Cerebral patterns of attentional habituation to emotional visual stimuli

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Abstract

Attentional habituation in response to emotional stimuli, an aspect of the interaction between cognitive and emotional processes that has received scant attention, was investigated. Event-related potentials were recorded using a 60-electrode array from 25 participants who attended to 120 presentations of three different picture types: emotionally negative (S–), positive (S+), and neutral (S0). The affective content of the stimulation was assessed, through questionnaires, by the participants themselves. N1 showed different patterns of habituation as a function of the stimulation: amplitudes indicated that S– was more resistant to habituation than S0 and S+. This pattern, which reflects a greater capacity of S– to attract and maintain the participant’s attention, is interpreted as a manifestation of the “negativity bias,” a phenomenon that reflects an evolution-favored set of mechanisms that facilitate a rapid and intense response to aversive events.

Descriptors: Emotion, Attention, Habituation, ERPs, N1, Negativity bias

The strong interdependence of cognitive and affective neural processes has been systematically studied only in the last few years. In relation to the interaction between attention and emotion, it has been proposed that attention is more deeply engaged in events that have some type of affective value than in routine, neutral events (Lang, Bradley, & Cuthbert, 1997). Several research lines support this proposal. For example, behavioral (reaction time) results suggest that attention is mainly directed to emotional, and particularly aversive, stimulation (Mogg & Bradley, 1998, 1999). Moreover, affective visual stimuli trigger a greater mobilization of resources than neutral stimuli in attention-related areas in the anterior cingulate cortex (Canli, Desmond, Zhao, Glover, & Gabrieli, 1998; Northoff et al., 2000; Teasdale et al., 1999) and the visual association cortex (Lane, Chua, & Dolan, 1999; Lang et al., 1998; Simpson et al., 2000). Reciprocally, the amygdala, a nucleus known to be related to emotional processes, has been found to modulate visuospatial attention (Holland, Han, & Gallagher, 2000). Finally, ERP research also supports greater involvement of attentional cerebral mechanisms for affective stimulation (Carretié, Martin-Loeches, Hinojosa, & Mercado, 2001). Importantly, the extent of a stimuli’s capacity to attract the subject’s attention is reflected in another important neural mechanism, scarcely explored in this field: habituation.

Habituation is a reduction in the response to a stimulus when it is repeated, and is a ubiquitous phenomenon displayed by most multicellular organisms (Thompson & Spencer, 1966). It constitutes an adaptive mechanism by which the organism moves limited processing resources away from an event that is well known or familiar, making them available for other concurrent or forthcoming stimuli (Stephenson & Siddle, 1983). This phenomenon involves attentional resources, whose mobilization decline with stimulus repetition. Thus, habituation to visual stimuli is associated with a decrement in the visual cortex activation (Desimone, Miller, Chelazzi, & Lueschow, 1995; Fischer, Furmark, Wik, & Fredrikson, 2000). According to main theories of habituation (Öhman, 1979; Sokolov, 1969), this process is produced when perceptual learning occurs due to stimulus repetition and, consequently, a neural representation of it is formed and stored. Once this representation or model is formed, attentional resources are free to focus on events that do not match with it. Along with behavioral research (for a review, see Öhman, Hamm, & Hugdahl, 2000), neurophysiological data confirm that, once a repeated visual stimulus is stored in memory areas of the inferior temporal cortex, attentional resources may better process new stimuli (Desimone et al., 1995).

Of particular interest for this research is the fact that the actual information provided by the stimulus influences habituation patterns. In the light of several experimental studies on the peripheral psychophysiological patterns that characterize the orienting response, it has been proposed that signal stimuli (i.e., those important for the individual) become habituated...
less and more slowly than non-signal (non-important) stimuli (Ohman et al., 2000; Siddle, Stephenson, & Spinks, 1983). Emotional stimuli are, by definition, signal stimuli (Ohman et al., 2000). Maintaining processing resources mobilized towards emotional events, even when they are familiar (i.e., even when they have been repeatedly perceived), constitutes an adaptive mechanism that often represents an aid to survival. Though habituation is a process occurring at central levels of the nervous system (being different from other peripheral processes that also elicit response decrements towards repeated stimulation, such as sensory adaptation), no studies on brain activity, to the best of our knowledge, have tested the relationship between the stimuli’s emotional information and habituation patterns.

The preferable techniques for studying habituation are those recording temporally agile physiological signals, such as those based on the electrical activity associated with neural functioning. The main reason for this is that brain indices of habituation involve key rapid (short latency) and brief (short duration) neuronal mechanisms occurring within the first 200 ms after each stimulus presentation (e.g., Bruin, Kenemans, Verbaten, & Van der Heijden, 2000), which are not recordable by other methodologies employed for studying brain activity. The main objective of this research was to explore the pattern of attentional habituation towards emotional and neutral stimulus through event-related potentials (ERPs), a manifestation of brain electrical activity. A possible different habituation pattern in relation to the emotional valence (positive or negative) of stimulation was also explored.

Data currently available indicate that the N1 component of the ERPs is particularly well suited to the study of attentional habituation. This component is usually obtained through an experimental paradigm used for studying visuospatial selective attention (described below). This paradigm typically elicits two components, maximal over occipital and parietal areas, whose greatest amplitude is produced in response to attended stimuli: P1 (75–130 ms) and N1 (150–190 ms). The P1 and N1 are two differentiated attention effects, N1 reflecting a wider range of attention-related processes that are not strictly circumscribed to visuospatial attention. For example, it has also been linked to visual discrimination processes (Vogel & Luck, 2000). Interestingly, the amplitude of N1 has been shown to be susceptible to habituation (Bruin et al., 2000; Kenemans, Verbaten, Roelofs, & Slangen, 1989; Verbaten, Roelofs, Sjow, & Slangen, 1986). We expect the attentional processes evoked by emotional stimuli to present greater resistance to habituation than those evoked by neutral stimuli. Therefore, we hypothesize that amplitude decrements of N1 in final presentations, with respect to initial presentations, will be smaller in response to emotional stimuli than in response to neutral stimuli.

Methods

Subjects
Twenty-five right-handed students from the Universidad Autónoma de Madrid took part in this experiment. These 25 participants (19 women) were aged between 20 and 27 years (mean = 22.32). They took part voluntarily in the experiment, and reported normal or corrected-to-normal visual acuity.

Stimuli and Procedure
Figure 1 shows, schematically, the structure of the experimental design employed in the present experiment, which resembles the usual paradigm employed in the study of visuospatial attention (see, e.g., Mangun & Hillyard, 1995). Cues consisted of arrows 3.5° (visual angle) long presented in the center of the screen, pointing towards the left or right. This presentation lasted for 200 ms. Fifteen hundred milliseconds later, a color photograph (17.1° high × 12° wide) or target was presented, also for 200 ms, on the side of the screen previously indicated by the arrow.1 The center of the target was located 12° to the right or left of the center of the screen. Targets were three color photographs with neutral or affective content (as evaluated through questionnaires, explained below): an opposite-sex nude (positive stimulus or S+), a tropical, cockroach-like insect (negative stimulus or S−), and a glass (neutral stimulus or S0). The order in which these three types of trial was presented was semi-random (i.e., avoiding the consecutive presentation of the same photograph more than twice). For all the stimulus categories, the right–left proportion of target location was 50%–50%. Finally, 1,000 ms after target onset, a 100-ms beep sounded.

The task consisted, in all trials and with the right hand, in pressing a different key whenever a “glass,” an “insect” or a “nude” appeared. Requiring the active classification of all the stimuli (pressing different keys) served to control which stimuli were not actually attended, and helped to avoid a situation whereby participants considered that some of the stimuli were more important for the task than others (e.g., emotional stimuli more important than neutral ones), and thus to avoid a relevance-for-task effect, often described in previous studies (Carretié, Iglesias, García, & Ballesteros, 1997; Duncan-Johnson & Donchin, 1977). Participants were instructed to look continuously at a small mark located in the center of the screen and to respond and to blink only after the beep. Intertrial interval was 3,000 ms, and 120 trials were presented for each of the three target stimuli: S+, S−, and S0 (i.e., a total of 360 valid trials were carried out).2

As previously indicated, participants completed a bidimensional scaling test for each picture after the recording sessions. This test assessed the valence and the arousal content of the pictures, two affective dimensions that are considered as explaining the principal variance of the emotional meaning (Lang, Greenwald, Bradley, & Hamm, 1993; Osgood, Suci, & Tannenbaum, 1957; Russell, 1979; Smith & Ellsworth, 1985).

Recording and Data Analysis
Electroencephalographic data were recorded using an electrode cap (ElectroCap International) with tin electrodes. A total of 58 scalp locations were used: Fp1, Fpz, Fp2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7,

1In some other “invalid” trials, randomly inserted in the sequence and not analyzed, arrows signaled the opposite, wrong side of the screen. Invalid trials, irrelevant for the scope of studying habituation to attended stimuli, were presented in order to facilitate the maintenance of controlled attention: The relative difficulty that the presentation of invalid trials supposes would attenuate a voluntary (unrelated to habituation) decay in attention.

2Additionally, as already mentioned, 30 invalid, not analyzed trials were presented for each stimulus category. The stimuli in these trials were the same as in valid ones.
Habituation to emotional stimuli

valence was that which was assumed a priori, and secondly, that participants in order to confirm, firstly, that their affective control analyses were ANOVAs on these assessments given by bidimensional scaling test for each picture after the recording analyses described below were carried out using the SPSS 10.0 selected from the 58 channels actually used, are represented. All Six recording channels (AF3, AF4, C3, C4, PO3, and PO4), final'' difference waves for each of the three stimulus categories. Figure 2b shows the ''initial minus ERP) obtained in initial and final trials for the average of the grand averages (once the baseline had been subtracted from each recording session. The continuous recording was divided into 960-ms epochs for each trial, beginning 160 ms before the target onset. Trials where subjects pressed a wrong key (i.e., a key corresponding to a different stimulus category from that actually presented) were eliminated. A visual inspection was also carried out, eliminating epochs with eye movements or blinks (2.4% were rejected, no differences between conditions were observed). ERP averages were categorized according to each type of stimulus (S+, S0, S–).

Results

Only the ERPs elicited by the first 30 and the last 30 artifact-free trials of each stimulus category (which from now on will be referred to as “initial” and “final,” respectively) were taken into account for analysis. Even after trial inspection and elimination, these initial and final trials never overlapped: the range of sequence positions for the initial trials did not surpass, in any subject, trial 50 of category S+; 82 of S0, and 79 of S–. To illustrate the N1 habituation effect, Figure 2a shows grand averages (once the baseline had been subtracted from each ERP) obtained in initial and final trials for the average of the three stimulus conditions. Figure 2b shows the “initial minus final” difference waves for each of the three stimulus categories. Six recording channels (AF3, AF4, C3, C4, PO3, and PO4), selected from the 58 channels actually used, are represented. All analyses described below were carried out using the SPSS 10.0 software.

Control Analyses

As explained in the Methods section, each participant filled out a bidimensional scaling test for each picture after the recording sessions, assessing their valence and their arousal level. First control analyses were ANOVAs on these assessments given by participants in order to confirm, firstly, that their affective valence was that which was assumed a priori, and secondly, that positive and negative pictures were balanced with respect to their arousal. Table 1 shows the means and standard error of means of both dimensions for each type of image. One-way repeated-measures ANOVAs were computed for valence and arousal dimensions, using Stimulus (three levels: S+, S0 and S–) as factor. The Greenhouse–Geisser (GG) epsilon correction was applied to adjust the degrees of freedom of the F ratios. Post hoc comparisons were made to determine the significance of pairwise contrasts, using the Bonferroni procedure (alpha = .05). ANOVAs yielded significant differences in both valence and arousal, $F(2,48) = 78.513$, GG epsilon = 0.93, $p < .001$ and $F(2,48) = 29.254$, GG epsilon = 0.92, $p < .001$, respectively. Post hoc contrasts indicated that S+ and S– showed different valences but not different arousal levels. S+ and S– differed from S0 in both arousal and valence.

Secondly, differences with respect to the task difficulty associated with each stimulus were analyzed, to ensure that this variable did not represent an interference with respect to the relevant, emotion-related, experimental effects. The presence of differences in the level of difficulty may cause attentional demand (which affects the habituation rate) to differ between stimulus categories for nonaffective reasons. Therefore, number of errors in the task (i.e., number of wrong keys pressed) with respect to each type of stimulus was analyzed via a one-way repeated-measures ANOVA on the Stimulus factor (three levels: S+, S–, and S0). Means and standard error of means of incorrect answers in the task are shown in Table 1. The low error rate, which ranges from 0.48 to 1.08 trials out of 120, can be seen. Differences were not significant, $F(2,48) = 2.36, p > .1$.

Detection and Quantification of the ERP Components: Temporal Principal Component Analysis

Components explaining most of the ERP variance were extracted through temporal principal component analysis (tPCA). This technique has been repeatedly recommended for the detection and quantification of components, because the exclusive use of the traditional visual inspection of grand averages may lead to several types of misinterpretation (Chapman & McCrary, 1995; Coles, Gratton, Kramer, & Miller, 1986; Donchin & Heffley, 1978; Fabiani, Gratton, Karis, & Donchin, 1987; McGillem & Aunon, 1987). A single covariance-matrix-based tPCA was carried out for both initial and final ERPs, those evoked by S+, S– and S0 being considered jointly in this analysis. To reduce the amount of data (only for this tPCA), we averaged each two adjacent digitized points for each ERP (each two adjacent points represent 8 ms). The decision on the number of components to select was based on the scree test (Cliff, 1987). Extracted components were then submitted to varimax rotation.

Following this selection criterion, four components were extracted from ERPs. Factor 1 explained 57.29% of total variance, Factor 2 explained 19.78%, Factor 3 explained 4.28%, and Factor 4, 3.35% (43.70%, 18.45%, 15.05%, and 7.50%, respectively, after rotation). Figure 3 shows the rotated loadings plotted over time for these four components. Additionally, mean factor scores for each location and for each component are shown in Figure 4 in the form of scalp maps. Factor scores, which are calculated for each individual ERP, represent the product of the factor coefficient and the original data point, so that they can be interpreted as reflecting the amplitude of a component. Factor peak-latency and topography characteristics associate Factor 4 (peaking at 176 ms) with the wave indicated by the label “N1” in grand averages (Figure 2). This label will be employed from now on.

Figure 1. Schematic representation of the experimental paradigm employed in the present experiment. All values in milliseconds. ITI: intertrial interval.
Figure 2. (a) Grand averages obtained in the 30 initial and the 30 final trials for the average of the three groups of stimuli. (b) Initial minus final difference waves for each of the three stimulus categories (S+, positive; S-, negative; S0, neutral). Gray vertical lines mark the inversion of polarity in frontal, with respect to posterior, N1 amplitudes. Scales are shown in C3 grand averages.

Table 1. Means and Standard Error of Means (in Parentheses) of Valence (−2, Negative to +2, Positive) and Arousal (−2, Calming to +2, Arousing) Assessments Given by the 25 Participants to the Three Types of Stimulation (Neutral, Positive, and Negative)

<table>
<thead>
<tr>
<th></th>
<th>Neutral</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arousal</td>
<td>−0.64 (0.16)</td>
<td>1.12 (0.18)</td>
<td>0.80 (0.16)</td>
</tr>
<tr>
<td>Valence</td>
<td>0.56 (0.18)</td>
<td>1.36 (0.15)</td>
<td>−0.96 (0.09)</td>
</tr>
<tr>
<td>Errors</td>
<td>0.48 (0.16) [0.40%]</td>
<td>0.68 (0.23) [0.57%]</td>
<td>1.08 (0.23) [0.90%]</td>
</tr>
</tbody>
</table>

Note: Additionally, the last row shows means and standard error of means (also in parentheses) of incorrect answers in the experimental task (percentages with respect to the total number of trials, 120, are also provided).
on to facilitate understanding of the results. This component tends to present different polarity in frontal regions with respect to parietal/occipital regions (see Figure 2).

**Analyses on Experimental Effects**

Analyses on experimental effects required the 58-location ERPs to be grouped into different scalp regions to better describe the spatial distribution of the experimental effects. This “regional grouping” was carried out through a covariance-matrix-based spatial PCA (sPCA) on the N1 temporal factor scores corresponding to each of the 58 electrode locations, a system that is preferable to an a priori subdivision into scalp regions. Two spatial factors, one frontal (explaining 66.25% of total variance) and the other posterior (12.71%), were extracted (also through the scree test; Figure 5). Subsequently, ANOVAs on frontal and posterior spatial factors were computed. The factors were Trial type (two levels: initial and final) and Stimulus (three levels: S+, S0, and S−). The effect of Trial type alone helped to detect the susceptibility to habituation of N1 (i.e., whether repeated stimulation mobilizes to a lesser extent the attentional mechanisms reflected in this ERP component), which was the first objective of these analyses. As expected, Trial type had an effect on N1, this effect being significant in the frontal spatial factor, $F(1,24) = 16.975$, $GG\, \text{epsilon} = 1$, $p<.001$. The second objective of the analyses was to detect any differential pattern of habituation as a function of the stimulation. In this case, the Trial type × Stimulus interaction was the relevant contrast. This interaction was also significant in the frontal spatial factor, $F(2,48) = 3.575$, $GG\, \text{epsilon} = 0.782$, $p<.05$.

![Figure 3. tPCA analysis on initial and final trials: factor loadings after Varimax rotation. TF: temporal factor.](image)

![Figure 4. tPCA analysis on initial and final trials: topographic maps representing the factor scores (averaged for the three types of stimuli) obtained in each of the 58 recording channels. TF: temporal factor.](image)
positive; S0, neutral).

Figure 6 shows the mean factor scores (directly related to amplitudes, as explained above) with respect to the interaction Trial type × Stimulus. The interpretation of this figure must take into account that, as already indicated, N1 is negative in parietal/occipital areas but positive in frontal areas: In the latter case, habituation is reflected by decreasing (from left to right) slopes. Though all three stimuli are associated with some level of habituation, S− shows the least pronounced slopes, which indicates a stronger resistance to habituation. In fact, post hoc comparisons indicated that only S+ and S0 elicit significantly lower amplitudes in final than in initial trials. Interestingly, whereas in initial trials the highest amplitudes are elicited by S+ (which, according to post hoc analyses, differ significantly from the lowest, elicited by S0), in final trials the highest amplitudes are elicited by S− (which also differ significantly from the lowest, again elicited by S0). In any case, differences between amplitudes elicited by S− and S+ are not significant in either initial or final trials.

Figure 6. Mean N1 factor scores (directly related to amplitudes) for the frontal spatial factor in response to the three types of stimuli (S+, positive; S−, negative; S0, neutral).

Discussion

First, it is appropriate to recapitulate the characteristics that define N1. Studies on attentional neural mechanisms have shown that N1 is a clear index of the level of attention: It is higher in response to attended than to nonattended stimulation (e.g., see reviews by Hillyard, Teder-Sälejärvi, & Münte, 1998; Luck & Hillyard, 2000; Mangun & Hillyard, 1995). Because its amplitude decreases significantly with stimulus repetition (Bruin et al., 2000; Kenemans et al., 1989; Verbaten et al., 1986), this component constitutes a useful tool for studying attentional habituation. An important question is which type of attention is reflected in N1. As explained in the introduction, it is the attention process in its broader sense (and not only its visuospatial aspect, to which N1 has been traditionally related) whose habituation would depend on the emotional content of the stimulation. Does N1 reflect attentional mechanisms other than visuospatially related ones? Although functional correlates of visual N1 are not yet well understood, some recent data suggest that N1 behavior is far from being limited to visuospatial attention. For example, in visual discrimination tasks (the task employed in the present experiment combined the traditional visuospatial paradigm with a “choice” or “discrimination” one), an “N1 discrimination effect” is observed, consisting in an increase in its amplitude (e.g., Ritter, Simson, & Vaughan, 1983; Vogel & Luck, 2000). Present results suggest that this discrimination effect could also be subjected to habituation.

The analyses presented here have shown that N1 is mainly distributed in two spatial components, one frontal and the other posterior, and that the former is that which presents susceptibility to habituation and a dependence of this habituation on the emotional content of the stimulation. The origin of N1 has been studied less than the origin of P1, its “companion” in ERP research on visuospatial attention, although their spatial characteristics, and particularly the involvement of frontal areas in the generation of N1, may support the P1/N1 dissociation. Thus, although it has been suggested that, like P1, N1 originates in the VAC (Mangun & Hillyard, 1995), previous studies have also found frontal sources for N1 in visuospatial attention experiments (Bruin et al., 2000). Therefore, this specific (with respect to P1) frontal aspect seems to be responsible for the habituation-related effects observed in the present and previous studies. Further research is necessary to locate the possible frontal source of visual N1, although several frontal regions, such as the anterior cingulate cortex or the medial frontal gyrus, have already been found to be involved in both selective attentional processes (Janer & Pardo, 1991; Nobre et al., 1997) and emotional processes (Bush, Luu, & Posner, 2000; Harmer, Thilo, Rothwell, & Goodwin, 2001).

As hypothesized, the lowest level of habituation (or the highest resistance to it) was associated with emotional, and not with neutral, stimulation. However, this trend is not elicited to the same extent by all types of emotional stimulation. Particularly, analyses on N1 indicate that the highest resistance to attentional habituation is specifically produced in response to S−, whereas N1 habituation to S+ and to S0 is similar (due to this pattern of habituation, whereas in initial trials the highest N1 amplitudes are elicited by S+, in final trials the highest amplitudes are elicited by S−, a trend suggesting that the attractiveness of the stimulation decreases with familiarity: see, in this regard, Koukounas & Over, 2001). Because S− and S+ have the same arousal content (see Results section), it may be stated
that habituation differences observed between them are due to the "valence, but not to the arousal, of S−. As explained in the introduction, the resistance of an event to attentional habituation constitutes an index of its capacity to attract the subject's attention. The fact that S− is the most resistant to attentional habituation appears to be a manifestation of the "negativity bias." This bias refers to the fact, as suggested by several studies, that negative events elicit more rapid and/or more prominent emotional responses (involving cognitive and physiological changes) than neutral or positive ones (Cacioppo & Gardner, 1999). The existence of the negativity bias has recently received experimental support from studies on brain activity (Ito, Larsen, Smith, & Cacioppo, 1998; Northoff et al., 2000). This phenomenon would have obvious adaptive and evolutionary advantages: The consequences of a dangerous or harmful event are often much more dramatic than the consequences of ignoring or reacting slowly to neutral or even appetitive stimuli (Ekman, 1992; Öhman et al., 2000).

In relation to this, and although the implication of attention (and its habituation) in the negativity bias has not been theoretically established, it could be expected that the attentional engagement towards negative emotional stimuli should be more intense than that towards neutral or positive stimuli. Experimental data support this assertion, as the privileged access of negative stimulation to attentional resources has been suggested by studies on autonomic physiological responses (Öhman, Esteves, Flykt, & Soares, 1993) and behavioral studies using reaction time (Pratto & John, 1991) or visual fixation (Fiske, 1980) as dependent variables. Moreover, behavioral (reaction time) data indicating that anxious subjects present an attentional bias towards negative events appear to be generalizable to nonanxious individuals (Mogg & Bradley, 1998, 1999).

Recent research directly exploring brain activity suggests that, in fact, attention-related cerebral mechanisms constitute a relevant element in the neural substrate of the negativity bias. Specifically, it has been observed that the maximum attentional response to negative stimuli is produced earlier than the maximum response to positive stimuli (Carretié et al., 2001). Although these trends were obtained using a different experimental paradigm than the one employed here (e.g., spatial location was not manipulated), they are convergent with those obtained in this experiment. As a conclusion, and even if the influence on the N1 response to repeated stimulation of variables other than habituation is assumed (i.e., the lowering of subjects' arousal from the beginning to the end of the task), present data indicate that negative stimulation would present a greater capacity to demand attentional resources and to maintain them active even when such negative stimulation is familiar.

REFERENCES


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