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Two eyes make a pair: facial organization and perceptual learning reduce visual extinction

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Abstract

We examined a patient with left spatial neglect and visual extinction due to right parietal damage in tasks where identical stimuli were presented before and after they were primed so as to be perceived as the eyes of schematic faces. In a first block, we presented alphanumeric stimuli (+ , o, T, 6) on the right, left, or both sides of fixation on a blank background, and established that the patient could perceive unilateral stimuli on either side but extinguished most of the left-sided ones in the bilateral trials. In a second block, some of these stimuli (+ , o) were presented again, but now in the position of eyes within the context of an oval frame which created the impression of a schematic face. Other stimuli (T, 6) were presented as previously on a blank background for an equal number of trials. In the third critical block, all stimuli were presented once again on a blank background, as in the first block. Now the patient extinguished very few of those left-sided stimuli primed to be seen as a pair of eyes in face configuration (+ , o), but still extinguished most of the other stimuli (T, 6). A second control experiment showed no effect of repeatedly exposing stimuli in a common region of space defined by meaningless shape boundaries. These results suggest that facial organization can group eye features before the level where attentional selection or extinction occurs, and that such grouping may be influenced by rapid perceptual learning.

Keywords: Facial organization; Face perception; Perceptual learning; Visual extinction; Spatial neglect

1. Introduction

Visual extinction is commonly associated with right brain damage and unilateral left spatial neglect [7,12]. Patients with visual extinction often fail to perceive stimuli in their contralesional field when simultaneously presented with ipsilesional stimuli, although they have intact visual fields and can perceive the same contralesional stimuli when presented alone. Extinction is thought to reflect a deficit in mechanisms of spatial attention towards the contralesional side, such that sensory inputs from the left field fail to reach awareness when attention is attracted by competing stimuli on the right side [4,7,12]. However, extinction can be reduced when bilateral stimuli are grouped together on the basis of 'preattentive' gestalt principles, such as similarity, symmetry, alignment, etc. [4,5,10,19,20,22]. In these conditions, bilateral stimuli can be processed as a single perceptual object, and hence do not compete for attentive selection and awareness.

Here we show that similar grouping effects can operate on the basis of top-down influences from higher-level object-based representation, namely, face structure. We examined visual extinction using a task adapted from Bentin et al. [2], who showed context-dependent priming effects in face perception in normal observers. This task presents observers with the same visual stimuli in three successive phases (see Fig. 1). Initially, these stimuli are seen as nonfacial alphanumeric characters (phase 1), but after they have been repeatedly exposed in the context of a face structure as portraying eyes (phase 2), they will induce the subjective perception of a pair of eyes even if the face structure is removed (phase 3). Remarkably, these stimuli can produce face-specific neural responses in ERPs (N170) and fMRI (fusiform gyrus) after they have been

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primed (i.e. in phase 3), but not otherwise (i.e. in phase 1) [2]. We asked whether such perceptual learning would still occur despite contralesional inattention in extinction, and afford the grouping of bilateral stimuli into a single facial structure. We also examined whether such effects are specific to grouping based on a face configuration rather than on lower level processes, such as a the inclusion within a common bounded region of space [9].

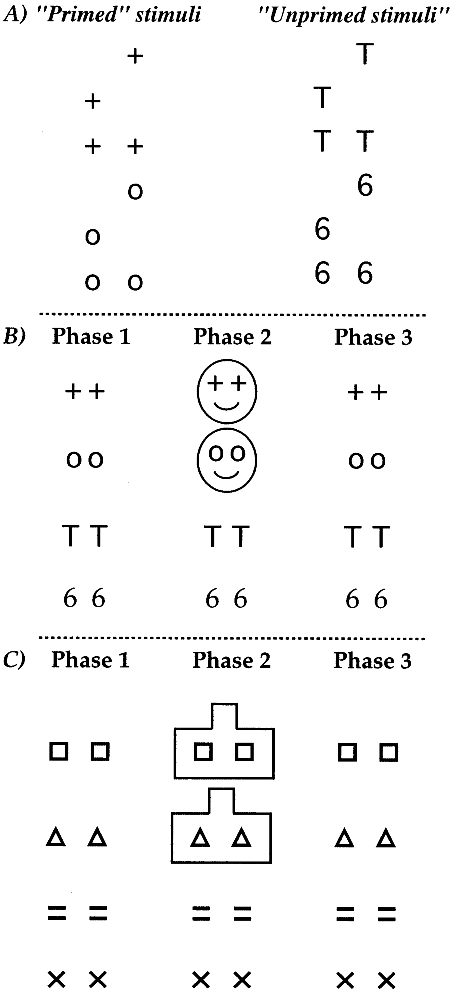

Fig. 1. Illustration of stimuli and priming procedure. (A and B) Illustration of experiment 1. (A) In the first experiment, four shapes (+ , o, T, 6) were presented either on the right, left, or both sides in three successive phases. (B) Phase 1 and phase 3 were similar, with shapes presented on a blank background. In phase 2, two stimuli (+ , o) were always presented in the context of a face structure, while the two other stimuli (T, 6) were presented again on a blank background like in phase 1 and phase 3. The critical experimental condition concerned the bilateral stimuli in phase 3, as compared to the same bilateral stimuli in the initial phase 1, according to whether they were primed by face structure (+ , o) or not (T, 6) during phase 2. (C) Illustration of experiment 2. The second experiment was similar to the above but used different stimuli (□, △, × , =). In phase 2, two of the stimuli (□, △) were presented in the context of meaningless shape, while the two other stimuli (× , =) were presented once again on a blank background.

2. Methods

2.1. Patient

SD is 64-year-old right-handed woman who suffered a right hemisphere stroke in 1996. Her neurological condition has remained stable since then. On clinical examination, she still shows severe weakness and sensory loss of the upper and lower left limbs. She has intact visual field on both sides, but marked left visual extinction on bilateral simultaneous stimulation during confrontation testing. Mild left spatial neglect is found in letter cancellation (17/60 omissions) and line bisection tasks (mean 15 mm rightward deviation/180 mm lines). General cognitive functioning is preserved. Chronic brain CT scan shows a large infarct in the right middle cerebral artery territory, with fronto-parietal cortical damage mainly involving inferior and posterior parietal cortex, pre- and post-central gyri, inferior and middle frontal gyri, and subcortical lenticulocapsular structures. An exact reconstruction of the patient's lesion is illustrated in a previous study [17].

The first experiment reported in the current study was carried out three years post-stroke onset (January 1999), and the second experiment was carried out two years later (February 2001). During this time, the severity of her neglect and extinction has remained unchanged over repeated testing occasions [17].

2.2. Experiment 1

2.2.1. Material and procedure

Extinction was tested using four different visual stimuli, arranged in two pairs with similar low-level features (+ and o; T and 6). They were presented on a computer screen at ~ 50 cm from the patient (visual angle ~ 0.8°). The experiment involved three successive phases for each of these stimuli pairs. On each trial in each phase, either one stimulus was presented unilaterally (in RVF or LVF) or two similar stimuli were presented bilaterally, in random order (exposure duration 50 ms). Bilateral stimuli were separated by ~ 3°. All stimuli were preceded by a central fixation dot (500 ms). An experimenter sitting opposite to the patient checked that the dot was correctly fixated before initiating each trial. There were 24 bilateral and 24 unilateral trials for each stimulus category in each phase (total 576 trials). The patient had to report the name and number of stimuli on each trial.

Phases 1 and 3 were similar in all respects, with all stimuli appearing on a blank background screen. Phase 2 served as a priming phase, in which one pair of stimuli ('primed' stimuli, + and o) appeared in the context of an oval face that remained on the screen between trials, while the other pair of stimuli ('unprimed' stimuli, T and 6) appeared again on a blank

Table 1
Results of experiment 1 in all conditions [a]

Hemifield	Stimuli	No. of trials	No. of stimuli missed		
			Phase 1	Phase 2	Phase 3
RVF	T	12	0	0	0
	6	12	0	0	0
	+	12	0	0	0
	o	12	0	1	0
LVF	T	12	0	0	2
	6	12	1	1	2
	+	12	2	6	3
	o	12	1	4	1
Bilateral	T	24	12	7	12
	6	24	19	14	16
	+	24	23	17	4
	o	24	19	16	5

[a] RVF/LVF = right/left visual field.

screen (see Fig. 1A and B). In all three phases, blocks with Ts and 6s preceded blocks with +s and os. All stimuli were thus exposed for exactly the same number of trials so as to rule out any confounding effects due to familiarity or frequency. The three phases followed each other within the same testing session, with brief resting breaks between the blocks. The critical prediction concerned whether extinction would change for identical stimulus condition in phase 3 as compared to phase 1, due to face priming during phase 2, and whether this would be specific to those stimuli that have been exposed in the face context (+ and o). We predicted that if face priming occurred for these stimuli as described in the normals by Bentin et al. [2], bilateral presentation might then yield a subjective perception of an unitized object (a pair of eyes) in phase 3, instead of disjointed alphanumeric characters as in phase 1, thus reducing competition for attention and extinction.

2.2.2. Results

Table 1 shows the patient's performance across all conditions. All errors were misses, with no misidentified stimuli. Overall, SD exhibited marked extinction of left stimuli in bilateral trials (57% missed) as compared to unilateral left trials (16% missed). Critically, extinction was significantly reduced in phase 3 only for those stimuli seen in a face structure in the preceding phase 2 (+ and o), while there was no reduction for other stimuli (T and 6).

A three-way ANOVA was performed on the percentage of left-side misses across all trials using the factors of field condition (bilateral versus unilateral stimuli), experimental phase (first, second or third) and stimulus category ('primed' stimuli + and o, vs 'unprimed' stimuli T and 6). This showed a main effect of field condition ($F(1,22) = 79.1$, $P < 0.0001$) consistent with extinction on bilateral simultaneous stimulation, but only a marginal main effect of experimental phase ($F(2,21) = 3.8$, $P = 0.053$) and stimulus category ('primed' stimuli + and o, vs 'unprimed' stimuli T and 6; $F(1,22) = 3.8$, $P = 0.073$). Most importantly, however, there was a significant interaction between phase and stimulus category ($F(2,21) = 10.7$, $P = 0.002$), and between the phase and field condition ($F(2,21) = 8.9$, $P = 0.004$). As shown in Fig. 2, extinction was similar across the three phases for stimuli that were not primed by face context (64–44–58%, $F(2,3) = 0.69$, $P = 0.56$), whereas it decreased in the third phase for those stimuli primed by the face context (87–67–19%, $F(2,3) = 48.5$, $P = 0.005$). There was no significant change for unilateral LVF stimuli across the three phases ($F(2,9) = 3.3$, $P = 0.11$).

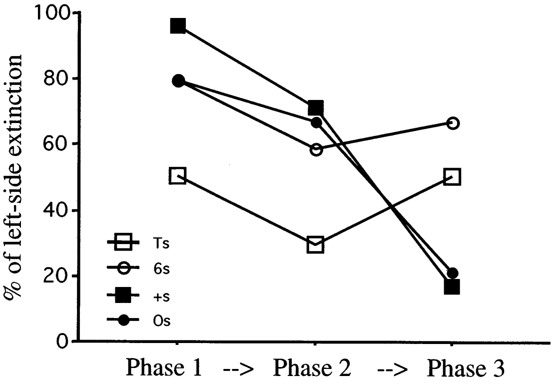

Fig. 2. Extinction rate across the three phases, showing the percentage of left-side stimuli missed in bilateral trials. Extinction decreased only slightly from phase 1 to phase 2 for all stimuli alike, but decreased much more markedly in phase 3 for the two stimuli previously primed by face structure (+, o) than for the other stimuli (T, 6).

Table 2
Results of experiment 2 in all conditions [a]

Hemifield	Stimuli	No. of trials	No. of stimuli missed		
			Phase 1	Phase 2	Phase 3
RVF	×	12	0	0	0
	=	12	0	0	0
	□	12	0	0	0
	△	12	0	0	0
LVF	×	12	1	2	1
	=	12	0	3	0
	□	12	0	4	1
	△	12	0	0	1
Bilateral	×	24	24	23	23
	=	24	24	24	24
	□	24	20	18	21
	△	24	23	21	20

[a] RVF/LVF = right/left visual field.

A direct comparison of phases 1 and 3 (in which stimuli were physically the same and task entirely similar) confirmed the critical prediction that extinction rate was modulated for the two primed stimuli ($\chi^2(1) = 27.4$, $P = 0.0001$, and $\chi^2(1) = 14.1$, $P = 0.0002$, for + and o, respectively, Yates correction applied), but not for the two other unprimed stimuli ($\chi^2(1) \leq 0.42$, $P \geq 0.51$, for T and 6). By contrast, direct comparison of extinction in phase 1 and 2 indicated no reliable change: there was only a slight decrease on bilateral trials with + in phase 2 ($\chi^2(1) = 3.75$, $P = 0.053$), and no difference for other bilateral trials with o, T, and 6 ($\chi^2(1) \leq 1.39$, $P \geq 0.24$).

2.3. Experiment 2

2.3.1. Material and procedure

This second experiment examined whether similar perceptual learning might occur for a stimulus pair configuration through the priming of lower visual processes, such as the grouping by a common region within any shape boundaries [9], or whether these effects indeed depend on the activation of higher level representation in the long-term memory, such as facial structure. Experiment 2 was similar to experiment 1 in all respects, including four types of stimuli presented in three successive phases, all given within a single testing session. One pair of stimuli (primed stimuli: □ and △) appeared on a blank screen in the first and third phase, but in the context of a meaningless geometric shape in the second 'priming' phase (see Fig. 1C); again this shape remained on the screen between trials. The other pair of stimuli ('unprimed' stimuli, × and =) appeared on a blank screen in all three phases. All stimuli were preceded by a central fixation dot (500 ms) and exposed for a 150 ms duration. The critical question concerned whether extinction would again change in phase 3 as compared to phase 1 when 'primed' stimuli have been conjointly perceived within a common bounded region. If the learning effects found in experiment 1 depend on the face representation rather than on grouping by any other common shape surface, we should predict that no significant change in extinction would occur in this experiment.

2.3.2. Results

Table 2 shows the patient's performance across conditions. Most errors were misses, with only four stimuli being detected but misidentified. Extinction of the left stimuli in bilateral trials was again severe (91% missed) as compared to the unilateral left trials (9% missed). However, the rate of extinction did not change for the stimuli presented within a shape contours (□ and △), just as for the other pair of stimuli (× and =).

An ANOVA of the percentage of left-side misses across all trials as above showed again a strong effect of field condition (bilateral vs unilateral, $F(1,22) = 588$, $P < 0.0001$), consistent with extinction on bilateral stimulation, and a marginal effect of stimulus category (primed vs unprimed stimuli, $F(1,22) = 4.54$, $P = 0.054$) due to the fact that the primed pair (□ and △) tended to be less severely extinguished than the unprimed pair (× and =). Critically, however, there was no effect of the experimental phase ($F(2,21) = 1.14$, $P = 0.35$) and no interaction between the phase and stimulus category ($F(2,21) = 0.28$), nor between any other factors (all Fs < 3.5).

Direct comparison of the proportion of extinguished stimuli in the three phases confirmed that there was no modulation of extinction across the three phases for either type of stimuli ($\chi^2(1) \leq 1.03$ in all cases), and therefore no significant perceptual learning due to exposure in a common region with a meaningless shape.

3. Discussion

These results demonstrate that perceptual grouping can occur and modulate the rate of extinction based on a context-dependent activation of face recognition mechanisms. In experiment 1, contralesional extinction on bilateral simultaneous stimuli was decreased after these were repeatedly exposed in the context of a face structure, suggesting that these stimuli could then be grouped into a perceptual gestalt and treated as a single object, namely, a pair of eyes. Such grouping may allow to reduce competition for attention and thus decrease extinction [4,19,22]. Decrease in extinction occurred even though stimuli and task were similar, and facial organization was totally irrelevant to task. Furthermore, decrease in extinction was specific to stimuli primed by the face context, and did not occur for other stimuli that had been presented on an equal number of trials, yet not in the face context. In addition, experiment 2 showed that these effects did not occur when stimuli were repeatedly exposed in a common region of space defined by meaningless shape boundaries [9].

These results have a number of implications. They provide a new demonstration that extinction can be modulated by grouping mechanisms despite pathological inattention towards contralesional information usually observed in the presence of bilateral stimuli [5,10,19,22]. However, previous demonstrations of grouping effects in extinction have implicated elementary visual processes (such as figure-ground segmentation and collinearity) which depend on mechanisms taking place in early striate and extrastriate cortex [5,10,19,20,22]. The latter areas are typically preserved in patients with parietal damage and may still operate on contralesional visual inputs so as to organize them into an unitized object despite extinction or neglect [4,21]. By contrast, our results show that similar grouping effects can arise through perceptual learning and influences from higher-level representation based on the facial structural encoding. Such a preserved organization of bilateral stimuli into an unitized face gestalt suggests that contralesional visual inputs can still access perceptual mechanisms in ventral temporal areas that encode face structure, in spite of the pathological ipsilesional bias in attention associated with extinction and neglect. This converges with other findings in extinction patients [17] and normal subjects [6,16], suggesting that encoding of facial configuration may operate relatively automatically at a 'preattentive' stage of processing. Thus, unattended faces can be detected more readily than other unattended stimuli both in neglect patients [17] and normals [8,11]. Preserved activation of face recognition mechanisms by visual information from the unattended hemifield despite neglect and extinction is also consistent with the recent ERPs and fMRI findings in parietal patients, showing that extinguished stimuli can still evoke face-specific neural responses in ventral temporal cortex [13,14,18].

Our results also differ from previous demonstrations of 'preattentive' grouping in that the present facial organization effects were determined by prior perceptual experience and learning, whereas grouping by other elementary gestalt principles typically depended on hard-wired connectivity in early visual cortex [10,15]. Here extinction was reduced due to priming of face recognition processes, and not due to some intrinsic properties of the stimuli themselves. This provides the first demonstration that such learning can operate on contralesional stimuli in the presence of unilateral inattention and extinction. In keeping with this, evidence in normal subjects suggests that visual priming can arise even under conditions of inattention [8], and that perceptual learning may also influence visual object segmentation and grouping (for computational and experimental evidence, see Ref. [1]). An important implication of these findings is that awareness of contralesional stimuli can potentially be restored by perceptual learning, and that residual processing capabilities in intact brain pathways might be usefully exploited in the perspective of rehabilitation in patients with extinction and neglect.

A puzzling aspect of our results was that grouping effects emerged in phase 3 after learning but not in phase 2 when facial cues were physically present in the display. We have no straightforward explanation for this difference. However, we had no a priori prediction regarding phase 2 and our experiment was specifically designed to look at the effect of priming by comparing identical stimuli in phase 3 versus phase 1, following the procedure used by Bentin et al. [2]. We note that a stronger rightward bias in attention might have occurred due to the presence of the face contours extending farther in the peripheral field towards the right side. The presence of these face contours could also have induced some form of object-based neglect [3,23], as suggested by a trend for more misses on unilateral left trials in this condition, and this may have cancelled out with any concomitant benefit due to facial grouping.

While the different results in experiments 1 and 2 suggest that perceptual grouping and learning in extinction were mediated by face-specific processes (rather than by the common region of any meaningless shape), future studies should examine whether such effects are limited to the face domain or can occur with other objects. We suspect that faces represent a special visual category for which normal people have a natural expertise (and specialized neurons) allowing very efficient and automatic encoding of stimulus configuration [6,16,17]. However, it is possible that similar priming effects could be mediated even by novel shape stimuli if these were overlearned up to the point where they could become familiar and support some stored representation in long-term memory [1]. Such learning effects would still be consistent with our hypothesis that grouping effects can operate on the basis of top-down influences from higher-level object representation and thus influence the distribution of spatial attention.

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