Behavioural Processes 91 (2012) 244–252

Contents lists available at SciVerse ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Human perceptual learning: The effect of pre-exposure schedule depends on task demands

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ARTICLE INFO

Article history:
Received 22 April 2012
Received in revised form 5 September 2012
Accepted 18 September 2012

Keywords:
Attention
Differentiation
Perceptual learning
Stimulus pre-exposure

ABSTRACT

The effects of the pre-exposure schedule (concurrent, intermixed, and blocked) to two similar visual stimuli were assessed in three different tasks. Participants were more accurate identifying one of two pre-exposed stimuli as the target by means of same/different judgments after concurrent than intermixed or blocked pre-exposures. Regardless of pre-exposure schedule, participants were accurate in identifying the same target stimulus in a subsequent multiple choice task. However, the other pre-exposed stimulus was incorrectly chosen as the target in a greater proportion after blocked than intermixed or concurrent pre-exposure. Finally, participants who received the blocked schedule showed a greater ability to construct the target in a puzzle test than those who received a concurrent or intermixed schedule. These results suggest that the effect of pre-exposure schedule may depend on task-specific demands. But all these results might be explained by a selective attention mechanism like that proposed by Gibson (1969) to account for perceptual learning.

1. Introduction

It is well known that simple non-reinforced pre-exposure to similar stimuli enhances discrimination between them (i.e., a perceptual learning effect, see, e.g., Hall, 2001, for a review). According to the first non-associative account of this kind of learning (Gibson, 1969), repeated experience with stimuli leads to the detection of properties, patterns, and distinctive features not previously perceived, with the result that "perceptions become more specific with respect to physic stimulation, that is, in greater correspondence with it" (Gibson, 1969, p. 77). Unfortunately, the mechanism/s potentially involved in this progressive increment of correspondence between final perception and physical stimulation sources were not fully described in the Gibsonian account of perceptual learning. But she specified the pre-exposure conditions in which stimulus differentiation could be enhanced: those that offer a good opportunity for stimulus comparison. According to this account, stimulus comparison would promote a selective process by which attention would be increased to distinctive features of the stimuli and reduced to the common features, facilitating their differentiation.

The role of stimulus comparison in perceptual learning has been addressed mainly by the manipulation of the pre-exposure schedule, and it was found that the magnitude of the pre-exposure effect on stimulus differentiation depends on the specific way in which stimuli are presented. Specifically, intermixed pre-exposure (i.e., AX, BX, AX, BX, ...) increases differentiation, or reduces generalization, between similar stimuli to a greater extent than equivalent exposure in separate blocks (i.e., AX, AX, ..., BX, BX, ...) both in human (e.g., Dwyer et al., 2011; Lavis and Mitchell, 2006; Mitchell et al., 2008a, 2008b; Nelson and Sanjuán, 2009) and non-human animals (e.g., Blair and Hall, 2003; Honey et al., 1994; Rodríguez and Alonso, 2004; Symonds and Hall, 1995). Stimulus comparison should be facilitated to a greater extent when stimuli are experienced in the intermixed fashion rather than in separate blocks. Thus, such a differential effect of pre-exposure schedule (usually referred as "*intermixed-blocked effect*") is entirely consistent with the Gibsonian perceptual learning account.

Gibson (1969) noted that the opportunity for stimulus comparison should be even greater if stimuli were repeatedly presented as close in time and space as possible, that is, simultaneously (AX–BX, AX–BX, ...) and thus, stimulus differentiation should be also enhanced to a greater extent. This prediction has been recently confirmed in two studies conducted with humans. Both found evidence of better stimulus differentiation between similar visual stimuli after simultaneous than either intermixed or blocked pre-exposure (Mundy et al., 2007, 2009). But in contrast to the findings of Mundy et al. (2007, 2009), studies with non-human animals and conditioning preparations have consistently reported greater generalization between similar stimuli when the interval between their intermixed presentations is shortened (Bennet and Mackintosh, 1999; Honey and Bateson, 1996) or reduced

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0376-6357/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.beproc.2012.09.003

nominally to zero by presenting them concurrently (Alonso and Hall, 1999; Rodríguez and Alonso, 2008; Rodríguez et al., 2008). These latter results with animals clearly conflict with the Gibsonian non-associative theoretical approach. But the results of Mundy et al. (2007, 2009) are, on the other hand, critical for associative theoretical formulations (Hall, 2003; McLaren et al., 1989; McLaren and Mackintosh, 2000, 2002). These theories have competed with the Gibsonian account to explain the "intermixed-blocked effect" but presently, they are insufficient to explain why the human ability to differentiate similar stimuli could be greater after concurrent than intermixed or blocked stimulus presentations. Associative approaches assume that the benefit of intermixed over blocked pre-exposure occurs because the former schedule facilitates associative activation of distinctive features of the stimuli when they are physically absent. This activation will lead to preserving the salience of distinctive features according to Hall, and to develop inhibitory links between them according to McLaren et al. During concurrent pre-exposure, associative activation of the stimuli in their physical absence cannot occur as the stimuli are always physically present, and no contribution of mechanisms based on that activation would be expected. Thus, discrepancies between findings reported in human and non-human animal studies concerning concurrent pre-exposure challenge both associative and non-associative approaches to perceptual learning. It seems reasonable to suppose that the current theoretical deadlock might be overcome if the causes of such discrepancies were uncovered.

To that effect, some procedural details of tasks employed to assess stimulus differentiation in human and non-human animals are being analysed. For example, because tasks employed with non-human animals involve conditioning preparations and generalization measures as differentiation indexes, but human studies usually do not (but see, e.g., Dwyer et al., 2004), the role of several associative phenomenon in the generalization process has been discussed (see, e.g., Lavis and Mitchell, 2006). In this regard it was suggested that the extent of generalization between similar stimuli could be increased after their concurrent pre-exposure by several associative factors (i.e., the establishment of excitatory links between stimuli, or the reduced latent inhibition of their common elements), albeit greater generalization does not necessarily mean the stimuli were less discriminable (see, Mundy et al., 2007, Experiment 5; Rodríguez and Alonso, 2008; Rodríguez et al., 2008). It follows that generalization measures should be interpreted with care if they are used to assess stimulus differentiation.

From human studies, the role of the specific demands of the task used to asses stimulus differentiation is also being analysed. Task demands are outlined to the participants directly by the instructions and, as several authors have argued, instructions could affect how the stimuli are processed in several ways (see the special section of *Learning & Behavior*, 2009, vol. 37, no. 2, for several analyses of this issue). For example, certain instructions could activate top-down attentional processes not activated in their absence (Tsusima and Watanabe, 2009), whereas other instructions could lead to the instrumental conditioning of an attentional response that does not occur otherwise (Mackintosh, 2009).

To date, the effect of concurrent pre-exposure has been tested in humans only by explicit discrimination procedures, with feedback, in which participants are required to assign pre-exposed stimuli to two different categories (Mundy et al., 2007, 2009). Thus, investigating the effect of pre-exposure schedules using different stimuli and procedures could contribute to a better understanding of perceptual learning, extending the generality of some effects. The principal aim of the present study was to address precisely this issue. Thus, the effect of simultaneous-concurrent, simultaneous-blocked, successive-intermixed and successive-blocked pre-exposure was assessed in three different tasks.

As Lavis and Mitchell (2006) have noted, the simplest way in which stimulus discriminability could be assessed, limiting the impact of associative factors on generalization, would be asking to participants directly whether pre-exposed stimuli are the same or different. Following this suggestion, participants were required to judge two visual stimuli as same or different during pre-exposure. In this stage of the experiment, the pre-exposure schedule received determines the correct response, which was always different for simultaneous-concurrent and successive-intermixed pre-exposure conditions, and always same for the simultaneous-blocked and successive-blocked conditions (see pre-exposure procedure below). Clearly, performance during the pre-exposure phase could not be suitably compared for all experimental conditions. So, after pre-exposure, the proportion of both kinds of correct responses was equated in a target identification task similar to that employed in the pioneering study of Gibson and Gibson (1955). One of the pre-exposed stimuli was designated as the target and participants were required to judge whether a set of subsequent stimuli (the target and the other pre-exposed stimulus) presented individually and successively, were the same or different from the target stimulus. To the best of our knowledge, same-different tasks have not yet been used to assess the effect of concurrent pre-exposure, and in those employed before to assess the "*intermixed-blocked effect*" (i.e., Lavis and Mitchell, 2006), the stimuli to be judged as same or different were always presented consecutively and close in time. In such cases, the detection of differences between the stimuli is sufficient to produce accurate performance on the task. So, the possibility that a good performance could be guided by a transitory sensorial contrast effect, instead of a longer-lasting improvement in stimulus differentiation, could not be ruled out. On the target identification task used here, however, same-different judgments are made in relation to an absent stimulus by retrieving its memory. Thus, it seems unlikely that a good performance on the task could be based on a sensorial contrast effect. In addition, because the target identification task was separated in time from the pre-exposure phase, the effects that will be expected to transfer to it could be interpreted as long term effects more easily than in previous procedures. Finally, another potential benefit of this task compared to procedures used previously (Dwyer et al., 2004; Mundy et al., 2009) is that neither conditioning nor feedback was ever provided and therefore associative factors potentially related with feedback could be excluded.

It should be noted, however, that if "target identity" was acquired by the establishment of an associative link between the stimulus representation and the name "target", one could also expect some generalization of this learning. Generalization between pre-exposed stimuli could be boosted by the dichotomous nature of the response (same/different) and in addition, some previous unpublished experiments conducted in our laboratory indicate that the task could be affected by a bias to judge the stimuli as the same (see also Lavis and Mitchell, 2006). Therefore, in a subsequent task, participants were required to identify the same target stimulus by selecting it from among five similar ones in a multiple-choice task. This task allowed us to test the ability of participants to recognize the target while differentiating it from similar distractors, controlling for a potential response bias.

Finally, participants were required to construct the target stimulus in a puzzle task. This task was conceived as a possible way to test how well the target stimulus could be retrieved in memory after target identification tasks. But it also allowed us to check whether the pre-exposure schedule affected stimulus encoding, addressing a potential incongruence in the Gibsonian theoretical approach. Recent reformulations of Gibson's account (e.g., Mitchell et al., 2008a, 2008b) have argued that increased attention to the unique features of similar stimuli would be related to a better processing and encoding of these in the internal representation of the stimulus. The same logic should be applicable to the common elements and thus, reduced attention to these will result in a poorer encoding of the elements that, in fact, constitute the majority of the overall stimulus (at least when the compared stimuli are similar). If the opportunity for comparison promotes an attentional shift as that described by Gibson (1969), and differential processing and encoding of distinctive and common elements would be expected on the basis of that, then the final memory of the stimulus should be represented mainly by the unique elements, that is, by the smaller portion of the overall stimulus, when the opportunity for comparison is facilitated. One can hardly assume that an internal stimulus representation like this will correspond more closely with the physical stimulus than another in which all elements of the stimulus are equally represented. To the extent that the final perception of the stimulus depends on its internal representation, paradoxically for the Gibsonian account, the opportunity for stimulus comparison (which should increase stimulus differentiation) will reduce the correspondence between physical stimuli and their perception.

If this is true, the opportunity to compare the stimuli during pre-exposure could enhance stimulus differentiation, improving performance on tasks that require responding to distinctive features of similar stimuli. That is, in tasks in which participants must identify a specific stimulus and differentiates it from similar ones (here, the target identification task and multiple choice task). But at the same time, the opportunity for comparison may hinder performance on tasks requiring an accurate knowledge of the stimulus as a whole. An example of this could be a puzzle reconstruction task.

2. Method

2.1. Participants

Forty-eight native Spanish (non-Arabic speaking) undergraduate students (age 17–30 years) from the Psychology Centre at the University of the Basque Country participated voluntarily in the experiment in exchange for course credit. They were predominantly women (ratio 10:1). All participants had normal or corrected vision, were naïve to the exact problem being investigated in the study, and gave their informed consent to participate in the experiment.

2.2. Stimuli and apparatus

Six nonsense compounds of 5 Arabic characters were employed as stimuli. Only one character was different in each compound, with the other four being common to all the stimuli (see Fig. 1). In addition, 20 individual Arabic characters were employed in the final puzzle test (see Fig. 2). Stimuli were presented on a computer monitor of a DELL-compatible PC, appearing in black colour over a white background with a Times New Roman letter format and font size 88 from Microsoft Word. On-screen dimensions of the compounds were 3 cm × 9.3 cm ($h \times w$). A personal computer was available for each participant, who was seated approximately 60 cm from the monitor. Instructions were displayed on the screen and responses were recorded in a written form for all phases except the puzzle task, in which final stimulus reconstruction was recorded in a PowerPoint file in the computer for subsequent individual and group analyses.

2.3. Procedure

The experiment was run in a single, approximately 40-min session, divided into four stages: pre-exposure, target identification task, multiple choice task, and puzzle task. These stages were run in the same order for all participants with a 2 min rest period between each stage. Participants were assigned randomly to one of the four

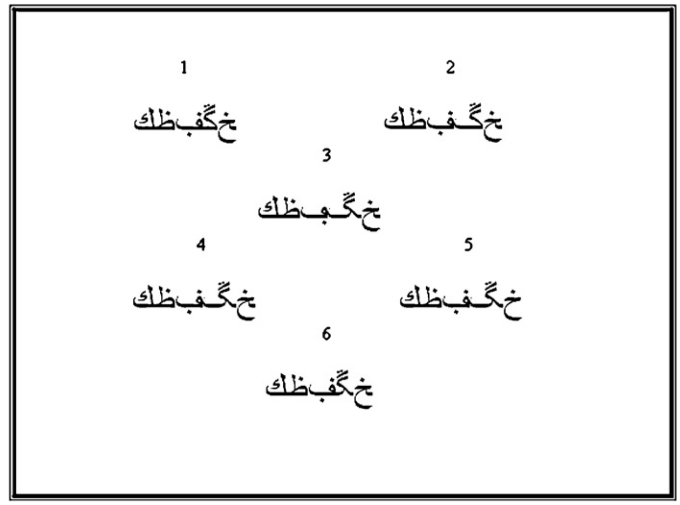

Fig. 1. Example of stimuli employed in multiple choice task trials. Pre-exposed stimuli were those numbered as 2 and 4.

equal-size ($n = 12$) groups, simultaneous-concurrent (SIM-CNC), simultaneous-blocked (SIM-BLK), successive-intermixed (SUC-INT), and successive-blocked (SUC-BLK), that only differed in the pre-exposure schedule received during the first stage.

2.3.1. Phase 1: pre-exposure

All participants received 30 pre-exposure trials with the two similar Arabic character compounds labelled stimuli 2 and 4 in Fig. 1. In each trial, two stimuli were presented, side by side on the screen in a simultaneous fashion (at the same time during 5 s) for half the participants (SIM-condition), and individually in the centre of the screen in a successive fashion (one stimulus during 5 s followed by the other also during 5 s, 3 s apart) for the other half (SUC-condition). Thus, each stimulus was presented 30 times total, with an inter-trial interval (ITI) also of 3 s for all experimental conditions. Participants judged whether the stimuli presented in each trial were the same or different, with the stimuli being always different for half of the participants of the previous conditions (groups SIM-CNC and SUC-INT), and always the same for the other half (groups SIM-BLK and SUC-BLK). Thus, in BLK condition, one stimulus was presented twice during the 15 first trials, and the other in the remaining trials, with the order of stimulus presentation counterbalanced in each group. Order of stimulus presentation was

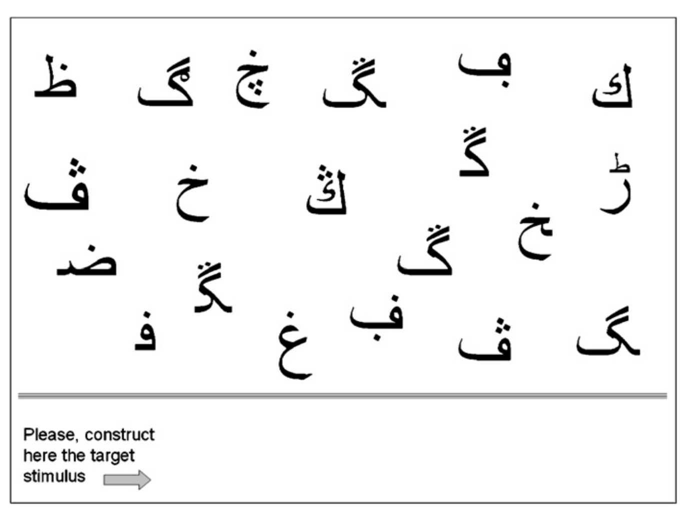

Fig. 2. Screen used on the "puzzle" test.

counterbalanced also for group SUC-INT, while for group SIM-CNC stimulus position (left–right) on the screen was counterbalanced. No feedback about the correctness of responses was provided during pre-exposure trials. Explicit instructions given to participants before the pre-exposure stage started were the following:

> "Next, visual stimuli will appear on the screen. They will be presented in pairs and you should indicate whether those stimuli are the same or different".

2.3.2. Phase 2: target identification task

This task began with the presentation of a white screen with the word "target" in the centre during 3 s, indicating the next target onset. The target stimulus was one of the two pre-exposed Arabic character compounds (counterbalanced in each group) presented during 5 s. Then, all participants received a set of 20 trials consisting of a single stimulus presentation for 5 s in the centre of the screen with an ITI of 3 s. This stimulus was the target on half of the trials and the other pre-exposed stimulus in the remaining trials. Presentations of the two stimuli were intermixed for all the participants and they were required to judge whether the stimulus presented in each trial was the same or different from the target. This procedure, including the prior presentation of the target stimulus, was repeated three times consecutively with an interval of 10 s between repetitions. No feedback was provided to participants about the correctness of their responses. The following instructions were displayed on the screen at the beginning of second stage:

> "Now, visual stimuli will appear on the screen. The first stimulus is named target and you should observe it during the time it is presented. The subsequent stimuli are named items. You have to indicate whether each of these stimuli is the same or different from the target. You will see the target and the other stimuli three times with a short resting period between presentations".

2.3.3. Phase 3: multiple-choice task

Next, participants received 5 multiple-choice trials. Each trial consisted of the simultaneous presentation on the screen of 6 Arabic character compounds during 110 s with an ITI of 5 s. These compounds were the two pre-exposed stimuli (the target stimulus and the other one) and four new compounds very similar to them (see Fig. 1). The location of the compounds on screen was randomly changed from trial to trial, with the only restriction that the pre-exposed compounds were never in the same location. Participants were required to choose the stimulus designated as the target on the previous task from among all the stimuli presented in each trial. The following instructions were shown on the screen prior to the beginning of this task:

> "Next five screens will appear, one followed by another. You should indicate which of the stimuli presented in each was the target in the previous task".

2.3.4. Phase 4: puzzle task

Finally, a single puzzle test trial was conducted. Twenty individual Arabic characters were presented on the upper two-thirds of the screen (see Fig. 2). These included the same 4 characters that the pre-exposed stimuli shared, the 2 unique characters that differed between them, and 14 new similar ones. On the lower third of the screen, participants had to rebuild the target compound (the same target stimulus as that of the previous tasks) by selecting characters from the upper part of the screen and dragging them with the mouse directly to the lower part of the screen. The maximum time allowed to reconstruct the target was 5 min. Instructions for this task were the following:

> "Next the final screen will appear. At the top of the screen you will find some individual Arabic characters. At the bottom of the screen you will see a free space in which you should "assemble" the target stimulus as a puzzle with characters that you need. Use the mouse to pick up and drag the characters which you think to be appropriate. You have 5 minutes maximum to do it".

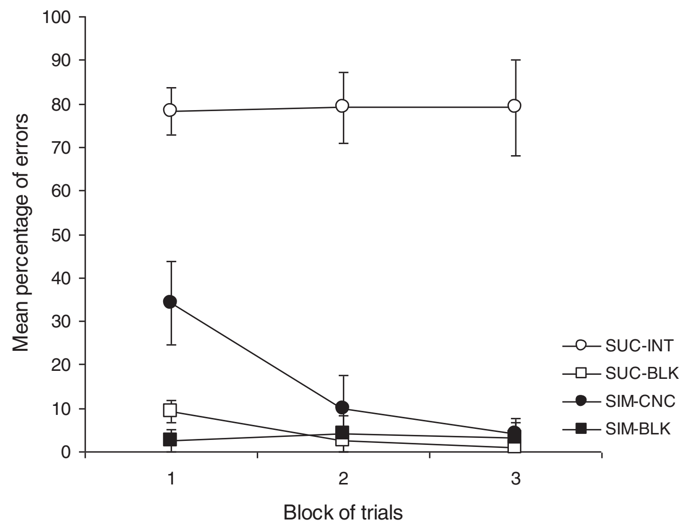

Fig. 3. Mean percentage of errors (±SEM) on judgments for each experimental condition across the three blocks of pre-exposure trials.

It should be noted that the experimental conditions differed only in the pre-exposure schedule received, so the fact that task order was not counterbalanced could be a methodological problem only if the treatment interacted with the different tasks. We have no basis for expecting such an interaction, predicting the nature it would take, or how it would impact the results. Moreover, counterbalancing task order would break down the logic of the study in a manner more problematic than the lack of counterbalancing itself. In order for a given task to refer to a target stimulus, one of the pre-exposed stimuli must be designated in advance as the target. Thus, the target identification task (or some version of it) must be completed before the remaining tasks. The puzzle task, on the other hand, is largely under the control of the participant and therefore better placed at the end of the experimental procedure. Finally, it could be argued that, if a pre-exposure schedule effect persists through all three tasks, conclusions about robust long-term effects become stronger. From an ecological perspective, therefore, the sequential nature of the procedure may be advantageous rather than a drawback.

3. Results and discussion

The performance measure for phases 1 and 2 was accuracy on same/different judgments (as percentage of errors averaged over blocks of 10). Mean proportion of target stimulus correct choices and incorrect choices of the non-target pre-exposed stimulus were calculated as performance measures for phase 3, while for phase 4 the number of correct puzzles constructed in each group was recorded. Data extracted from phases 1, 2, and 3 were evaluated by analysis of variance (ANOVA) adopting a significance level of $p < 0.05$, and those obtained from the puzzle test were analysed by Pearson's chi-square test of independence.

3.1. Pre-exposure

Fig. 3 shows the mean percentage of errors made for participants of the four groups on their judgements through three blocks of 10 pre-exposure trials. At the beginning of pre-exposure, the percentage of errors was greater when the correct response was "different" (groups SIM-CNC and SUC-INT, particularly for the latter, which maintained that level throughout pre-exposure) than when it was "same" (groups SIM-BLK and SUC-INT). Along pre-exposure the percentage of errors decreased for group SIM-CNC until reaching the negligible level showed by groups SIM-BLK and SUC-BLK.

A 2 (Mode of stimulus presentation: Simultaneous vs. Successive) × 2 (Stimuli presented on pre-exposure trials: Same vs. Different) × 3 (Block of trials) ANOVA conducted on the percentage of errors during the pre-exposure phase confirmed these impressions. There were significant main effects of Mode, $F(1, 44) = 39.31$, $p < 0.001$; Stimulus, $F(1, 44) = 74.39$, $p < 0.001$; and Block, $F(2, 88) = 6.51$, $p = 0.002$. There were also significant Mode × Stimulus, $F(1, 44) = 37.28$, $p < 0.001$; and Mode × Stimulus × Block, $F(2, 88) = 8.09$, $p = 0.001$, interactions. The double interactions, Mode × Block, $F(2, 88) = 2.26$, $p = 0.109$; and Stimulus × Block, $F(2, 88) = 2.40$, $p = 0.097$, were not significant.

Subsequent analysis of simple effects revealed that effect of Mode was significant with different stimuli, $Fs(1, 22) \geq 16.87$, $ps < 0.001$; but not with same stimuli, $Fs(1, 22) \leq 3.41$, $ps \geq 0.078$, in all blocks of trials, with the percentage of "different" errors being significantly greater for the successive pre-exposure condition (group SUC-INT) than for the simultaneous condition (group SIM-CNC). The effect of Stimulus was significant for both simultaneous, $F(1, 22) = 10.40$, $p = 0.004$, and successive, $F(1, 22) = 148.29$, $p < 0.001$, presentation modes in the first block of trials, but only for the successive mode in the second, $F(1, 22) = 81.52$, $p < 0.001$, and third blocks of trials, $F(1, 22) = 50.04$, $p < 0.001$ [remaining $Fs(1, 22) \leq 0.44$, $ps \geq 0.512$], indicating that the percentage of errors was greater for groups SIM-CNC and SUC-INT than for groups SIM-BLK and SUC-BLK in the first block of trials, while in the second and third block this percentage was greater for group SUC-INT than for the remaining groups. Finally, the effect of Block was significant for the simultaneous mode of stimulus presentation and different stimuli (group SIM-CNC), $F(2, 22) = 11.14$, $p < 0.001$, and for the successive mode and the same stimuli (group SUC-BLK), $F(2, 22) = 7.00$, $p = 0.004$, with errors decreasing as exposure progressed.

In summary, during the pre-exposure phase participants were more accurate judging the stimuli as different when they were pre-exposed concurrently as opposed to in an intermixed fashion and performance improved across blocks of trials only in the former case. This result suggests that the simultaneous concurrent schedule conferred greater immediate benefits for the detection of stimulus differences than the successive intermixed schedule. In the blocked conditions, the accuracy to judge pre-exposed stimuli as the same seemed to be unaffected by presentation mode. But because the stimuli presented to be judged were actually the same in these pre-exposure conditions, nothing can be said about the participants' ability to differentiate between the two pre-exposed stimuli. In the next phase of the experiment, same and different correct responses were equated for all groups and the stimuli to be judged as same or different from the target were presented individually and successively for all participants. So, if concurrent pre-exposure offers better opportunities to detect differences between stimuli and also provides an enduring basis for accurate differentiation, better performance would be expected for group SIM-CNC than for the others in the target identification task.

3.2. Target identification task

Fig. 4 shows the mean percentage of errors for the four groups through the three blocks of 10 same trials and 10 different trials in the target identification task. Participants were substantially more accurate in same than in different trials with the sole exception that those receiving concurrent pre-exposures to the stimuli (group SIM-CNC) showed exceptional accuracy in both kinds of trials. On same trials, the percentage of errors was low and quite similar for

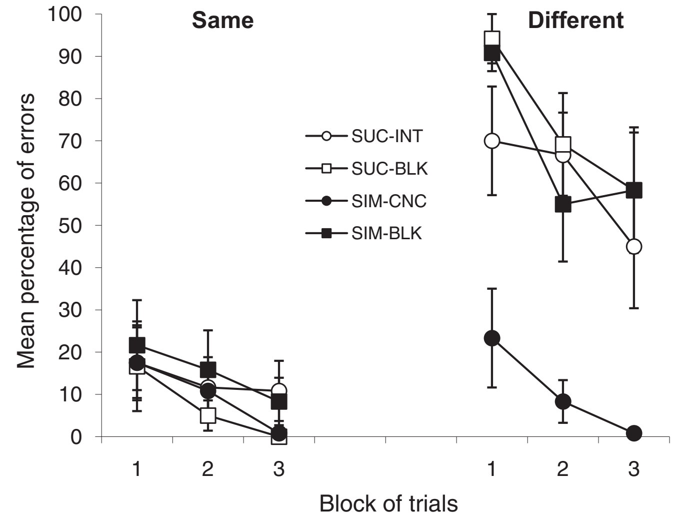

Fig. 4. Mean percentage of errors (±SEM) on judgments for participants of the four groups through the three blocks of 10 same and 10 different trials during target identification task.

all groups, improving slightly with training. But on different trials, the percentage of errors was notably lower for group SIM-CNC than for the others. A general improvement with training on these trials seemed to occur in all groups, but the performance of group SIM-CNC was remarkably superior.

A 2 (Mode) × 2 (Stimulus) × 2 (trial type: same or different) × 3 (Block) ANOVA conducted on the percentage of errors during the target identification task found significant main effects of Mode, $F(1, 44) = 8.77$, $p = 0.005$; Stimulus, $F(1, 44) = 16.45$, $p < 0.001$; Trial, $F(1, 44) = 49.6$, $p \leq 0.001$; and Block, $F(2, 88) = 12.90$, $p < 0.001$; and the following interactions: Mode × Stimulus, $F(1, 44) = 10.36$, $p = 0.002$; Mode × Trial, $F(1, 44) = 6.34$, $p = 0.015$; Stimulus × Trial, $F(1, 44) = 8.91$, $p = 0.005$; Trial × Block, $F(2, 88) = 4.42$, $p = 0.015$. The remaining interactions were not statistically significant (largest $F = 1.83$).

A simple effects analysis of the Mode × Stimulus interaction revealed that the effect of pre-exposure mode was significant when pre-exposed stimuli were different, $F(1, 22) = 15.43$, $p = 0.001$, but not when they were the same, $F(1, 22) = 0.43$, $p = 0.837$. This confirms that participants were more accurate in this task when they have been pre-exposed to different stimuli simultaneously (groups SIM-CNC) than successively (group SUC-INT). In accordance with the pre-exposure results, here it was also confirmed that stimulus presentation mode had no effect when the stimuli to be judged during pre-exposure were the same. Likewise, the effect of Stimulus was significant in the simultaneous pre-exposure condition, $F(1, 22) = 34.89$, $p < 0.001$; but not in the successive, $F(1, 22) = 0.28$, $p = 0.601$, confirming that participants were more accurate in this task when they had been pre-exposed simultaneously to different stimuli (groups SIM-CNC) than to same stimuli (group SIM-BLK), while no such effect was found when stimuli were successively pre-exposed.

Mode × Trial and Stimulus × Trial interactions were both due to the effects of Mode and Stimulus being statistically significant on different trials, $F(1, 46) = 6.56$, $p = 0.014$, and $F(1, 46) = 11.60$, $p = 0.001$, respectively, but not on same trials, $Fs(1, 46) \leq 0.20$, $ps \geq 0.653$. Thus, only on different trials, participants were more accurate after simultaneous than successive pre-exposure, and also after pre-exposure to different than to same stimuli. Judgment accuracy was always lower on different than on same trials, regardless of whether the stimuli had been pre-exposed simultaneously, $F(1, 23) = 10.25$, $p = 0.004$; or successively, $F(1, 23) = 33.08$, $p < 0.001$; and whether Stimulus was the same, $F(1,$

23) = 45.83, $p < 0.001$; or different $F(1, 23) = 7.02$, $p = 0.014$. Finally, a simple effects analysis of the Trial × Block interaction revealed that, in general, the percentage of errors was greater on different than on same trials in all blocks, $Fs(1,47) \geq 22.98$, $ps < 0.001$; although the percentage of errors decreased across blocks both on same, $F(2, 94) = 4.26$, $p = 0.017$; and different trials, $F(2, 94) = 15.22$, $p < 0.001$.

These results are consistent with the idea that concurrent pre-exposure to similar stimuli not only offered immediate benefits for the detection of differences between them but also resulted in an enduring enhancement of discriminability. The simultaneous mode of presenting two different stimuli (group SIM-CNC) provided an advantage that was maintained even when the presentation schedule was more similar to the successive than the simultaneous pre-exposure schedule. Moreover, this advantage was observed when the memory requirement of the task was greater. Different from what was observed during the pre-exposure phase, the accuracy of judgments was lower for participants who received blocked pre-exposure (both in the simultaneous and successive condition) than for those who received simultaneous concurrent pre-exposure. Thus, it could be accepted that simultaneous concurrent pre-exposure enhanced stimulus differentiation to a greater extent than the other pre-exposure schedules.

Performance differences observed between same and different trials deserves some comment. As mentioned earlier, performance was better on same than on different trials but, in addition, only the latter were sensitive to schedule effects (see, Lavis and Mitchell, 2006, for similar results). The lack of a similar effect of schedule on same trials could be explained in several ways. As Lavis and Mitchell (2006) have argued, a general bias to respond "same" when the stimuli can be not differentiated could explain better performance on same than on different trials. A response bias like this could lead to a ceiling effect on same trials, preventing any scheduling effect.

The nature of the target identification task allows, however, for another possibility. Unlike the pre-exposure phase (and the study reported by Lavis and Mitchell, 2006), in the target identification task participants had to identify one specific stimulus by means of a same/different judgment, instead of judging two stimuli presented in a particular trial. Therefore, for accurate performance, detecting differences between similar stimuli would not be enough. Participants must be able to recognize the target stimulus by means of same judgments, and differentiate it from the other pre-exposed stimulus by means of different judgments. This logic raises the possibility that same and different judgments could be assessing two different processes in which perceptual learning could be potentially involved: stimulus recognition and stimulus differentiation. If this were the case, then the results of the target identification task could be suggesting that stimulus recognition may be improved before stimulus differentiation (as indicated by better performance on same than on different judgments), allowing for the effect of pre-exposure schedule to be observed on this latter process but not on the former. This latter point is not so surprising considering that the effect of schedule is expected in relation to the ability to *differentiate* the stimuli. A priori one might think that recognizing a specific stimulus involves differentiating it from similar stimuli. Thus, the idea of a dissociation between recognition and differentiation processes could be considered somewhat counter-intuitive. But any case, it can be experimentally tested. If the results discussed here were reflecting such a dissociation instead of the effect of a response bias, it should also be found in other tasks in which same/different judgments are not used as the performance measure. For example, in one in which participants had to identify the same target by choosing from among several similar stimuli presented simultaneously.

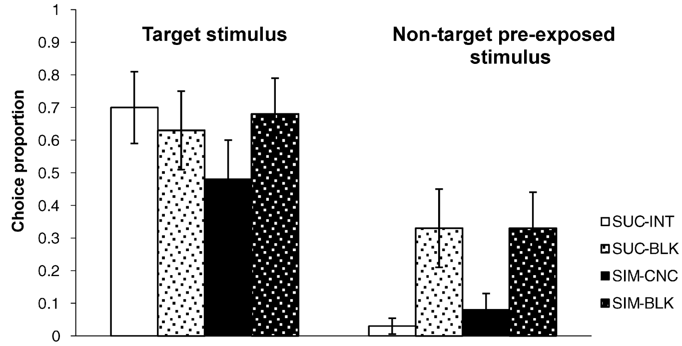

Fig. 5. Mean proportion (±SEM) of correct choice of target stimulus and incorrect choice of the other pre-exposed non-target stimulus, for the four groups in multiple-choice task.

3.3. Multiple-choice task

The left side of Fig. 5 shows the mean proportion of correct choices of the target stimulus for participants of all four groups in the multiple-choice task. As can be seen, participants in all four conditions chose the target stimulus from among the 6 stimuli presented simultaneously in similar proportions. These impressions were confirmed by a 2 (Mode) × 2 (Stimulus) ANOVA conducted on these data where no effects were significant, $Fs(1, 44) \leq 1.63$, $ps \geq 0.208$

The right side of Fig. 5 shows the mean proportion of incorrect choices of the non-target pre-exposed stimulus (as if it were the target) for all participants in the multiple-choice task. Those participants who had been pre-exposed to the stimuli in separate blocks of trials chose the non-target pre-exposed stimulus in a greater proportion than those who received concurrent or intermixed pre-exposures.

These impressions were also supported by a 2 (Mode) × 2 (Stimulus) ANOVA conducted on these data, as only the main effect of Stimulus was significant, $F(1, 44) = 9.42$, $p = 0.004$. As figure 5 shows, the proportion of incorrect choices of the non-target stimulus (as if it were the target) was significantly greater when the stimuli were pre-exposed in separate blocks of trials (groups SIM-BLK and SUC-BLK) than either concurrently (group SIM-CNC) or intermixed (group SUC-INT). Neither the main effect of Mode nor the Mode × Stimulus interaction was significant, $Fs(1, 44) \leq 0.078$, $ps \geq 0.781$.

As the target identification task results suggested—with respect to same trials—we found again that participants were similarly accurate at recognizing the target stimulus (the proportion of target-correct choice was similar in all groups). However, participants who received the blocked schedule chose the non-target pre-exposed stimulus to a greater extent than those who received concurrent or intermixed schedules. This finding suggests that the blocked schedule led participants to confuse the pre-exposed stimuli to a greater extent than the other schedules and, therefore, pre-exposure schedule had an effect on participants' ability to differentiate the stimuli in this task as well. Since an effect of response bias would not be expected in this task, these results support the previous suggestion that, at least in some circumstances, stimulus recognition and stimulus differentiation processes might be dissociable.

3.4. Puzzle task

Table 1 shows the number of correct puzzles constructed in each group. More correct puzzles were made by those participants who received pre-exposures to the stimuli in separate blocks of trials (both simultaneously and successively) than concurrently

Table 1
Correct puzzles in each group.

Group	Correct puzzles
Successive-intermixed	3
Successive-blocked	7
Simultaneous-concurrent	1
Simultaneous-blocked	7

or in an intermixed fashion. Confirming this impression, Pearson's chi-square test of independence found a significant relation between the number of correct puzzles and the Stimulus variable, $\chi^2(1) = 8.88$, $p = 0.003$; but not with stimulus presentation Mode, $\chi^2(1) = 0.35$, $p = 0.551$. That is, in general, more correct puzzles were constructed when the stimuli were pre-exposed in separate blocks of trials.

In summary, participants who showed worse performance on the preceding tasks, that is, those who received blocked pre-exposure to the stimuli, exhibited the greatest ability to rebuild the target stimulus in the puzzle test. One might expect better performance on this task from the participants who performed better on the others. In fact, according to the Gibsonian account of perceptual learning (Gibson, 1969), a greater ability to differentiate the stimuli obtained in the other tasks would be based on a more accurate internal representation of the stimulus. But the puzzle task results offered evidence of just the opposite, showing that the internal representation of the target stimulus could be poorer for participants who received the concurrent pre-exposure schedule (and also for those who received the intermixed schedule), despite the fact that their performance was better in the previous tasks. Paradoxically for the Gibsonian account, this latter result may be explained by the same selective attention mechanism proposed to explain the enhancement of stimulus differentiation. The manner in which a selective attention mechanism may explain all the current findings will be elaborated in the discussion.

4. General discussion

This study assessed the effect of four stimulus pre-exposure schedules—simultaneous concurrent, simultaneous blocked, successive intermixed, and successive blocked—on three tasks differing in their demands: a target identification task, a multiple choice task, and a puzzle reconstruction task. During pre-exposure, participants were required to judge whether two stimuli presented on a given trial were the same or different. Such stimuli were always the same for participants who received blocked pre-exposure to the stimuli (successively or simultaneously) and always different for those who received intermixed (successive) or concurrent (simultaneous) pre-exposure. Thus, the participants' ability to discriminate between pre-exposed stimuli could be assessed only in these two latter conditions during the first phase of the present study. It was found that, in general, participants were more accurate judging the stimuli as same than different. But when the stimuli presented were different, participants who had received simultaneous concurrent stimulus presentations were more accurate in their judgments than those who had received successive-intermixed presentations. Furthermore, performance improved over pre-exposure in the concurrent pre-exposure condition but not in the intermixed. These results seem to be indicating that the detection of differences between stimuli was facilitated by the simultaneous concurrent schedule to a greater extent than by the successive intermixed schedule. As several authors have noted (e.g., Brown and Rebbin, 1970), the benefit of simultaneous presentations of similar stimuli for capturing differences between them does not necessarily guarantee better differentiation when they are presented successively later.

In contrast to Brown and Rebbin's (1970) caveat, it appears that the benefit of the concurrent schedule was transferred to the target identification task. Here, participants had to identify one of the two pre-exposed stimuli as the target also by means of same/different judgments (with the proportion of each type of correct judgment equalled for all participants) but in this case, they all received successive single presentations of the stimuli. It was found that participants' ability to judge one stimulus correctly as the target by means of same judgments was very good in all pre-exposure conditions. Nevertheless, participants who received simultaneous concurrent stimulus presentations were substantially more accurate than all other participants at judging the non-target pre-exposed stimulus as different from the target. That is, the ability to differentiate the target stimulus from the similar pre-exposed stimulus was clearly affected by pre-exposure schedule, being enhanced to a greater extent after concurrent than intermixed or blocked pre-exposure to the stimuli. We should note that the overall pre-exposure time to the stimuli was shorter for the simultaneous than the successive pre-exposure condition (two stimuli were presented in the former case while a single stimulus was presented in the latter during the same lapse of time). One would expect that the shorter exposure time would lead to a slower improvement in stimulus differentiation. However, evidence of better differentiation was obtained for the simultaneous mode of stimulus presentation than the successive mode when two different stimuli were presented on pre-exposure trials and they could be compared.

Only two previous studies have reported evidence of better stimulus differentiation with the concurrent than intermixed or blocked pre-exposure schedule in humans (Mundy et al., 2007, 2009). Thus, the confirmation of this effect here, extending its generality by the use of different stimuli and testing procedures, become important per se. Especially if is taken into account that, in contrast with the mentioned studies, here, feedback was never provided to participants (and then the potential effects of it in the results could be excluded); and, for the first time, at least for the best of our knowledge, stimulus discriminability could be assessed progressively by means of same-different judgments offering learning curves. But in addition, the target identification task supplied a new and interesting finding.

Participants were highly accurate judging as the same stimuli that actually were targets and, surprisingly, accuracy on same trials was not affected by pre-exposure schedule to the same extent than accuracy on different trials. This last finding raises the possibility that stimulus recognition and differentiation processes could be dissociated in this task, with the latter being affected by pre-exposure schedule but not the former. Certainly, it is also possible that a ceiling effect precluded the observation of any effect of pre-exposure schedule. But in this case, one should also assume that an improvement in stimulus recognition may be observed before any similar improvement in stimulus differentiation. Either way, a potential dissociation between recognition and differentiation processes should be considered.

The multiple choice task supplied additional evidence for this idea, ruling out the possibility that the results of the target identification task were due to a bias to respond "same". When participants were required to identify the same target stimulus used during the target identification task, choosing from among five similar stimuli, the proportion of correct target choice was also high and similar for all groups. However, participants who received blocked simultaneous or successive presentations of the stimuli chose the other pre-exposed stimulus as the target to a greater extent than those who received concurrent or intermixed presentations. That is, pre-exposed stimuli were more likely to be confused after blocked than concurrent or intermixed presentations, suggesting poorer stimulus differentiation in the blocked conditions. In the absence of differentiation, participants appeared to respond largely on the basis of whether they recognized a stimulus at all. Other than was found in the target identification task, in the multiple choice task fewer confusions between stimuli were observed following intermixed than blocked pre-exposure, indicating that stimulus differentiation could be improved to a greater extent in the former case than in the latter. It is hard to say for sure, why the "*intermixed-blocked effect*" did not appear in the target identification task but did in the next task. This effect has been found before in humans with tasks in which participants judged stimuli presented consecutively as same or different (e.g., Lavis and Mitchell, 2006). Thus, a priori, its absence in the target identification task could be related more likely with the task itself, or the stimuli employed, than with the discriminability measure assessed. For example, it is possible that the simultaneous presentation of all the stimuli on the screen during the trials of the multiple choice task (allowing their comparison), facilitated the target recognition and differentiation relative to the target identification task, where the stimuli were always presented separately. But given the high percentage of errors committed by participants in the successive-intermixed condition during the pre-exposure stage, it could be also argued that the stimuli employed here are more difficult to discriminate than those previously used by others (see Lavis and Mitchell, 2006). If this is true, perhaps, additional intermixed exposures to the stimuli provided by the target identification task could have facilitated the observation of a beneficial effect of the intermixed schedule over the blocked schedule in the subsequent multiple choice task. Consistent with both hypotheses, slightly better performance on the target identification task was observed after intermixed than blocked pre-exposure, although the differences between them were not statistically reliable. In any case, and irrespectively of their ability to differentiate the stimuli, all participants seemed to be equally accurate at target recognition.

Finally, participants were required to reconstruct the target stimulus from their single elements in a puzzle task, and it was found that participants who received blocked pre-exposure to the stimuli made more correct puzzles than those who received concurrent or intermixed pre-exposure. That is, although these participants previously showed a poorer ability to differentiate the stimuli, they were more accurate in re-creating one of them from its elements than other participants. If one makes the reasonable assumption that the ability to reconstruct the target depends on memory of the stimulus, and that this memory depends, at least in part, on how well the stimulus elements are internally represented, one should conclude that the representation of the target stimulus was more accurate after blocked than concurrent or intermixed pre-exposure. In this case, evidence from the puzzle task counters an important (previously untested) assumption of the Gibsonian account of perceptual learning. According to this account, the enhancement of differentiation will be mediated by an increase in correspondence between the physical stimulus and its perception. So, if the opportunity to compare stimuli will enhance their differentiation, it should also increase the correspondence between physical stimuli and their internal representations.

In contrast to this hypothesis, the results of the tasks employed here considered together suggest that good opportunities to compare the stimuli improved stimulus discrimination, and, at the same time, produced a poorer internal representation of them with respect to blocked exposures. Nevertheless, this paradox may be explained by a selective attention mechanism like that proposed by Gibson (1969). Pre-exposure conditions that offered good opportunities to compare the stimuli would have facilitated stimulus differentiation, because comparison boosted an attentional shift in stimulus processing. Attention would be directed selectively toward unique features of the stimuli, and as several authors have argued, attention paid to the stimulus elements could be directly related to the extent to which these are processed and encoded (e.g., Mitchell et al., 2008a, 2008b; for a similar argument, see Mundy et al., 2009). Thus, as a result of an attentional shift, the elements important for stimulus differentiation, the distinctive elements, will be better processed and encoded, increasing their discriminability. The attentional shift would also entail reduced attention to the common elements of the stimuli. These elements are not important for stimulus discrimination and compete with distinctive elements for attention and processing resources so, this shift could also facilitate stimulus differentiation. But applying the same logic described above to the common elements, one must conclude that these would be poorly internally represented. When stimuli to be compared are very similar, the majority of their total elements will be common, so the internal representation of stimuli as a whole would be less accurate in pre-exposure conditions that offer good opportunities for comparison. In the absence of the attentional shift discussed here, as could be expected to occur in the blocked pre-exposure conditions, all elements would be equally processed and encoded and the overall stimulus representation would be more precise.

In summary, the better opportunity to compare the stimuli provided by the intermixed schedule, and especially, by the concurrent schedule, relative to blocked schedules, could lead to an increased attention to the distinctive features of the stimuli, thereby improving stimulus differentiation and performance in tasks in which attending to distinctive features of the stimuli is important. This is the case for the pre-exposure phase, target identification task, and multiple choice task. However, reconstructing the target stimulus in the puzzle task required retrieving an accurate memory of the entire stimulus, not just the unique features. Therefore, performance on this task would be hindered by the opportunity for comparison, with performance being better when this comparison is impeded or made more difficult during pre-exposure.

Regardless of the theoretical analysis offered here, it is clear that the empirical effect of different pre-exposure schedules is not always the same. Schedule effects seem to be dependent on specific demands of the task employed to asses them. The findings reported here indicate that tasks or procedures designed to assess perceptual learning should be carefully analysed in order to elucidate whether the task might be assessing recognition or differentiation. This analysis could be especially important for future research trying to compare findings reported from studies conducted with human and non-human animals using tasks whose demands could be far from analogous.

Acknowledgements

This research was supported by grants from the *Spanish Ministerio de Ciencia e Innovación* (PSI2008-00412-PSIC), the *Spanish Ministerio de Economía y Competitividad* (PSI2011-24231), the *Basque Government* (IT-276-07), and also by a Predoctoral Fellowship from the University of the Basque Country to Rocío Angulo. We would like to thank Byron Nelson and Anton Navarro their corrections of the paper.

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