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Attentional changes in human perceptual learning

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ABSTRACT

In two experiments, participants were required to identify a target stimulus by means of same/different judgments. Previously, they had received simultaneous or blocked pre-exposures to the target and a similar stimulus. Participants' ability to judge pre-exposed stimuli as different was better after simultaneous than after blocked pre-exposures. However, the benefit of the simultaneous schedule disappeared when, after pre-exposure, the distinctive elements were made common (and some common elements made distinctive) by changing their shape and position within the stimulus (Experiment 1). Similar results were obtained when only one of the aforementioned physical features was modified (Experiment 2). These manipulations did not affect performance when the stimuli had been pre-exposed in separate blocks of trials. These findings support the idea that the effect of simultaneous pre-exposure on stimulus differentiation is based on a selective attention process by which attention is selectively directed towards the distinctive features of the stimuli and away from the common features (Gibson, 1969).

1. Introduction

Repeated exposures to similar stimuli improve in humans the ability to discriminate between them (Gibson and Gibson, 1955). This kind of learning, known as perceptual learning, can result from simple exposure to the stimuli in the absence of any reinforcement or feedback, and the magnitude of the benefit of pre-exposure on differentiation depends on the specific way in which stimuli are presented. For example, stimuli appear to be more easily differentiated after simultaneous pre-exposure (AX-BX, AX-BX. . ., where A and B represent distinctive and X common features of the stimuli) than after intermixed pre-exposure (AX, BX, AX, BX. . .), and both of these result in better differentiation than blocked pre-exposure (AX, AX. . .BX, BX. . .) (Mundy et al., 2007, 2009; see also Angulo and Alonso, 2012).

One of the earliest theoretical accounts of perceptual learning (Differentiation Theory) offered a non-associative explanation of how pre-exposure schedule could affect the ability to differentiate the stimuli (Gibson, 1969). According to this account, during repeated experience with similar stimuli, attention to the distinctive features (A and B) is selectively increased while attention to the common features (X) is reduced, thus enhancing stimulus differentiation. Unfortunately, the specific mechanisms involved in this attentional shift were not fully described, but the account emphasized that the differentiation process and the underlying attentional change would be boosted in exposure conditions that offer a good opportunity for comparing the stimuli. A simultaneous pre-exposure schedule offers optimal opportunities for comparing the stimuli, since it presents them as closely as possible in both time and space, and an intermixed schedule provides a better opportunity for stimulus comparison than a blocked schedule. Thus, the results of studies conducted with humans (e.g., Dwyer et al., 2011; Mundy et al., 2007, 2009; see also Angulo and Alonso, 2012) appear to support the importance of providing an opportunity for comparing the stimuli (but see Alonso and Hall, 1999; Bennet and Mackintosh, 1999; and Rodríguez and Alonso, 2008, for different findings from studies conducted with non-human animals and conditioning preparations; and Nelson (2009); special section of *Learning & Behaviour*, for a discussion of the possible causes of discrepancies between studies conducted with humans and those conducted with non-human animals).

What remains to be clearly determined is, however, whether the opportunity for stimulus comparison does in fact lead to increased attention to the distinctive features of the stimuli and reduced attention to the common features, as has been proposed (Gibson, 1969). Indirect evidence in this regard has been provided by studies conducted with rats and conditioning preparations that have reported greater conditioning of the distinctive features of stimuli after intermixed than after blocked pre-exposures (Blair and Hall, 2003a,b; Mondragón and Hall, 2002). The rate of learning about a conditioned stimulus depends in part on its salience (e.g., Rescorla and Wagner, 1972), so, controlling for other factors, faster or greater conditioning of the distinctive features of stimuli is consistent with the notion that they are more salient. It is widely accepted that

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stimulus salience correlates with the attention that the stimulus captures (see, for example, Hall, 2003; Mackintosh, 1975).

More evidence of a selective attention process has been provided by studies conducted with humans. For instance, using eye-tracking methods and a within-subjects design, Wang and Mitchell (2011) have recently reported that participants fixated on the distinctive features of similar visual stimuli for a longer time when the stimuli had been presented in intermixed, rather than in separate blocks of trials, thus suggesting greater attention to the distinctive features in the former case. But to the best of our knowledge, it has yet to be shown that the unique features receive greater attention when the stimuli are pre-exposed in the manner that offers the greatest opportunity for stimulus comparison, i.e., simultaneous, in comparison with blocked pre-exposure.

Some indirect evidence of an attentional shift during simultaneous pre-exposure was found in a study conducted in our laboratory (Angulo and Alonso, 2012). Accuracy in differentiating pre-exposed stimuli was greater after simultaneous than after intermixed pre-exposure, and both of these pre-exposure schedules resulted in greater accuracy than a blocked schedule. However, the opposite pattern was found in a subsequent puzzle task in which participants were required to reconstruct one of the pre-exposed stimuli from its components. In this case, performance was worse following intermixed or simultaneous pre-exposure than after blocked exposure. A Gibsonian account of perceptual learning predicts that, in comparison with blocked pre-exposure, intermixed and, especially, simultaneous pre-exposure direct attention towards distinctive features and away from common ones. Thus, although increased attention to the distinctive features in the simultaneous and intermixed pre-exposure conditions would improve the ability to differentiate similar stimuli, at the same time it would reduce attention to the majority of the stimulus elements, i.e., the common elements, resulting in poorer processing and encoding of these features. As a result, a greater opportunity for comparison would result in a less accurate internal representation of the stimuli, leading to a poorer performance in the puzzle test.

The main aim of the present study was to search for evidence of an attention shift after simultaneous pre-exposure in a more direct and novel way. The strategy was to introduce a modification in the distinctive-common status of some features of the stimuli after pre-exposure but before participants were required to perform a task involving same/different judgments. The process of selective attention towards the distinctive features and away from the common ones triggered during pre-exposure should lead to incorrect "same" judgments during the subsequent task because the more-attended features will, in fact, be the same. Similarly, reduced attention to those features that were common during pre-exposure may impair participants' ability to identify the new distinctive features in the subsequent task. Thus, if the optimal opportunity for stimulus comparison provided by simultaneous pre-exposure increases attention to the distinctive features of the stimuli and decreases attention to the common features, then stimulus change would be expected to have a more detrimental effect after simultaneous pre-exposure than after blocked pre-exposure.

2. Experiment 1

Borrowing from the general procedure previously reported by Angulo and Alonso (2012), Experiment 1 consisted of two phases: pre-exposure and the target identification task. During pre-exposure, four groups of participants were pre-exposed to two Arabic 5-character compounds. Stimuli differed only in one of these characters, with the others being common to both. Half the participants received simultaneous pre-exposures to the stimuli (SIM condition), while the other half received blocked pre-exposures (BLK condition). During the subsequent target identification task, participants were required to identify one of the pre-exposed stimuli as the target in three series of stimulus presentations. Only two stimuli were presented during these series, the target stimulus and another similar one, and participants were required to make same-different judgments, always in relation to the target stimulus. For half the participants in each previous condition, the non-target stimulus used in the task was identical to the other pre-exposed stimulus. In other words, neither of the two pre-exposed stimuli were modified for the subsequent task (SIM-noM and BLK-noM groups). However, for the remaining participants, the non-target stimulus was modified (SIM-M and BLK-M groups). Modification entailed within-stimulus changes, with the character that was distinctive during pre-exposure being rendered common for the stimuli presented in the target identification task, and one of the common features being rendered distinctive. Increased attention to the features that were distinctive during pre-exposure but are now common to both stimuli should lead to incorrect "same" judgments, thus resulting in poorer performance in the task. Furthermore, reduced attention to the features that were common during pre-exposure but which are now distinctive, should make it more difficult for participants to detect the current distinctive feature, thus rendering their performance in the target identification task even poorer. According to previous evidence (Angulo and Alonso, 2012; Mundy et al., 2007, 2009) and Gibson's prediction (1969), the situation described above is more likely to occur after simultaneous pre-exposure condition than after blocked pre-exposure, in which attention is balanced more evenly between all the stimulus features. Thus, accuracy in the target identification task would be expected to be greater for the simultaneous than for the blocked pre-exposure condition, but only when the stimuli presented are identical to those that were pre-exposed. When the non-target stimulus was modified as outlined above, this result should be reversed or, at least, cancelled.

2.1. Method

2.1.1. Participants

Sixty-four native Spanish-speaking (non Arabic-speaking) undergraduate students (aged 17–30) from the Psychology Centre of the University of the Basque Country participated voluntarily in the experiment in exchange for course credits. All participants had normal or corrected vision, were naïve to the exact problem being investigated by the experiment, and gave their informed consent to participate.

2.1.2. Stimuli and apparatus

Four of the eight nonsense compounds of 5 Arabic characters displayed in Fig. 1 were employed as stimuli, XAY, XBY, XAZ, and XBZ, in this experiment. All the stimuli shared the first three characters starting from the left (X), with the pair of stimuli presented during both pre-exposure and the target identification task differing in only one of the remaining characters (A and B or Y and Z). Stimuli were presented on a DELL computer, appearing in black over a white background with a Times New Roman letter format and font size 88 from Microsoft Word. The on-screen dimensions of the compounds were 3 cm × 9.3 cm ($h \times w$). Individual personal computers were made available to all participants, who were seated approximately 60 cm from the monitor and received the instructions on the screen. Same/different responses were recorded during both phases of the experiment.

2.1.3. Procedure

The procedure comprised two phases that were conducted sequentially. A pre-exposure phase and a test phase (target identification task). The experiment was conducted in a single 30-min session with phases separated by a 2-min rest interval.

2.1.3.1. Phase 1: pre-exposure. All participants received 30 pre-exposure trials. Pre-exposure began with the instructions,

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

Each trial consisted of the simultaneous presentation of a pair of stimuli on the screen for 5 s. At the end of each presentation, participants judged whether the stimuli were the same or different. No feedback was provided. The inter-trial interval (ITI) was 3 s. Pre-exposed stimuli were two similar Arabic character compounds, XAY and XBY, or XAZ and XBZ (counterbalanced in each group). As shown in Fig. 1, pre-exposed compounds differed only in one of their characters (A and B). Half the participants (SIM condition) received a simultaneous pre-exposure schedule to the stimuli, with the left/right position of the stimuli being counterbalanced. The other half received a blocked pre-exposure schedule (BLK condition), in which two identical copies of one stimulus were presented during the first half of the trial and two copies of the other in the second half, with the stimulus order being counterbalanced. The correct response during pre-exposure was, therefore, always "different" for those participants receiving simultaneous pre-exposure, and always "same" for those in the blocked condition.

2.1.3.2. Phase 2: target identification task. This task began with a 3 s presentation of a white screen with the word "target" in the centre, indicating the next target onset. The target stimulus, presented immediately afterwards for 5 s, was one of the two pre-exposed Arabic-character compounds, chosen randomly and counterbalanced in each group. Next, all participants received 20 identification trials in which they were asked to decide whether a single stimulus, presented during 5 s, was the same as or different from the target. Half the participants in each of the two previous pre-exposure conditions, SIM and BLK, were tested with the same pre-exposed stimuli, XAY and XBY, or XAZ and XBZ (groups SIM-noM and BLK-noM). For the other groups, SIM-M and BLK-M, one of the pre-exposed stimuli was replaced with another for the test, while the other one was used as the target stimulus. The new stimuli differed only in one character from the target, Y or Z, which had been common elements during pre-exposure, while the previous distinctive elements (A or B), were now common elements to both stimuli. For example, if the target stimulus was XAY, the new stimulus in different trials was, XAZ, and if the target stimulus was XBY, the new stimulus was XBZ (or vice versa when the pre-exposed stimuli were XAZ and XBZ). This test procedure was repeated three times consecutively, making a total of 3 initial presentations of the target and 60 identification trials, with a 10 s interval 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 the target and you should observe it during the time for which it is presented. The subsequent stimuli are called items. You have to indicate whether these items are the same as or different from the target. You will see the target and the other stimuli (items) three times with a short resting period between presentations."

Fig. 1. Stimuli employed in the experiments.

2.2. Results

The measure of performance for the two phases was the accuracy of the same/different judgments, expressed as the percentage of errors averaged over blocks of 10 trials. The data were evaluated by analysis of variance (ANOVA).

2.2.1. Pre-exposure

Fig. 2 shows the mean percentage of errors in same/different judgments for participants of the two pre-exposure conditions (SIM and BLK), throughout the three blocks of 10 trials during the

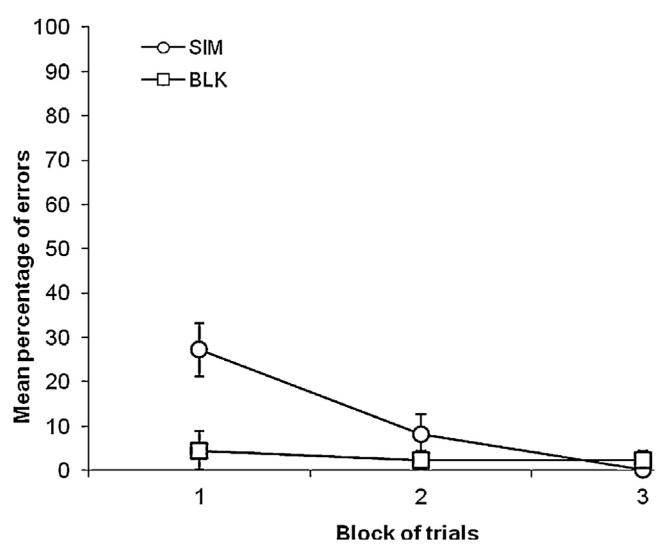

Fig. 2. Mean percentage of errors (±SEM) in simultaneous (SIM) and blocked (BLK) pre-exposure conditions across the three blocks of 10 trials during the pre-exposure phase of Experiment 1.

pre-exposure phase. At the beginning of pre-exposure, i.e., during the first block of trials, the percentage of errors was higher when the correct response was "different" (SIM condition) than when it was "same" (BLK condition). After that, the percentage of errors decreased for the SIM condition to the negligible level shown by the BLK condition from the beginning of pre-exposure.

A 2 (Schedule) × 3 (Block) ANOVA performed on the percentage of errors during the pre-exposure phase confirmed these impressions. The main effects of Schedule, $F(1, 62) = 6.59$, $p = .013$, and Block, $F(2, 124) = 18.38$, $p < .001$, and the interaction between them, $F(2, 124) = 12.99$, $p < .001$, were significant. The subsequent analysis of simple effects revealed that the percentage of errors in the simultaneous condition was significantly higher than in the blocked condition in the first block of trials, $F(1, 62) = 13.71$, $p < .001$, but not in the second and third blocks of trials (Fs ≤ 3.52), $ps \geq .07$. Furthermore, the percentage of errors decreased significantly across trials for the simultaneous condition, $F(2, 62) = 16.32$, $p < .001$, but not for the blocked condition, $F(2, 62) = 2.71$, $p = .074$.

2.2.2. Target identification task

Fig. 3 shows the mean percentage of errors in same/different judgments for participants of the four groups throughout the three blocks of 10 same and 10 different trials during the target identification task. Participants were substantially more accurate on same than on different trials, with the effect of experimental treatments appearing only in different trials. Participants who received simultaneous pre-exposures to the stimuli showed exceptional accuracy on different trials when the stimuli were not changed (group SIM-noM), but when the stimuli were modified, performance was poorer and similar to that exhibited by participants who received blocked schedules. Stimulus modifications had little effect on the accuracy in different trials of participants who received the blocked pre-exposure schedule (groups BLK-noM and BLK-M).

A 2 (Schedule, SIM or BLK) × 2 (Modification or not) × 2 (Trial type: same or different) × 3 (Block) ANOVA conducted on the percentage of errors in the target identification task confirmed these impressions. There was a three-way Schedule × Modification × Trial interaction, $F(1, 60) = 8.85$, $p = .004$. Among the effects and interactions not superseded by this three-way interaction was an effect of Block, $F(2, 120) = 10.13$, $p < .001$, and a significant interaction Trial × Block, $F(2, 120) = 3.26$, $p = .042$. The remaining interactions were not significant (Fs < 1.27). Subsequent analyses revealed that neither the main effects of Schedule or Modification, nor the interaction between them were significant in same trials (all Fs < 1). In different trials, there was a reliable Schedule × Modification interaction, $F(1, 60) = 12.46$, $p = .001$. The Schedule × Modification interaction was due to the significant effect of Schedule when the stimuli used in the target identification task were identical to those used during pre-exposure, $F(1, 30) = 41.85$, $p < .001$, but not when they were modified, $F(1, 30) = .09$, $p = .77$; as well as to the significant effect of Modification when the stimuli had been pre-exposed simultaneously, $F(1, 30) = 18.76$, $p < .001$, but not when they had been pre-exposed in separate blocks of trials, $F(1, 30) = 1.45$, $p = .24$. Finally, the analysis of the simple effects of the Trial × Block interaction revealed that the percentage of errors decreased significantly over blocks in different trials, $F(2, 126) = 11.85$, $p < .001$, but only marginally in same trials, $F(2, 126) = 2.79$, $p = .065$, and that the percentage of errors was greater in different than in same trials in all blocks (Fs ≥ 28.57).

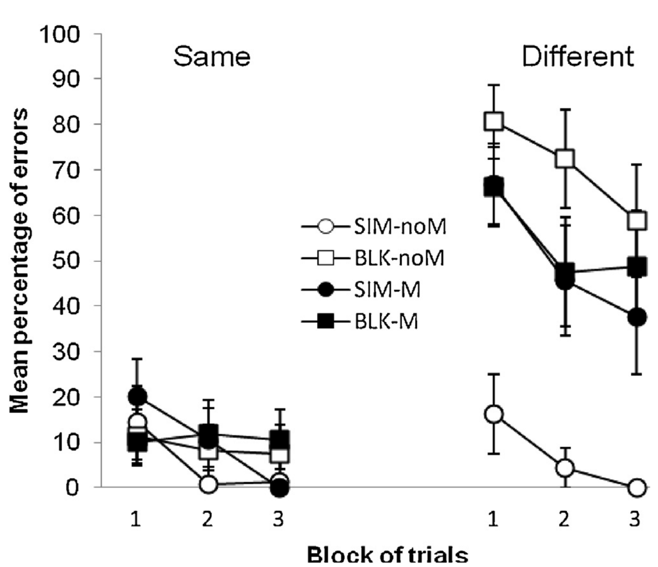

Fig. 3. Mean percentage of errors (±SEM) in judgments made by participants of the four groups throughout the three blocks of 10 same and 10 different trials during the target identification task of Experiment 1.

2.3. Discussion

Results of this experiment confirmed and extended those previously reported by Angulo and Alonso (2012). Few errors were made by participants of the concurrent pre-exposure condition at the beginning of the pre-exposure phase and at the end, errors were virtually zero. Participants receiving blocked pre-exposures to the stimuli hardly made any mistakes at all right from the beginning of the pre-exposure phase. Little can be said about the ability of participants in the blocked pre-exposure condition to differentiate the stimuli. The expected response when the stimuli are not discriminable is "same", and for participants in the blocked pre-exposure condition, "same" was precisely the correct response in all pre-exposure trials. However, because for participants receiving simultaneous pre-exposure the correct response was always "different", what does seem clear is that these participants were able to differentiate between the stimuli at the end of the pre-exposure stage.

The number of correct "same" and "different" responses was balanced in the subsequent target identification task. Thus, any potential bias generated by the pre-exposure schedule (the tendency to respond "same" for the blocked pre-exposure condition, and/or to respond "different" for the simultaneous condition) should be equally balanced in both types of trials. Response biases like these should manifest not only as a higher percentage of errors in different trials for the blocked than for the simultaneous pre-exposure condition, but also as a higher percentage of errors in same trials for the simultaneous than for the blocked conditions. The results of the target identification task do not seem to support this idea. These results show that when the stimuli employed in the task were exactly the same as those that were pre-exposed, participants who had received the simultaneous pre-exposure schedule showed a substantially better ability to differentiate the target stimulus from the other pre-exposed stimulus by means of "different" judgments than participants who received the blocked schedule. Pre-exposure conditions did not, however, influence "same" responses. These results are entirely consistent with our previous findings (Angulo and Alonso, 2012; see also Mundy et al., 2007, 2009), as well as with the idea that the opportunity of comparing the stimuli (provided especially by the simultaneous schedule) may improve stimulus differentiation (Gibson, 1969).

The novel and most important finding here was that the benefit of simultaneous pre-exposure for the target identification task vanished when the stimuli were modified after pre-exposure. The high accuracy showed by participants who received the simultaneous schedule when judging the non-target stimulus as different from the target, was substantially hindered by stimulus modification after pre-exposure, while this same modification had no effect on performance when the stimuli had been pre-exposed in separate blocks of trials. This last finding seems to be consistent with the hypothesis that the benefit of the simultaneous pre-exposure schedule on stimulus differentiation could be mediated by an attention shift, as described by the Differentiation Theory (Gibson, 1969).

But what did participants actually learn to attend to during pre-exposure? Did they learn to attend selectively to the specific position within the stimuli where the distinctive features were located? Or did they learn to attend to the specific shape of the distinctive features? Experiment 1 might not answer this question because these two dimensions of the distinctive features, shape and position, were changed together. But this was not the case in the next experiment, in which shape and position were changed separately. If participants do indeed learn to attend to just one specific location of the stimuli in order to respond "same" or "different", it would be difficult to generalize the results of Experiment 1 to perceptual learning involving non-visual stimuli.

3. Experiment 2

Experiment 2 was designed to determine whether the detrimental effect of stimulus modification demonstrated in Experiment 1 for the simultaneous pre-exposure condition was due to a change of distinctiveness in shape, position or both. As in Experiment 1, four groups of participants received simultaneous pre-exposures to two Arabic character compounds, and were then required to identify one of them as the target. Two of these groups received treatments identical to groups SIM-noM and SIM-M in the previous experiment. In other words, for these groups, the stimuli employed in the target identification task were either identical to those pre-exposed (Group NoM), or were modified both in shape and position within the stimulus (Group M-SP). For the other two new groups, only the shape or position of the distinctive features of the stimuli was modified. In one case, modification entailed the replacement of the previous distinctive feature with another one, but maintaining the same position in the stimulus (Group M-S); while for the other, the shape of the distinctive feature was maintained in the target identification task, but it was located in a different position within the stimuli (Group M-P). Any "same" response to the modified stimulus was taken as an error.

3.1. Method

3.1.1. Participants, stimuli and apparatus

Sixty-four native Spanish (non Arabic-speaking) undergraduates (aged 17–30) from the Psychology Centre of the University of the Basque Country participated voluntarily in return for course credits. All participants had normal or corrected vision, were naïve to the exact problem being investigated by the experiment, and gave their informed consent to participate. The stimuli employed were the eight nonsense compounds of 5 Arabic characters displayed in Fig. 1 as stimuli XAY-XYB. As in the previous experiment, the three first characters were common to all stimuli (X), and the stimuli presented during both the pre-exposure phase and the target identification task differed only in one of their characters (see below). Other details not mentioned here were identical to those described in Experiment 1.

3.1.2. Procedure

The general procedure was identical to that described for the simultaneous conditions in Experiment 1. Thus, there were two phases, pre-exposure and the target identification task, conducted sequentially. Participants were randomly assigned to one of four equal-size ($n = 16$) groups (noM, M-SP, M-S, M-P), which differed only in the stimuli that were pre-exposed and tested. For participants in groups noM and M-SP, pre-exposed and tested stimuli were the same as those pre-exposed and tested for groups SIM-noM and SIM-M, respectively, in Experiment 1, namely, XAY and XBY or XAZ and XBZ. Thus, as in Experiment 1, the stimuli presented during pre-exposure and testing were the same for group noM, while for group M-SP the distinctive elements of the pre-exposed and tested stimuli differed in both shape and position. The stimuli employed for group M-S were XAY, XBY, XCY and XDY (counterbalanced). For this group, the position of the distinctive elements in the compound during the test was the same as during pre-exposure, but these elements differed in shape, i.e., if the pre-exposed stimuli were XAY and XBY, the stimuli presented during the test were XAY and XCY, or XBY and XDY. Finally, the stimuli used for group M-P were XAY, XBY, XYA and XYB (counterbalanced). In this case, the distinctive features of the stimuli during pre-exposure and testing were exactly the same, but were located in a different position in the compound. For instance, if XAY and XBY were pre-exposed, the stimuli presented in the test were XAY and XYA, or XBY and XYB. Any other details not mentioned here were exactly as described for Experiment 1.

3.2. Results

3.2.1. Pre-exposure

Fig. 4 shows the mean percentage of errors made by participants of the four groups throughout the three blocks of 10 trials of the pre-exposure phase. The percentage of errors decreased during pre-exposure, and by the end of the phase was similar for all groups and near to zero.

A 4 (Group) × 3 (Block) ANOVA conducted on the pre-exposure data confirmed these impressions, with only the main effect of Block, $F(2, 120) = 47.55$, $p < .001$, being significant. Neither the main effect of Group, $F(3, 60) = 1.51$, $p = .22$, nor the Group × Block interaction, $F < 1$, were significant.

3.2.2. Target identification task

Fig. 5 shows the mean percentage of errors made by participants of the four groups throughout the three blocks of 10 same and 10 different trials of the target identification task. As found in

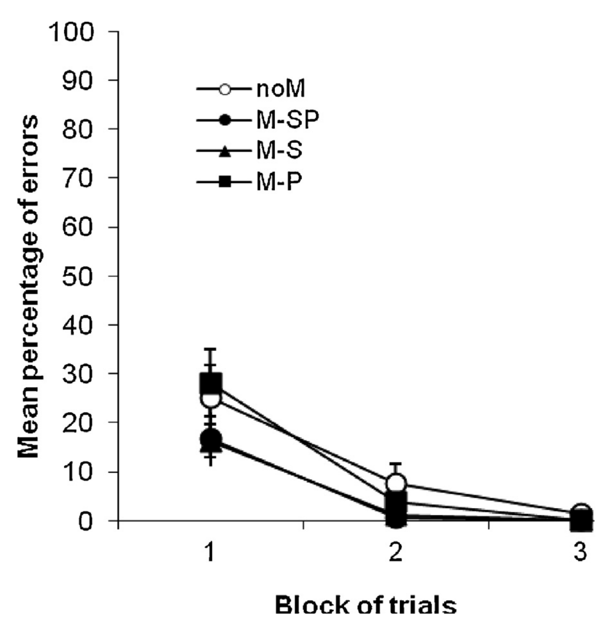

Fig. 4. Mean percentage of errors (±SEM) of the four groups across the three blocks of 10 trials during the pre-exposure phase of Experiment 2.

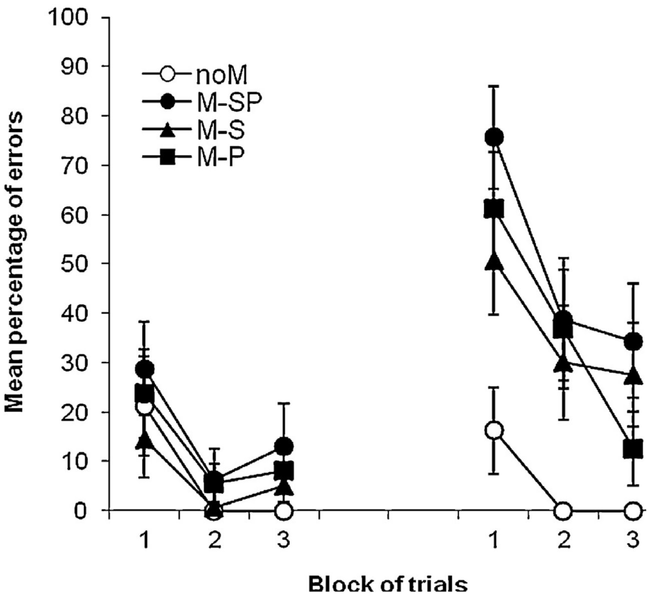

Fig. 5. Mean percentage of errors (±SEM) on judgments made by participants of the four groups throughout the three blocks of 10 same and 10 different trials during the target identification task of Experiment 2.

the previous experiment, accuracy was greater in same than in different trials and the effect of the experimental manipulations was observed only in different trials. In these latter trials, performance was very accurate when the stimuli employed were exactly the same as those that had been pre-exposed. But when the stimuli were modified between pre-exposure and the target identification task, performance was significantly impaired. The three types of modifications seemed to have a similar detrimental effect on performance.

A 4 (Group) × 2 (Trial type: same or different) × 3 (Block) ANOVA conducted on these data found significant main effects of Group, $F(3, 60) = 5.49$, $p = .002$, Trial, $F(1, 60) = 26.33$, $p < .001$, and Block, $F(2, 120) = 22.26$, $p < .001$, and the double interactions Group × Trial, $F(3, 60) = 3.60$, $p = .018$, and Trial × Block, $F(2, 120) = 5.43$, $p = .006$. Neither the Group × Block, $F < 1$, nor Group × Trial × Block, $F(6, 120) = 1.44$, $p = .21$, interactions were significant. Subsequent analyses of the simple effects of the Group × Trial type interaction revealed that the groups differed in Different trials, $F(3, 60) = 5.93$, $p = .001$, but not in Same trials, $F < 1$. Pair-wise comparisons conduced with Tukey's HSD test revealed that the percentage of errors in different trials was significantly lower for group NoM than for groups M-SP ($p = .001$), M-S ($p = .03$), and M-P ($p = .03$). The remaining pair-wise comparisons were not statistically significant ($ps \geq .602$). On the other hand, the percentage of errors was greater in Different than in Same trials for group M-SP, $F(1,15) = 7.34$, $p = .016$, group M-S, $F(1, 15) = 10.57$, $p = .005$, and group M-P, $F(1, 15) = 13.92$, $p = .002$, but not for group NoM, $F(1, 15) = 3.33$, $p = .088$. Finally, the analysis of the simple main effects of the Trial × Block interaction confirmed that the percentage of errors was greater in Different than in Same trials in Block 1, $F(1, 63) = 22.13$, $p < .001$, Block 2, $F(1, 63) = 9.21$, $p < .001$; and Block 3, $F(1, 63) = 6.30$, $p = .001$, and that the percentage of errors changed across blocks both in Same trials, $F(2, 126) = 12.69$, $p < .001$, and in Different trials, $F(2, 126) = 19.79$, $p < .001$.

3.3. Discussion

These results confirm those obtained in Experiment 1. After simultaneous pre-exposure to the stimuli, modification of their common-distinctive features (affecting both their shape and position within the stimulus) undermined performance in the subsequent target identification task. Furthermore, this experiment provides evidence that it is enough to change just one of these stimulus features in order to observe a detrimental effect of stimulus modification. Both types of modification had a similar detrimental effect on performance during the target identification task. Thus, these results suggest that the good performance observed in this task after simultaneous pre-exposure to the stimuli used in it, may result from an increased attention to distinctive features of the stimuli and/or to a reduced attention to the common features. Furthermore, the results obtained here seem to indicate that attention may be governed by all stimulus attributes, such as shape or position.

4. General discussion

Confirming the results obtained previously by Angulo and Alonso (2012), and extending the generality of other previous studies (Mundy et al., 2007, 2009), Experiment 1 showed that participants were more accurate in identifying a stimulus as a target, by means of same/different judgments, after simultaneous pre-exposure than after blocked pre-exposure to the target stimulus and another similar one. This replication is important per se because to date, there are very few studies (those cited above) which provide evidence of the advantages of a simultaneous pre-exposure schedule in comparison with a blocked one in relation to stimulus differentiation.

More interestingly, this study also found that the benefit of the simultaneous schedule disappeared when the distinctive and common features of the stimuli were modified prior to the subsequent target identification task (Experiment 1), regardless of whether the modifications entailed the position within the stimulus, shape, or both (Experiment 2). Nevertheless, stimulus modifications did not have the same detrimental effect when the stimuli had been pre-exposed in separate blocks of trials. These results support the idea that attention to the distinctive features of the stimuli was greater, and/or lower for the common features, when the stimuli had been simultaneously pre-exposed than when they had been presented in separate blocks of trials. During the target identification task, participants had to detect the distinctive features of the stimuli in order to judge whether those presented were the same as or different from the target. Thus, both increased attention to the distinctive features and reduced attention to the common features, in simultaneous as opposed to blocked pre-exposure, would improve performance in the target identification task. But, when the distinctive/common status of some features were modified after the presumptive shift in attention towards the distinctive features, selective attention to the formerly distinctive features would lead participants to incorrectly judge different stimuli as being the same, while reduced attention to formerly common features would hinder the probability of identifying the new distinctive feature.

Before continuing with the discussion, there in one important methodological, but also theoretical, issue that deserves some comment. The stimulus modification used for some participants (groups SIM-M and BLK-M in Experiment 1; and groups M-SP, M-S and M-P, in Experiment 2), implied that one of the stimuli presented in the target identification task was actually a novel stimulus (although only one character differed from the familiar stimulus), while for other participants (groups SIM-noM and BLK-noM, in Experiment 1; and group NoM in Experiment 2), both the target and non-target stimuli were completely familiar during testing. In this circumstance, the role of stimulus novelty should be discussed. Because the "novelty" dimension itself attracts attention, one would expect the novel feature of the modified stimulus to compete more effectively for attention than the familiar features, to which the participant should be habituated after pre-exposure, thus rendering them less salient (e.g., Hall, 2003). So, taking into account that the novel feature is also a distinctive feature that allows for stimulus differentiation, the modification should, if anything, have a beneficial effect on differentiating the target from the new stimulus, regardless of the pre-exposure schedule received. Some evidence of a potential benefit of stimulus modification was observed in the blocked pre-exposure condition in Experiment 1. Although the differences observed between groups were not statistically reliable, performance in the target identification task seemed to be somewhat better for group BLK-M than for group BLK-noM. In any case, the same experimental manipulation had a more detrimental effect on the task when the stimuli were simultaneously pre-exposed. Accepting the analysis offered here, one might conclude that the attentional shift occurring during simultaneous pre-exposure may be strong enough to reverse the potential and general facilitating effect of stimulus change. Thus, the present findings provide the first indication that an attentional shift like that previously found with intermixed pre-exposure (Wang and Mitchell, 2011), may also underlie the greater beneficial effect of simultaneous pre-exposure, in comparison with a blocked schedule, on the ability to differentiate similar stimuli. But in that case, what mechanism generates the attentional shift? And why is this shift boosted more by intermixed and simultaneous pre-exposure than by blocked pre-exposure?

Several accounts of perceptual learning have suggested mechanisms able to explain why attention to the distinctive features of stimuli may be greater following intermixed than after blocked pre-exposure (e.g., Gibson, 1969; Hall, 2003; Mackintosh, 2009; McLaren et al., 1989; McLaren and Mackintosh, 2000; Mitchell et al., 2008a,b). However, most of them have difficulty explaining why an attention shift would be greater following simultaneous than after blocked pre-exposure. For example, according to Hall (2003), heightened attention to distinctive features would stem from the greater salience of these features. On the basis of a general habituation mechanism, repeated exposures to a stimulus will lead to a progressive loss of its salience. But Hall (2003) assumes that the salience of the distinctive features of similar stimuli may be better preserved during intermixed than during blocked pre-exposure, due to the associative activation of the distinctive features' internal representations in their physical absence. It could be assumed that the associative activation of absent distinctive features would occur to a greater extent during intermixed than during blocked pre-exposure (see, Hall, 2003, for a more detailed explanation). However, one could hardly assume this mechanism would operate during simultaneous pre-exposure, when all the distinctive features are physically present in all pre-exposure trials.

The account offered, by McLaren et al. (1989, 2000), entails a similar problem. The account predicts a greater attentional shift during intermixed than during blocked pre-exposure due to the unitization mechanism. This mechanism involves the establishment of excitatory links between the elements of any stimulus, and between these and the contextual background during their repeated presentation. According to McLaren et al. (1989; McLaren and Mackintosh, 2000), the unitization mechanism is able to reduce the salience of a stimulus element, with the magnitude of this reduction being directly proportional to the strength and number of associations between this stimulus element and all the others. When similar stimuli are repeatedly presented, their common elements and the context are sampled in every trial, but the distinctive elements are not. As a result, the common elements of the stimuli and the context will have stronger associations than the distinctive ones, and therefore will be less salient. Based on this unitization mechanism, Dwyer et al. (2011) offered another explanation of why attention to the distinctive features of stimuli may be greater after their intermixed than after blocked presentations. During blocked pre-exposure, the same stimulus is presented consecutively, so the common and distinctive elements of a stimulus will be equally associated with each other (and the context) and salience will be equally reduced for all of them. During intermixed pre-exposure, however, where stimuli alternate in appearance, the associative links of the distinctive elements will develop more slowly than those of the common elements, and will therefore be more salient. During simultaneous pre-exposure, all stimulus elements, common and distinctive, will be available equally often for sampling and linking, meaning that all their stimulus elements should lose salience to a similar degree. In short, without additional assumptions, the unitization mechanism is unable to explain why attention to the distinctive features of stimuli may be greater after simultaneous than after blocked pre-exposure, and if anything, predicts reduced salience and attention to these features. During blocked pre-exposure to two similar stimuli, the distinctive features are only present in half the trials, and so should be more weakly linked (and therefore more salient) than during simultaneous pre-exposure to the stimuli in all trials.

More recently, Mitchell et al. (2008a,b) have developed an alternative explanation of this issue based on memory mechanisms drawn from previous accounts of this process (Jacoby, 1978; Wagner, 1981). According to Mitchell et al., the more-attended features of a stimulus are those that have a better internal representation, and the amount of resources invested in stimulus processing are directly related to the extent to which the stimulus can be remembered. Fewer resources will be invested in processing a well-remembered stimulus, and more resources will be dedicated to processing to a poorly remembered stimulus. These authors propose that the memory of a stimulus can be affected by the interval between presentations and intermixed and blocked schedules clearly differ in this regard. During intermixed pre-exposure, the interval between the presentations of the distinctive elements of a given stimulus is twice as long as during blocked pre-exposure. So, following this logic, distinctive elements will be more poorly remembered during intermixed than during blocked pre-exposure, greater processing resources will be invested in them, and they will be better encoded in the memory of the stimulus and therefore more available for subsequent learning. Like the other accounts we have described (Hall, 2003; McLaren et al., 1989; McLaren and Mackintosh, 2000), this account predicts reduced attention to common elements in comparison with distinctive ones in general. Common elements are always present, so they will be well remembered and poorly processed during pre-exposure and therefore will be more poorly encoded. But if this is true, why would attention to distinctive features be greater during simultaneous than during blocked pre-exposure? Again, during simultaneous pre-exposure all stimulus elements are presented at the same time, so in the absence of additional assumptions, all should be equally remembered, processed and encoded. Since the simultaneous schedule offers the shortest possible interval between stimulus presentations, it ought to generate the poorest stimulus encoding. Empirical evidence appears to reject this prediction (Angulo and Alonso, 2012; Mundy et al., 2007, 2009), showing better performance in tasks requiring stimulus differentiation following simultaneous than following intermixed or blocked pre-exposure.

It should be acknowledged that complementary top-down mechanisms have been proposed as interacting with the aforementioned process in order to explain the effect of simultaneous pre-exposure on human perceptual learning (see Mundy et al., 2007, 2009; Dwyer et al., 2011). Some of these have been related to instructions given to participants during pre-exposure (e.g., Mackintosh, 2009; Tsusima and Watanabe, 2009). But because instructions are always the same regardless of the pre-exposure schedule, it is not clear how factors related to the instructions themselves could affect stimulus processing differently in different pre-exposure schedules.

Only the Gibsonian approach to perceptual learning offers a general idea which is able to explain why attention to distinctive features of similar stimuli may be greater after intermixed or simultaneous pre-exposure than after a blocked schedule: attentional shift is boosted by the former schedules because they offer better opportunities for stimulus comparison. It should be noted that in order to fully evaluate the effect of the opportunity for stimulus comparison on an attentional shift, simultaneous, intermixed and blocked schedules should be tested together, studying attention to both the distinctive and common elements. And even if it were proven, the mechanisms operating in what is vaguely described as a "good opportunity to compare the stimuli" would still need to be fully specified.

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