group mean total consumption of BX over the course of pre-exposure was 2.0 and 2.7 ml for groups AX/BX-L and AX/BX-S, respectively.

On the first conditioning trial with A, all rats consumed almost all the fluid offered (9 ml). Those in group AX/BX-L drank 8.67 ml, those in group AX/BX-S drank 8.54 ml, those in group AX-L drank 8.61, and those in group AX-S drank 8.52 ml. An analysis of variance (ANOVA) conducted on these data with number of pre-exposed stimuli (AX and BX or AX) and distribution of AX trials (L or S) as variables revealed no significant main effects, nor any interaction between the two (Fs < 1; here and elsewhere a significance level of $p < .05$ was adopted). This suggests that the different pre-exposure conditions resulted in similar consumption levels to flavor A at the start of conditioning.

Next, we analyzed the data that would be affected by conditioning (i.e., consumption of the CS A during the second conditioning trial, and during the final test trial). Fig. 1 shows group means on these trials. It is evident that the conditioning procedure was effective in establishing an aversion to A, as consumption in all four groups declined by the final extinction trial. However, acquisition of this aversion apparently occurred more readily in subjects given pre-exposure to AX and BX (groups AX/BX-L and AX-BX-S) than in those given pre-exposure only to AX (groups AX-L and AX-S). This description was confirmed by an ANOVA conducted on these data, with number of pre-exposed stimuli (AX and BX or AX), distribution of AX trials (L or S) and trial (second conditioning trial and extinction trial) as variables. This revealed a main effect of number of pre-exposed stimuli, $F(1, 28) = 4.95$, and trial, $F(1, 28) = 258.02$. No other effects or interactions were significant (Fs < 1).

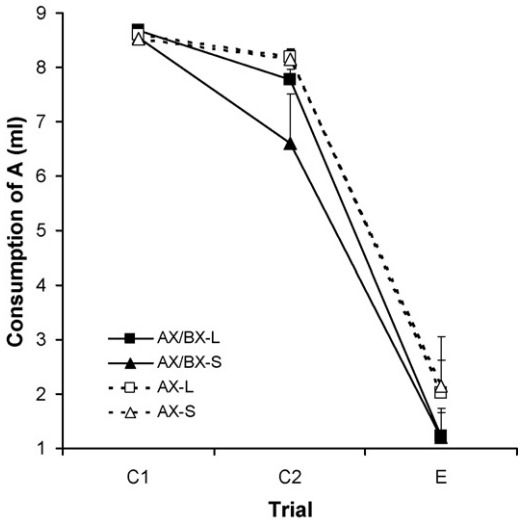

Fig. 1. Group mean consumption of flavor A during the first (C1) and second (C2) conditioning trials, and the later extinction test trial (E). Groups AX/BX-L and AX/BX-S had previously received alternating presentations AX and BX; the interval between these presentations was long (24 h) for group AX/BX-L, and short (5 min) for group AX/BX-S. Groups AX-L and AX-S matched, respectively, groups AX/BX-L and AX/BX-S in their pre-exposure conditions except that they received presentations of water rather than presentations of BX. Vertical bars represent the standard errors of the means (S.E.M.s).

3. Discussion

Acquisition of the aversion to the unique stimulus feature A proceeded more rapidly (i.e., A was learned about more readily, indicating it to be more effective or salient) after alternating pre-exposure to AX and BX than after pre-exposure just to AX. This extends the results found by Mondragón and Hall (2002; Experiment 2; see also Blair et al., 2004; Experiment 4) in a study conceptually similar to this. They also found that an aversion to A was established more readily after alternating pre-exposure to AX and BX, but in this case relative to a control condition in which AX and BX were presented on separate blocks of trials. Thus, the present results add to a growing body of evidence (e.g., Blair and Hall, 2003; Blair et al., 2004; Hall et al., 2006; Mondragón and Hall, 2002; Rodríguez and Alonso, 2004) suggesting that alternating pre-exposure to two similar stimuli (e.g., AX and BX) engages a process that increases (or, at least, preserves) the salience of their distinctive features (e.g., A). But, what is the nature of the process responsible for these changes in stimulus salience? Could this be the differentiation process proposed by Gibson (1969)?

According to Gibson, differentiation (and thus the increase in the effectiveness of the distinctive features of the stimuli) will be related to the degree to which pre-exposure allows comparison to occur. The faster conditioning to A which was observed after alternating presentations of AX and BX in the present experiment could be considered consistent with Gibson's proposal: stimulus comparison would have been possible during pre-exposure to AX and BX (in groups AX/BX-L and AX/BX-S) but not during pre-exposure to only AX (in groups AX-L and AX-S). However, the fact that the rate at which conditioning to A occurred was not affected by the interval between presentations of AX and BX argues against this interpretation. As Gibson (1969, p. 145) assumed, and as it is usually conceived, stimulus comparison will proceed most readily when two stimuli are presented simultaneously or, at least, very close together in time. In our experiment, decreasing the interval between the AX and BX presentations from 24 h (in group AX/BX-L) to 5 min (in group AX/BX-S) did not increase the rate at which conditioning to A occurred. This absence of a difference suggests, as strongly as any null result can, that some of the Gibson's assumptions could be wrong.

The most obvious possibility challenges the core of the Gibson's account: perhaps differentiation is not mediated by stimulus comparison. In line with this idea, Hall (2003) has proposed that changes in stimulus salience would depend on an associative mechanism rather than on a stimulus comparison process. Specifically, according to Hall, direct presentations of a stimulus will reduce its effective salience, but, the associative activation of the central representation of that stimulus, in the absence of the event itself, will restore lost effectiveness. This hypothesis predicts that the salience of A and B will be higher after alternating pre-exposure to AX and BX than after pre-exposure schedules in which just AX is presented or AX and BX are presented in blocks of trials (and so also anticipates the perceptual learning effects found when alternating pre-exposure is compared with these control conditions). During alternating pre-exposure to AX and BX, initially within-compound associations will be formed between A and X and between B and X. Consequently, A will be associatively activated on the BX trials (by way of the X–A association), and B will be associatively activated on the AX trials (by way of the X–B association). This repeated associative activation of A and B will allow these stimulus distinctive features to restore their salience. Such a process will not be possible if just one of the two stimuli (e.g., AX) is presented during pre-exposure (since X is never presented in the absence of A). And will not be so efficient if AX and BX are presented in separate blocks of trials (since X–B associations will not yet have formed during the first block of trials with AX, and X–A associations will not be maintained, due to extinction, during the second block of trials with BX, or vice versa). In addition, and consistent with our findings, an absence of a temporal interval effect is to be expected from this account. Given the standard assumption that associative links tend to be long-lasting, it is not obvious why reducing the interval between the presentations of AX and BX should be more (or less) effective in allowing associative activation of A and B (and thus in restoring their salience). Our results thus seem to be comfortably accommodated by the associative view of differentiation proposed by Hall (2003).

However, a last effort to reconcile the present findings with a comparison account can be still attempted. It could be the case that Gibson was right in characterizing differentiation as a process mediated by stimulus comparison; but wrong in assuming that presentation of the stimuli in close succession provides optimum conditions for stimulus comparison. Intuitively, the comparison process under these conditions can be seen as the result of perceiving one event when the representation of the other is still held in short-term memory. But, as Mondragón and Hall (2002) noted, with longer interval conditions, comparison of another sort could occur. The formation of within-compound associations, previously described, could supply a mechanism by which this might occur. Alternating pre-exposure to AX and BX thus would allow comparison between the directly perceived A element and the associatively activated representation of B (during the AX trials, via the X–B association), and between the directly perceived B and the associatively activated representation of A (during the BX trials, via the X–A association). That is, although mediated by different processes, comparison of some sort (and thus differentiation) would be possible in both short and long interval conditions. What is not clear in this analysis, however, is why long-term comparison should be just as effective as short-term comparison. It seems reasonable to assume that the more degraded the representation of the event being compared (and some degradation would be expected when this representation passes from the short-term to the long term memory) the less effective comparison will be.

Our current conclusion is that the associative view of differentiation (Hall, 2003) seems to offer a more satisfactory explanation for the present and previous results. However, clarification on the mechanisms that allow stimulus comparison seems to be necessary in order to evaluate an account of differentiation based on Gibson's ideas.

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