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Perceptual learning after test-stimulus exposure in humans

Mª del Carmen Sanjuan*, J.B. Nelson

Universidad del País Vasco UPV/EHU, Sarriena, s/n, 48940, Leioa, Bizkaia, Spain

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ABSTRACT

Exposure to a to-be-tested stimulus produces a reduction in generalization to that stimulus from another similar conditioned stimulus (e.g. Bennett et al., 1994; Symonds and Hall, 1997). Generally, this effect has been interpreted as the result of a loss of effectiveness of the common elements of the stimulus to be conditioned (e.g., latent inhibition). However, Sanjuan et al. (2006) questioned this interpretation after finding that exposing rats to either the test stimulus or to its elements had different effects when the amount of exposure to the common elements was equated. Only exposure to the test stimulus reduced generalization. In the study presented here, this effect was assessed in human participants using a videogame method and colors as stimuli. Generalization after exposure to the test stimulus, or to its elements was assessed. Results show that with people, as in rats, pre-exposure to the test stimulus leads to a greater reduction in generalization than to the elements. Therefore, latent inhibition cannot be the only mechanism responsible for this perceptual learning effect. Results are discussed in terms of current associative theories addressing perceptual-learning phenomenon.

1. Introduction

Exposure to two similar stimuli reduces generalization between them (e.g. Honey and Hall, 1989; Symonds and Hall, 1995; Sanjuan et al., 2004), an effect seen as an instance of perceptual learning. It is widely assumed that perceptual learning results from a change in the perception of stimuli caused by, among other conditions, mere exposure. A wide range of studies in this area have analyzed the effect of different schedules of stimulus presentation to determine the optimal conditions to produce the effect. It has been shown, for instance, that a schedule which offers the possibility of comparing the stimuli best promotes perceptual learning. Alternated presentation of two complex stimuli (e.g., AX and BX) reduces generalization more than presentations of the stimuli in separate blocks (Blair and Hall, 2003; Honey et al., 1994; Symonds and Hall, 1995). That observation has been a driving force in research to elucidate the associative and non-associative mechanisms underlying changes in the representation of the stimuli.

However, few studies (e.g. Bennett et al., 1994; Symonds and Hall, 1997). have evaluated the effect of exposure to only the test stimulus (e.g., BX). Such exposure has been shown to reduce generalization over and above conditions that control for the exposure to the elements that comprise the test stimulus. In a study by Sanjuan et al. (2004) repeated exposure to a compound flavor BX reduced generalization of a conditioned aversion to another similar compound, AX, and did so more so than exposure to the elements. This effect is very interesting because the advantage of exposing the compound has not been well anticipated by current associative accounts of perceptual learning.

Associative and non-associative accounts of learning assume that stimuli are formed by unique and common elements. Both accounts share the idea that exposure reduces the effectiveness of those elements. McLaren et al. (1989) propose that exposure to two similar stimuli, AX and BX produces a differential loss of effectiveness between the unique and common elements. In their words, “to the extent that such exposure produces latent inhibition…, it will be more marked for the common elements, X, which occur twice as often as the unique elements, A and B (McLaren et al., p 111). Thus, X becomes less effective at being conditioned, and less effective in promoting generalization. But this mechanism could not be responsible for the difference in generalization observed after intermixed, as opposed to blocked, exposure. X is equally exposed in both schedules.

A second mechanism provides the explanation as to why exposure in alternation has a greater generalization-reducing effect. According to McLaren et al. (1989), every presentation of AX would evoke the representation of element B by way of its association with X. The physical absence of the otherwise predicted B would promote an inhibitory A–B association, and vice versa on BX trials. In the test with BX, the inhibition between A and B would eliminate any source of mediated

* Corresponding author at: Departamento Procesos Psicológicos Básicos y su Desarrollo, Avenida de Tolosa, 70, Universidad del País Vasco, San Sebastián, 20018, Spain.

E-mail addresses: mariadelcarmen.sanjuan@ehu.eus (M.d.C. Sanjuan), JamesByron.Nelson@ehu.eus (J.B. Nelson).

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generalization caused by the memory of a conditioned A being activated via the common element X during the test. There are additional factors at play in this theory that predict that, along with X experiencing a reduction in salience, A and B will also better retain their salience after intermixed exposure, and therefore also enhance discriminability. Nevertheless, as McLaren et al. (2012) describe the process, "The outcome is that X suffers from greater differential latent inhibition (relative to A and B) and the discrimination between AX and BX is more easily acquired" (McLaren et al., 2012;).

There is evidence that shows that these two mechanisms can have a role in perceptual learning, but both have difficulty in accounting for the effects of exposure to only BX. In Sanjuan et al. (2004) study, using a conditioned taste aversion procedure, exposure to BX resulted in a higher reduction in generalization than even exposure to AX and BX in an alternated fashion. In the experiment (Experiment 2), a group of rats received 4 exposures to both AX and BX in alternation while another group received the same amount of exposure to the stimuli in separated blocks. A third group was exposed to BX eight times. In this way, all three groups were matched in the amount of exposure to X. After conditioning AX, the groups were tested with BX. Exposure to BX resulted in less generalization than exposure to both stimuli. A subsequent experiment (Experiment 3) replicated this effect.

When BX is the only stimulus exposed, the mutual A–B inhibition proposed by McLaren and Mackintosh (2000) cannot contribute to any effect, as such inhibition does not have the opportunity to form. Thus, latent inhibition to X would be the main remaining mechanism with which to account for the effect. The procedure used in these experiments should have produced a similar loss in the effectiveness of X between the groups as exposure to X was matched. Not only does exposure to BX remove the conditions under which inhibitory associations between A and B would be formed, the prolonged exposure to BX might lead to particularly strong B–X associations. Thus, a representation of B could be evoked by X during conditioning of AX, allowing the image of B (e.g., Holland, 1981; Ward Robinson and Hall, 1999) to become conditioned. Such an effect would produce even more, not less, apparent generalization.

The independence of the perceptual-learning effect from latent inhibition was further confirmed by Sanjuan et al. (2006). Different groups of rats received eight exposures to BX and another flavor C, exposures to B and CX, or eight exposures to each of B, C, and X. Exposure was followed by conditioning of AX and testing with BX. Exposure to X was equivalent across all groups, yet exposure to BX was more effective in reducing generalization than exposure to B or X separately, regardless of whether X was presented in a compound or not. Thus, it cannot be argued that exposure to BX alters the amount of latent inhibition accrued to X because of X being presented in compound.

In a second experiment, different groups of rats received eight pre-exposure trials consisting of either one exposure to BX and seven to X, four to BX and four to X, or eight exposures to BX, or no pre exposure at all. Following conditioning of AX, testing of BX revealed that generalization varied as a function of the number of BX exposures. Again, as all groups received the same exposure to X, if only latent inhibition were operating there would be no differences in the response to BX. Another interesting finding in this second experiment points to a mechanism other than latent inhibition. Pre-exposure to BX affected the generalization of latent inhibition itself. That is, generalization of latent inhibition appeared susceptible to a perceptual learning process. After one exposure to BX (and 7 to X) or four exposures to BX (and 4 to X), conditioning of AX occurred more slowly than a group receiving no pre exposures. However, after 8 exposures to BX, conditioning of AX proceeded normally. The amount of latent inhibition generalizing from pre-exposure to conditioning varied as a function of exposure to BX. Generalization of latent inhibition is expected to occur on the basis of the X element shared by AX and BX. As BX is exposed, retardation in the conditioning of AX can be expected compared with a condition where X was never exposed before. As exposure to X was equivalent in all conditions, no differences in generalization of latent inhibition were expected. However, the amount of exposure to BX determined both the degree of generalization of latent inhibition and the degree of generalization of conditioning (Sanjuan et al., 2006). These results indicate that some mechanism other than latent inhibition operates in making BX discriminable from other similar stimuli.

A different explanation of perceptual learning comes from Hall (2003). He explains perceptual learning as a result of changes in the effectiveness of the unique features of the stimuli. What differs in his idea is how that effectiveness is modified with experience. According to him, repeated exposure to a stimulus produces habituation that might be observed as a change in the effective salience of the stimulus. After exposure to AX and BX, the unique elements A and B become less effective, and X even more so. The new idea was that if a representation of a stimulus is retrieved in the absence of the stimulus itself, the effectiveness of the actual stimulus will be restored. When AX and BX are pre-exposed in alternation, within-compound associations form between A and X and between B and X so that on every other trial X evokes the representation of an absent stimulus, restoring its effectiveness. From that moment on, the unique A and B elements would be more attended to than the common X elements. Thus, during conditioning A would become more conditioned than X, as would be predicted by McLaren et al., (1989) and, during testing with BX, the neutral B would be considerably more salient than the weakly conditioned X, controlling more of the total response. This mechanism requires that a representation of B be retrieved in its physical absence during pre exposure.

Hall's ideas regarding the restoration of a stimulus' effectiveness cannot explain the results of Sanjuan et al., (2006) described above. The group that received four exposures to BX and four to X is where the effectiveness of B should be best restored. The four pairings of B with X on the BX trials should ensure that these elements are associated so that X can retrieve B on those trials where X is exposed. In any case, the group receiving 8 exposures to BX should be the least effective in restoring the salience of B as there is no opportunity during pre-exposure for B to be retrieved by X. Thus, on test, B would not be more salient than X, and should not contribute to a reduction in responding. As discussed earlier, the eight exposures to BX might produce strong associations between B and X so that B's representation is evoked on AX + trials. Here, the salience of B might be restored, but the result could be reasonably expected to increase generalization rather than decrease it. As mentioned earlier, the presence of B's representation on the AX + conditioning trials should serve to condition B (Ward Robinson and Hall, 1999). Thus, the ideas presented by Hall (2003) cannot readily explain the generalization-reducing effects of exposure to only the test stimulus.

The present experiment was conducted with straightforward goals. It was to determine if the effect of test-stimulus exposure can be extended to humans, which would demonstrate that the prior results were not simply chance "flukes" or idiosyncratic to the methodology employed. The experiment determined, first, whether exposure to BX produces perceptual learning in humans and, second, whether the effect only appear after exposure to BX and not to its elements alone.

The method was that developed by Nelson and Sanjuan (2006). The method has demonstrated an effect that could be considered to be latent inhibition (Nelson and Sanjuan, 2006), a perceptual learning effect (Nelson and Sanjuan, 2009), and that perceptual learning is affected by contextual change (Nelson and Sanjuan, 2008). Thus, it has proven to be an effective tool for studying the issues at hand. Participants play a first-person "space shooter" video game where they earn points by firing torpedoes at a spaceship by clicking a computer mouse on a variable-ratio schedule. On that baseline of responding colored sensors appear at the bottom of the screen that can indicate that the spaceship is about to attack. Participants learn to suppress their own mouse clicking to conserve power to prepare for the effects of the attack.

Table 1
Design of experiment.

Group	Exposures	Exposure type	Conditioning	Test
BX-4	4 trials	BX	AX+	BX
B/X-4		B / X		
None-4		None		
BX-8	8 trials	BX		
B/X-8		B / X		
None-8		None		

Notes: B, A and X refer to different colors (A and B counterbalanced); / indicates separated presentations of the stimuli and + indicates conditioning trials.

Nelson and Sanjuan (2009) showed that exposure to two sensors composed of color compounds, prior to conditioning of one of them, will reduce generalization to the other. The oval sensor was predominately green ("X"), with a small portion of either yellow or blue ("A" or "B", counterbalanced) on its left. Exposure to AX and BX prior to conditioning of AX reduced generalization between them, with alternated pre exposure being more effective than blocked. The experiment presented here used the same stimuli.

The design and the rationale of the experiment were similar to that employed by Sanjuan et al. (2006). The design is shown in Table 1. Each of six groups received conditioning trials where AX was paired with the unconditioned stimulus (US) followed by testing with BX. Groups differed with respect to both the number of exposures and the type of exposure in the first phase. The design was a 2 × 3 factorial combining the length of the pre-exposure phase (4 or 8 trials) with whether there was no pre-exposure, pre-exposure to BX, or pre-exposure to B and X separately, creating Groups None-8, None-4, BX-8, BX-4, and B/X-8 and B/X-4.

On the basis of previous studies with animals (Sanjuan et al., 2004, 2006), we expected that the groups receiving exposure to BX would show a reduction in generalization, with the largest reduction being observed in the case of Group BX-8. Groups B/X-8 and B/X-4 might show some reduction in generalization as a result of the contribution of latent inhibition to X. In any case, the reduction shown by those Groups should not be equivalent to the reduction in Groups BX-8 and BX-4.

2. Materials and methods

2.1. Participants

63 university students volunteered to participate for bonus course credit. Credit could also be obtained through non-research activities, thus participation was voluntary. Participants were assigned to groups randomly with no attempt to equalize group sizes.

2.2. Apparatus

The method used in this experiment was a conditioned-suppression task implemented in a video game design to explicitly parallel conditioned suppression (e.g. Estes and Skinner, 1941) tasks in rats. The method has been proven to be effective tool to observe conditioning robustly and reliably. The video game has been described previously in Nelson and Sanjuan (2006; 2008), from which the description used here was adapted (with permission). Instructions informed the participants that they were playing a game where clicking a mouse earned points by shooting torpedoes at a spaceship. They were informed that they would be attacked and that attacks would drain their power, leaving them unable to continue until recharged. Participants were informed that attacks could not be avoided, but that they could prepare for attacks by suppressing their rate of torpedo firing (conserving power, resulting in less drain) when they were about to be attacked, which would prevent them from being offline for long periods of time. They were told that sensors would appear that might help them in the game, but were told neither what the sensors would indicate nor how they could be helpful. The exact instructions were those reported in detail in Nelson and Sanjuan (2006).

The video game was viewed on a standard 15-inch computer monitor where an image was presented as if the participant was sitting inside of a spaceship looking out of a viewscreen (images available in Nelson and Sanjuan, 2006; 2008). A box appeared at the top of the screen where the word "Points" appeared in yellow. At the bottom of the screen five black ovals were continually present that were each 3.28 cm in diameter. The third was centered from left to right and the other four ovals were spaced at intervals of approximately 2 cm to the left and right of the center oval. A colored background could be seen through the viewscreen on which a 3-dimensional representation of a spaceship was flying in a randomly determined path.

All conditioned stimuli (those pre-exposed, conditioned, and/or tested) were the 5-s illumination of the middle oval. During these illuminations, the oval appeared predominately one color, with a small section of the *left edge* appearing as a different color (see Nelson and Sanjuan, 2008, p 280). Stimuli were composed of the elements X, A, and B. X was the illumination of 97% of the oval from the right to the left with the color green. Elements A and B were created by illuminating the remaining 3% of the oval on the left-most side with either blue or yellow. Blue and yellow were counterbalanced as A and B. AX and BX were presented by illuminating the portions corresponding to A or B and X. When A, B or X were presented alone, the other portion of the oval remained black. When not lit, the oval remained black.

The "unconditioned stimulus" was an inescapable attack from the enemy spacecraft. On the offset of a sensor stimulus, the attack consisted of the emergence of a small, round, green "torpedo" from the rear of the spaceship that moved to the center of the screen where it grew larger until it exploded. The length of the sequence varied depending on the position of the spaceship on the screen, with the sequence being longer as the distance of the spaceship from the center increased. Nevertheless, the entire sequence was between 1 and 1.5 s regardless of the spaceship´s position.

Concurrent with the explosion, the message "Power at___ percent. Controls Frozen for ___ seconds" appeared in the center of the viewscreen and remained until "Power" incremented to 100 and "Controls Frozen for……" decremented to zero (changes occurring roughly every second). During this time, the computer mouse was inoperable and actions of the participant were not reflected on the screen. The numbers in the blanks above were determined by a modified suppression ratio (CS responses/(Average pre-CS responses + CS responses)). Average Pre-CS responses were simply the number of times the participant clicked the mouse in the five seconds immediately preceding the CS, averaged across all previous trials (including the current trial). The resulting ratio was then multiplied by 120. For example, if a participant clicked the mouse, on average, 10 times prior to the sensor CS and did not suppress their rate of mouse clicking, the ratio would calculate to 0.5 and their controls would be frozen for 60 s by an attack. If they did suppress, then the ratio would calculate closer to zero and their controls would be frozen for less time, allowing them to resume the game more quickly. Participants were not informed of that relationship.

2.3. Procedure

Participants were assigned to conditions randomly. The experiment was conducted in a computer classroom that could accommodate up to 15 participants at once. The participants were instructed not to talk among themselves or to try to look at the others' screens. They were seated at the computers, read and signed a consent form, and were given the instructions. They first read the instructions to themselves. When finished, the attending researcher read the instructions aloud to them. Participants were instructed to place their left hand on the "s" key and their right hand on the mouse. Then, they were instructed to press the "s" key, starting the game. All participants played the game

for 60 s with no stimulus presentations occurring. During that time as well as throughout the game, they clicked the mouse on a variable ratio schedule where a random one in three clicks launched a torpedo at the spaceship flying on the screen. A random half of those torpedoes exploded on the enemy spacecraft, adding a point to the point counter. The spacecraft was never destroyed to maintain continuity across the game. Following the first 60 s of gameplay pre-exposure started.

2.3.1. Pre-Exposure

When presented, the sensors were displayed for 5 s. Participants in the None-8 and None-4 conditions simply played the game without stimulus presentation during the same time periods as where stimuli were presented in the other groups. For Groups BX-8 and BX-4 pre-exposure consisted of 8 or 4 exposures to BX respectively, with an inter-trial interval of 23 s. For Groups B/X-8 and B/X-4, pre-exposure consisted of 16 or 8 alternating trials of exposure to B and X. The inter-trial interval averaged 11 s.

2.3.2. Conditioning

Conditioning consisted of 10 presentations of the stimulus AX with each followed by an attack US. The variable inter-trial interval averaged 11.2 s. The first conditioning trial began 11 s after the last pre-exposure trial.

2.3.3. Test

Stimulus BX was presented 4 times without attack. The first trial occurred 12 s after the last conditioning trial with AX. The inter-trial interval averaged 11 s.

3. Data analysis

The computer recorded the number of times that the participant clicked the mouse during the 5 s of presentation of the CS and during the 5 s preceding the CS. Standard suppression ratios, CS/(CS + pre-CS) were calculated. We adopted the procedure of Nelson and Sanjuan (2006) of excluding participants with an average response rate less than one click per second. Responding so slowly produces very coarse measures of suppression, and this criterion eliminated participants who were not responding prior to some trials where calculation of a suppression ratio would be impossible. Participants for whom suppression ratios on either trial nine or ten of conditioning to AX were 0.4 or higher were also excluded. A ratio of 0.5 indicates no conditioning. The test was conducted to observe the degree of generalization of the conditioned response from AX, and thus, the choice of a ratio of less than 0.4 provided some room for the observation of changes in the response. Though we applied the criteria to be consistent with our previous procedures, no participants were excluded based on these criteria.

Suppression ratio data were analyzed with mixed (within/between) factorial analysis of variance (ANOVA). Simple effects were conducted using error terms appropriately pooled from the overall analysis (Howell, 2009). Results where $p < 0.05$ were considered meaningful and exact probabilities are reported.

4. Results

In the groups receiving 8 pre-exposure trials, random assignment placed 14,10, and 11 participants in to groups BX, B/X, and None, respectively. In the groups receiving 4 pre-exposure trials, random assignment placed 9, 8, and 11 into groups BX, B/X, and None, respectively. The distribution did not differ from chance, $X^2(2) < 1$, $p = .76$.

Data from conditioning of AX were analyzed with an Exposure Type (BX, B/X or None) x Exposure (4 or 8) x Trials ANOVA. Despite that pre-exposure might produce some generalization of latent inhibition and cause some retardation of conditioning in the BX and B/X groups, there was no such effect. The analysis revealed only an effect of Trials $F(9, 513) = 15.31$, $p = 3.46 \times 10^{-22}$, and no other effects, $Fs \leq 1.65$, $ps \geq 0.1$. All groups acquired suppression to AX, and acquired it an equal rate. The data, collapsed across the insignificant Exposure variable, are presented in the left side of Fig. 1.

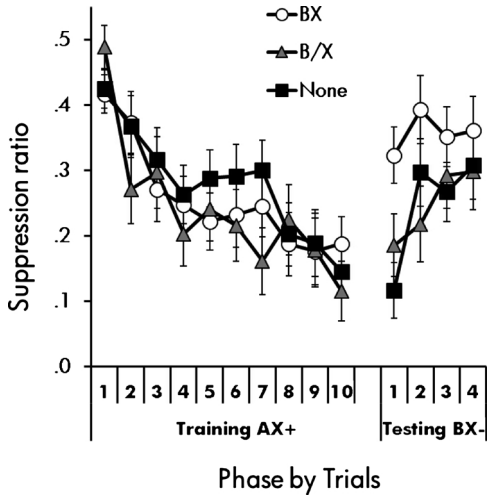

Fig. 1. Mean suppression ratio during conditioning with AX and test with BX in groups pre exposed to BX, B and X separately (B/X), or receiving no pre exposure (None), collapsed over the number of pre exposures (see text for details).

An Exposure Type x Exposure x Trials ANOVA of the four test trials revealed an effect of Trials, $F(3,171) = 9.85$, $p = 7.21 \times 10^{-.09}$ and an interaction between Exposure Type and Trials, $F(6,171) = 2.45$, $p = 0.02$. There were no other effects, $ps \geq 0.12$. As there were no effects of, or involving Exposure, we collapsed over that variable for analysis of the Exposure Type x Trials interaction. The data are shown at right in Fig. 1.

It is apparent from the figure, that Group BX showed less suppression than the B/X and None conditions, with that difference disappearing as extinction occurred. Simple-effect tests revealed that Group BX showed less suppression than Group None on Trial 1, $F(1,95) = 6.02$, $p = 0.016$. Group BX also tended to show less suppression than Group B/X on the first Trial, $F(1,95) = 3.74$, $p = 0.056$, and showed reliably less suppression on the second trial, $F(1,95) = 9.37$, $p = 0.003$. Groups B/X and None never differed, $Fs \leq 1.2$, $ps \geq 0.28$. In the comparisons between Groups B/X (n = 18) and None (n = 22), the odds supported the null on every comparison from weak (3.39/1, trial 2) to positive (6.25/1, trial 4) using the calculations and interpretations described by Wagenmakers (2007).

5. Discussion

In the present experiment, human participants played a videogame task in which a stimulus, AX, was conditioned and generalization of the response to a similar stimulus, BX, was measured. Substantial generalization was observed in the absence of any previous exposure to BX. Exposure to the elements B and X had no detectable effect on generalization. However, exposure to the test stimulus itself, BX reduced generalization, and did so over and above any effect exposure to B and X might have produced. The experiment provides a clear demonstration that the effect of exposure to BX in reducing generalization, found in previous studies with animals (Sanjuan et al., 2004, 2006), can also be found in humans. We are unaware of any similar demonstration of this perceptual learning effect in humans.

Exposure to BX should produce latent inhibition of the elements B and X, resulting in poor conditioning of the element X during conditioning of AX and thus, poor generalization to BX. In that way, a weaker response to BX, relative to a group that received no exposure, is predicted by any model that proposes that the effectiveness of X is reduced during its exposure (e.g., McLaren et al., 1989; McLaren et al.,

2012; McLaren and Mackintosh, 2000). It seems plausible then, that latent inhibition might be enough to explain the effect, but the same prediction is made when B and X are exposed alone. Latent inhibition should accrue to X. In this condition, there is no possible source of mediated conditioning of B, as B and X were never presented together. Based on that analysis, this type of exposure, if anything, should result in less generalization than exposure to BX, yet exposure to B and X alone was ineffective in measurably reducing generalization.

The discussion of our B/X control condition above seems plausible at face value, but there are other possibilities that arise when mechanisms assumed to produce the latent inhibition itself are considered. The model of McLaren et al., (1989), its subsequent revisions (McLaren and Mackintosh, 2000), and extensions (McLaren et al., 2012) essentially combine ideas from stimulus sampling theory with mechanisms proposed by Wagner (1981). Any stimulus (e.g., B) is composed of many elements (e.g., b1, b2, b3…) that can become associated with each other by way of a Rescorla and Wagner (1972) type delta rule. Furthermore, as Wagner (1981) proposed, when a stimulus is already predicted by another, its presence becomes less effective in becoming associated with other stimuli. McLaren and Mackintosh (2000) elaborated on this idea by directly assuming that it is the salience of stimuli that is modulated by whether or not they are predicted by other stimuli, with predicted stimuli being less salient.

As stimuli are exposed, their individual components become associated with each other, a process referred to as "unitization" (McLaren et al., 1989), reducing the individual salience of the stimulus components and reducing the overall salience of the stimulus. That process results in latent inhibition. First, we will consider the control group that received exposure to B and X in isolation. Although these stimuli occur in compound with a group of background contextual stimuli, those latter stimuli are constantly present in the inter-trial intervals. Thus, they should be well unitized and have difficulty entering into associations with the CSs when presented. Moreover, any associations established with the CSs on a trial should suffer extinction in the following inter-trial interval. Therefore, when B and X are presented separately, their components (e.g., b1, b2, b3…/ x1, x2, x3…) should become easily associated with each other (i.e., b1↔b2↔b3; x1↔x2↔x3). Thus, the individual B and X stimuli would be well-unitized and of reduced salience. When AX is conditioned, X will be conditioned very little, allowing A to absorb the majority of the associative strength. On test with BX, B, which is also well unitized, will be of low salience and interfere little with X. A reduction in generalization would be expected in the B/X control condition simply because X should have received little conditioning due to its unitization-based low salience.

No such result was observed in the group exposed to B and X in isolation, though overall support for the null was weak at best. However, the critical result is that any reduction in generalization which may have occurred in that condition was less than in the group that received exposure to BX. Exposure to BX was more effective in reducing generalization. That result appears difficult for the ideas presented in McLaren et al., (1989) and McLaren and Mackintosh (2000) to account for fully. Exposure to BX should result in unitization of X, but less so than exposure to X alone in the control group. That is because some elements of B will become associated with some elements of X, blocking other elements of X from being associated with those predicted by B. In short, B will partially block unitization of X, and X will partially block unitization of B. As a result, X and B will be more salient when presented outside the BX compound than in the control group. Thus, on AX + trials X will absorb more associative strength than X in the control group, which should promote *more* generalization to BX. B is also predicted to be more salient than in the control group, which could distract from the responding to X on the BX test more so than in the control group. Thus, we are left with a potential stalemate between processes unless there are reasons to assume that the maintained salience of stimulus B contributed more to distraction, reducing generalization, than the maintained salience of X contributed to X's conditioning, promoting generalization. Another possibility is that when B is present with X again, those elements of B that remained associated with elements of X activate those elements and reduce their salience, affecting the ability of X to control a response. However, it is unclear why that reduction should be more effective in the presence of the associated B elements than that produced by the unitization of X itself in the B/X control condition.

Artigas and Prados (2014) suggested that a block of exposure with a single compound results in the compound being treated as a configural stimulus. That treatment was assumed to come as the result of strong associations formed between the elements B and X. However, such strong associations should also facilitate mediated generalization as discussed earlier, with the result that exposure to BX would enhance generalization. If, however, the configural cue is conceived of more as a unique cue that arises from the joint combination of events (e.g. Wagner and Rescorla, 1972; Wagner, 2003), or the strong activation of peripheral cues (McLaren and Mackintosh, 2002), then the results of the present experiment would be expected (see also Rodriguez and Alonso, 2011). Exposure to BX would result in BX begin treated as a new cue, "C" which does not support generalization from the elements that constitute it. What remains to be specified is the mechanism by which pre-exposure would facilitate the processing of compounds as unique cues rather than collections of elements. Simply establishing associations between the elements, without further elaboration, would not be sufficient.

An additional possibility is that our effect is a demonstration of retrospective re-evaluation. Although this explanation might encounter difficulty in accounting for our findings with animals (e.g., Miller and Matute, 1996) it could easily apply to our work with humans. Retrospective revaluation is the phenomenon observed when the associative status of a cue appears to change as a result of the acquisition of further information with an associated cue (e.g., Chapman, 1991). For instance, when a compound AX is conditioned, reinforcement of A or of X can cause humans to revaluate the efficacy of the other element of the compound as a cause of conditioning. That is, following AX + trials, subsequent trials with A + or X + lead to a decrease in responding to the other element. Despite that under similar conditions the opposite effect, mediated conditioning, seems likely to occur in animals (e.g. Balleine et al., 2005; Best et al., 1985; Holland and Ross, 1981) humans often show signs of retrospective revaluation of the causal value of the stimuli.

In principle, presentation of X in AX during conditioning could have resulted in the retrospective revaluation of B in the group for which BX was pre-exposed. This interpretation is favored by the results of Balleine et al. (2005) who have shown that perceptual learning manipulations themselves (intermixed exposure) can facilitate retrospective revaluation effects. According to Dickinson and Burke (1996), conditioning of AX would result in a representation of B being paired with the US. Because the representation of B would be in a different state ("A2″, Wagner, 1981) than the US, which would be in "A1″, inhibition should form between B and the outcome. As B began as a neutral stimulus, it could become somewhat inhibitory for the outcome, suppressing performance on the test with BX.

An interpretation of the result as retrospective re-valuation might be expected based as well on the mechanisms presented in McLaren et al. (2012). That model processes input using the mechanisms that originated with McLaren et al., (1989) and then passes the output of that process to a separate system, the APECS model, developed by McLaren (1993; as discussed in McLaren et al., 2012). The APECS model has been shown to account for un-overshadowing effects, where after AB + training further training with B- increases the response to A (Le Pelley and McLaren, 2001). However, it is unclear whether the model would allow a neutral stimulus from a compound to become inhibitory with continued training of the other element, which would be required to explain the present findings. When BX is presented the stimuli feed their activation forward to a layer of "hidden units" which, in turn,

propagate to a "US" unit. Because the US is not present, the hidden units recruited by BX will acquire a negative bias, that is, a bias to be off. Following subsequent training with X (in AX) there will be some activation of the units recruited by BX and those recruited by AX. The final status of BX will be a tradeoff between the extent to which those hidden units' activation is offset the negative bias accrued during exposure.

A similar explanation, in terms of B becoming somewhat inhibitory, comes from the model of Hall and Rodriguez (2010). They explain latent inhibition, partly, as the acquisition of an association between a CS and "no event." The assumption is that organisms have an unconditioned tendency to expect that an unspecific "event" will follow when stimuli are presented. When no consequence occurs, an association is then formed with a representation of "No event." During preexposure to BX, a strong expectation of some event will be elicited. That expectation, in the face of multiple evoking stimuli, is expected to be greater than that produced by fewer stimuli. Each stimulus, B and X, is assumed to evoke an expectation of an event, with those expectations simply summing together when BX is presented. As a result of that strong expectation, which is not confirmed, B and X will each acquire a very strong "No event" association. Thus, B and X will have stronger associations with "No event" following compound presentations than after separate exposures. During AX + trials X will acquire little functional associative strength. On test with BX, that associative strength would be more strongly countered the B→No Event association acquired during exposure to BX than that acquired during exposure to B and X separately.

Exposure to a stimulus compound reduces generalization to that compound from other stimuli, and does so more than exposure to the elements that constitute the compound. The experiments here were modeled to parallel animal procedures where stimuli are pre-exposed, conditioned, and then generalization tested as a function of whether the test stimulus will elicit the same response. It remains to be seen whether this effect will emerge in other methods used to study perceptual learning effects in humans (e.g., Lavis and Mitchell, 2006). There, stimuli used are considerably more complex and generalization is assessed by the participants accuracy in reporting whether presented stimuli are the same or different. Nevertheless, such study is warranted. As illustrated throughout this discussion, the effect is not so readily accommodated by current theories, though a variety of possibilities exist.

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