What is extinguished in auditory extinction?

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Extinction is a frequent sequel of brain damage, whereupon patients disregard (extinguish) a contralesional stimulus, and report only the more ipsilesional stimulus, of a pair of stimuli presented simultaneously. We investigated the possibility of a dissociation between the detection and the identification of extinguished phonemes. Fourteen right hemisphere damaged patients with severe auditory extinction were examined using a paradigm that separated the localization of stimuli and the identification of their phonetic content. Patients reported the identity of left-sided phonemes, while extinguishing them at the same time, in the traditional sense of the term. This dissociation suggests that auditory extinction is more about acknowledging the existence of a stimulus in the contralesional hemispace than about the actual processing of the stimulus. *NeuroReport* 11:3059–3062 © 2000 Lippincott Williams & Wilkins.

Key words: Attention; Auditory extinction; Implicit processing; Phonetic discrimination; Spatial representation; Unilateral neglect

INTRODUCTION

Patients suffering from right hemisphere damage (RHD) frequently fail to detect, report or orient towards stimuli presented on their left side (unilateral neglect, UN), especially when these are presented simultaneously with stimuli on the right side (extinction) [1,2]. These deficits are reported more frequently in the visual modality, but are found also in the auditory and tactile modalities [3–6]. The investigation of UN and extinction is valuable not only because of the detrimental effect of these phenomena on the patient's outcome [7], but also because of their implications for theories of attention, space representation and consciousness [8]. One critical issue raised by UN and extinction, regarding these theories, is the fate of neglected or extinguished stimuli. That is, at what stage(s) does the processing of a neglected or extinguished stimulus fail.

In the visual modality, a few studies found evidence for implicit processing of extinguished stimuli, even to a categorical level. This evidence consisted mainly of above-chance same–different judgments [9] and preference judgments [10], and of priming effects induced by neglected stimuli [11,12]. Less is known about the fate of extinguished auditory stimuli. Some evidence for implicit processing of neglected auditory stimuli was recently provided by the finding that identification of contralateral consonant–vowel syllables by UN-RHD patients was improved by the 'ventriloquist effect': placing an inert fictitious loudspeaker on the ipsilesional side of the patient improved the identification of phonemes presented by a hidden loudspeaker on the contralesional side [13]. Also, in a group of UN patients, neglected left-sided syllables interacted with the lip reading of a human speaker presented on a video monitor positioned on the right (McGurk illusion) [14].

In most previous studies the processing of ignored stimuli could be inferred from the influence of these stimuli on subsequent behavior. However, the results of a recent study showed that extinguished auditory phonemes were sometimes overtly identified, but being focused at other issues, the implications of this finding were not further explored or discussed [6]. To examine this finding we used a similar paradigm, and presented patients with two different phonetic stimuli, one emitted from a loudspeaker positioned on the right side of the patient and the other from a loudspeaker on the left. By asking the patients not only to detect the stimuli but also to identify them, and by examining the trials where extinction occurred, we were able to test whether the patients actually processed the extinguished stimuli for their phonetic content. We present here cases in which unawareness of the existence of a contralesional stimulus was associated with stimulus processing, demonstrated by identification of the extinguished stimulus.

MATERIALS AND METHODS

Patients: Twenty-six RHD patients, who suffered a first ischemic or hemorrhagic stroke and were hospitalized for rehabilitation, were tested for auditory extinction, using the method described. The patients clearly segregated into two groups: 12 with mild or no extinction who missed 0–6 of 36 (0–17%) left-sided stimuli in conditions of bilateral simultaneous stimulation (BSS), and 14 displaying severe extinction, missing 18–36 of 36 (50–100%) left-sided stimuli on BSS. Since the target of this study was to examine cases of extinction, the latter group of 14 patients was included

in the analysis (Table 1). The patients had no previous neurological or psychiatric ailments. The study was approved by the local Helsinki committee and patients gave informed consent to participate in this study.

Stimuli: The stimuli were 12 different consonant–vowel (CV) syllables, naturally produced by a male speaker. The stimuli were digitized, trimmed to 200 ms duration and stored as 44 100 bps/16 bit digital audio files. The CV syllables were da, ba, pa, za, va, na, ma, ra, ka, la, ga, and ta, in a Hebrew accent. For bilateral presentations the following pairs were used: la-ba, da-ra, na-ma, va-za, ta-ka, pa-ga. The pairs were chosen to combine distinct consonants (i.e. with different places of articulation). This was done with two aims in mind. First, the distinction between the phonemes would make it less likely that one phoneme will mask the other. Second, in this situation it would be easier to tell which of the two phonemes the patient actually identified.

Extinction test: The patients were seated in an echo-reduced, dimly lit room. They were informed that they were about to hear syllables either from the right-hand, left-hand, or both loudspeakers together, and were required to first report the heard syllable(s) (identification), and then say whether the syllable(s) were on their left, right or both sides (localization). The patients did not know in advance which syllables were in the group to be identified or the composition of the pairs. Before the presentation of each trial a warning string appeared on a monitor, which the subject was looking at, and the patient was asked if she/he was ready. In the unilateral trials the patients were presented with a CV stimulus played by a loudspeaker located in front of the patient, 60° to the left or right, and at a distance of 90 cm from the patient's ear. In the BSS trials two different CV stimuli were presented simultaneously, one from the left- and one from the right-side loudspeakers. The syllables were presented with an intensity of 75 dB (SPL) measured at the location of the center of the subjects' head. There were 36 left, 36 right and 36 BSS trials mixed in a random order, with a short, self-terminated break provided after every 36 trials. In the BSS condition the pairs were presented in a within-subject counter-balanced fashion, so that one syllable of the pair was on the left half of the times and on the right on the other half of the times (and vice versa for the other syllable). An experimenter stood just behind the patient, to ensure that no head deviation occurred. The experimenter reassured the subject that he was doing well (regardless of the actual accuracy of the patient), reminded him occasionally that syllables could be presented from the left, right or both sides, and recorded the answers on the computer.

Data analysis: For unilateral trials the accuracy of localization (left or right) and identification were recorded. For each BSS trial, the localization was categorized as correct if the patient said 'both', as left extinction if the patient said 'right' and as right extinction if the patient said 'left'. The identification of the syllables was recorded independently of the localization score. Thus, the accuracy of identification of the left or the right phoneme was scored regardless of whether the localization was correct or erroneous, and regardless of whether the patient reported the identity of one or two syllables (in trials where no extinction occurred).

RESULTS

Unilateral trials: Some (mean $21 \pm 28.9\%$) of the left-sided stimuli were localized to the right (alloacusis [3]), whereas alloacusis from right to left occurred significantly less frequently (mean: $2.6 \pm 3.99\%$; $t(13) = 2.3$, $p < 0.05$, within-subject). Indeed, the patients varied considerably in the frequency of alloacusis, as one patient erroneously localized all left-sided stimuli to the right, whereas three patients correctly localized all left-sided stimuli. There was no difference in the rate of identification of left and right stimuli (90.1% and 90.2%, respectively) across the group.

Bilateral trials: Each patient was presented with 36 bilateral trials. On the great majority ($77 \pm 19\%$) of the trials, the patients reported having heard only a right-sided stimulus, that is, they 'extinguished' the left stimulus. The

Table 1. Demographic, clinical and lesion data of patients.

Patient	Age, Sex	Lesion type	Lesion site	TAO
KY	61/F	I	T,IPL	159
DY	64/M	I	T,P,F	83
GF	68/F	I	O,P, Post. Th	55
BS	49/M	I	T,P,F	145
HF	65/M	I	T, IPL	15
GH	54/M	I	BG	40
ZY	68/M	H	Th	25
ER	55/M	I	F,T, IPL	27
RY	55/M	H	BG, IC	25
CY	62/M	I	IPL,BG, IC	19
YB	52/M	H	BG	58
NM	58/M	H	Th, IC, PVWM	78
ZA	58/F	I	T,P,F,BG, IC	19
HS	34/F	I	T,P,F,BG	34

Lesion Site: BG, Basal ganglia; F, frontal; IPL, Inferior parietal lobule; LN, lenticular nucleus; P, parietal; PVWM, periventricular white matter; IC, internal capsule; T, temporal; Th, thalamus.
Lesion Type: I, ischemic; H, intracerebral hemorrhage
Time after onset: interval in days between the stroke and the test.

patients correctly detected the BSS trials as bilateral presentations on $15 \pm 19\%$ of the trials, and on the remaining $7 \pm 13\%$ of the trials the patients detected a left-sided presentation (i.e., right extinction). All of the patients extinguished more left-sided than right-sided stimuli.

Right-sided phonemes were identified significantly more often than left-sided phonemes by all the patients in the BSS condition (59% and 27%, respectively; the patients never identified both stimuli correctly). The within-subject difference between left and right side identification was therefore highly significant ($t(13) = 6.678$, $p < 0.0001$), apparently consistent with the extinction of left-sided stimuli. However, the identification of left- and right-sided phonemes in the condition of extinction was the target of the present study. Therefore, trials in which extinction of the left-sided stimulus was revealed were analyzed separately. In the majority of these trials ($62 \pm 14\%$) the patients identified the right sided phoneme (congruent with the localization), but in a considerable proportion of the trials ($21 \pm 8\%$) the patients identified (shadowed) the left-hand stimulus, and not the right, while reporting that only a right-hand stimulus was heard. Since 12 different consonants were used, the chance level for guessing the phoneme was at the most 0.083. In fact, since the patients did not know which consonants might be used, the chance level is much lower. As noted above, the patient group identified the left-hand syllables on left-extinction trials on $21 \pm 8\%$ of the trials, significantly above even the stringent 8.3% chance level ($t(13) = 6.092$, $p < 0.0001$). Indeed, all but one of the 14 patients identified the left-hand syllables on left-extinction trials above this chance level (Fig. 1)

DISCUSSION

In everyday clinical practice, extinction is measured by presenting two identical stimuli, such as the testers' moving fingers for visual testing [15], or noise produced by the testers snapping fingers for auditory testing. When the patient reports perception only of the ipsilesional side, it is impossible to tell what became of the information presented on the other side. In the present study we contrasted the simultaneous perception of two different phonemes, and asked the patients both to detect their presence and to report their identity. On unilateral presentations, alloacusis of left-sided stimuli (their erroneous localization on the right) occurred significantly more often than the alloacusis of right-sided stimuli [3]. In contrast, the rate of correct identification of left and right stimuli (independent of stimulus localization) was similar. This result suggests a distinction between spatial processing and identification of the contralesional stimuli, a possibility that was strongly supported by the patients' performance on the BSS trials.

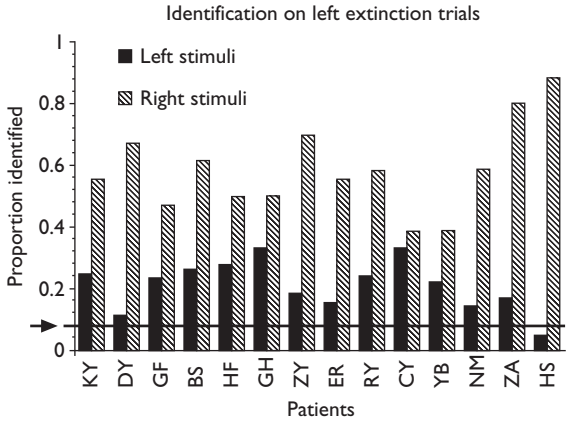

Fig. 1. Proportion of correct identification of left and right phonemes on trials in which the patients extinguished the left of the two simultaneously presented stimuli. The horizontal line marked by the black arrow indicates the stringent level of chance identification (see text).

On the BSS trials the patients extinguished, as expected, most of the left-sided stimuli and identified significantly more right sided stimuli. However, the more illuminating result emerged from the separate analysis of trials in which left extinction was demonstrated (i.e., when the patient declared hearing only one sound stimulus, coming from the right side, where in fact two simultaneous stimuli were presented, one on either side). On these trials, 13 of 14 patients reported the identity of the left-hand stimulus at above-chance level, on the very same trials in which the left-hand stimulus was extinguished. This result, which confirms at least one previous observation [6], is a demonstration of dissociation between the report of stimulus location and the explicit report of stimulus identity. Whereas the absence of detection on the contralesional side is a manifestation of extinction, the correct identification discloses the processing of the stimulus. This dissociation suggests that auditory extinction is more about acknowledging the existence of a stimulus in the contralesional hemispace than about the actual processing of the stimulus.

Extinction may be viewed as a problem of limited attentional capacity [16] or of shifting attention to the contralesional side [2,17] in the face of competition, so that the contralesional stimulus is not processed properly. Nevertheless, using paradigms aimed at unveiling implicit processing, it has been shown that extinguished visual stimuli are indeed processed, and may implicitly affect behavior [9–12]. To explain this dissociation, it was recently suggested that in extinction there is a dissociation between an intact within-object processing and a disrupted between-object processing [18,19]. Anatomically, this distinction was based on the division made, initially in the macaque [20], between the ventral visual pathway, engaged in object recognition, and the dorsal visual pathway, involved in processing the location of objects in space. The latter pathway, extending from the striate cortex in the occipital lobe to the superior parietal cortex, is apparently the one more commonly affected in cases suffering from visual extinction [15,21].

The current data join recent observations [6,13,14] demonstrating that the same distinction may be true for the auditory modality as well, although much less is known about the existence of object-based *vs* space-based cortical streams in audition. The results from the auditory modality lend even more support for the specific spatial deficit. Thus, in keeping with the facilitating influence of the ventriloquist effect on identification of stimuli similar to those used herein [13], the present results showed that the 'extinguished' data is accessible for overt response, so long

as it is attributed to the ipsilesional side (alloacusis). Moreover, we recently provided electrophysiological evidence that the preattentive processing of auditory spatial information from the affected side is disrupted more than the processing of other auditory features [22].

The fact that auditory neglect and extinction are not as obvious as visual neglect and extinction, may be explained by the fact that the nature of sound, which possess directionality but still fills space, makes it more amenable to misattribution of source location. Possibly, by artificially mapping the stimulus to the ipsilesional side, awareness and overt response are made possible. If so, this result emphasizes the role of spatial coding, over and above the role of intrinsic feature coding, for conscious awareness.

CONCLUSION

In testing for extinction, it is informative not only to ask for localization of the stimulus, but also for its identification. When a RHD patient extinguishes a left-sided stimulus in BSS, this may be a failure of awareness of events on the left rather than a failure to process the content of the events. By simply presenting content stimuli and asking the patient to identify them, it is possible to dissociate these two aspects of cognition. The connection between being aware of an event and localizing it, supports the importance of spatial coding in conscious awareness.

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