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Time course of the subjective emotional response to aversive pictures: relevance to fMRI studies

Amy S. Garrett*, Richard J. Maddock

Department of Psychiatry, University of California, Davis Medical Center, 2230 Stockton Blvd, Sacramento, CA 95817, USA

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Abstract

Using functional magnetic resonance imaging (fMRI) to study brain activity related to the experience of emotion presents unique challenges to neuroscientists. One important consideration arises when an experimentally induced subjective emotional response persists after the end of the emotional stimulation epoch. In this case, brain activity related to the emotional response may continue during the subsequent control or comparison epoch. The comparison epoch of the experiment may then contain a lingering emotional response. This study was conducted to better understand the time course of the subjective emotional response to intensely aversive pictures, with the goal of applying this knowledge to the design and analysis of fMRI studies of emotion. A total of 18 women in two separate experiments were shown a series of aversive, neutral and scrambled pictures presented in alternating block designs. Subjects rated the intensity of their negative feelings every 4 s while viewing the pictures. Results indicate that the subjective emotional response persists well after the end of the emotional stimulation epoch. Following a 16-s block of aversive pictures, an average of an additional 16 s elapsed before self-reported negative feelings showed a 74–80% decline. These data suggest that fMRI studies of emotion should consider the time course of the subjective response to emotionally laden stimuli.

Keywords: Emotions; Affect; Neuroimaging; Functional magnetic resonance imaging; Human

1. Introduction

Functional magnetic resonance imaging (fMRI) has been used to study the neural bases of emotion for only a few years. Not surprisingly, methodological studies of how best to approach the design and analysis of these experiments are lacking. One important consideration is based on an experience common to everyone: emotional reactions can persist long after the event that caused them is past. Empirical studies support this observation (Sirota et al., 1987; Bradley et al., 1996; Baker et al., 1997; Mayberg et al., 1999). The issue is pertinent to functional imaging studies of the emotional response if the subjective effects of

* Corresponding author. Tel.: +650-736-1874; fax: +650-724-4794.

E-mail address: a.garret@stanford.edu (A.S. Garrett).

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an emotional stimulation epoch persist after termination of the evoking stimulus and into the subsequent control or comparison epoch. In such a case, the control epoch would contain lingering subjective emotion. To effectively isolate the epochs containing the neural response to the emotional stimuli from the epochs containing the neural response to the comparison stimuli, knowledge of the duration of the emotional response is needed.

All fMRI designs that present a neutral or comparison condition directly following an emotional condition are potentially affected by this issue. In the analysis of both block and event-related designs, functional images are examined with the goal of detecting signal changes within a prescribed time frame, usually related to the occurrence of particular stimuli, tasks, or responses. Thus, it is essential to know approximately when the response to a particular stimulus begins and ends in order to localize related brain activation. Yet, fMRI studies of emotion often compare brain activity during emotional stimulation epochs with activity during the immediately following neutral stimulation epochs, without regard to the duration of the emotional response (Irwin et al., 1996; Maddock and Buonocore, 1997; Lang et al., 1998; Phillips et al., 1997, 1998; Canli et al., 1998; Teasdale et al., 1999; Whalen et al., 1998).

Certain fMRI analysis techniques correct for some aspects of signal timing but do not consider the effects of an extended subjective response. For example, it is well known that the hemodynamic response lags stimulus onset by approximately 4–8 s (Kwong et al., 1992), and this is taken into account by shifting the entire analysis window to temporally correspond to maximal changes in signal intensity. However, that approach adjusts for the onset of response, and is separate from addressing the possibility of a response extending into the next epoch. Another common analysis method models the blood oxygenation level dependent (BOLD) response by convolving a square wave at the task frequency with a Gaussian or Poisson waveform. The resulting reference vector has a gradual onset and/or offset that more closely resembles a hemodynamic response (Friston et al., 1994). However, this method typically extends the offset past the stimulation period by only a few seconds, which may or may not be sufficient to contain an emotional response that endures for a significantly longer time. Another approach, creating a reference vector from the actual imaging time-course data (e.g. Zarahn et al., 1997), will only circumvent this problem if the response to emotional stimuli has sufficiently subsided before presentation of the comparison condition. Thus, directly measuring and then taking into account the duration of the subjective emotional response may be the most effective method for temporally separating the emotional from the comparison epochs.

This study was designed to better understand the duration of the subjective emotional response to intensely aversive pictures, in preparation for fMRI studies in our laboratory using the same stimuli. We hypothesized that the aversive pictures would produce a change in the subjective emotional state that would endure substantially longer than completion of the picture block. If so, then the timing of the task in future fMRI studies should accommodate the duration of the emotional response. We recorded self-reported ratings of the intensity of the negative emotional response as the primary measurement in order to track changes in the subjective experience of emotion.

2. Experiment I

2.1. Methods

2.1.1. Subjects

Eleven female subjects were recruited by advertisement and paid for participation. Subjects were excluded for self-reported major medical illness, Axis I psychiatric conditions; substance use, or medications that affect cognitive functioning. One subject was rejected for failure to perform the experimental task correctly (described below). The remaining 10 subjects ranged in age from 26 to 55 years (mean = 37 years). They had acquired a mean of 16 years of education (range = 12–18 years). All of the subjects reported that they were right-hand dominant. Nine of the women were native English speakers. The remaining subject had been speaking English as a primary language for 20 years. Seven subjects were Caucasian, two were Asian and one was African American. All of the subjects gave informed consent that was approved by the Human Subject Protocol Review Committee at the UC Davis School of Medicine. Only women were included in the study in order to reduce gender-related variance in the duration of subjective emotional response.

2.1.2. Materials

Three categories of pictures were shown: aversive; neutral; and scrambled. None of the pictures or scrambled images were shown more than once. Forty-five pictures were selected from the International Affective Picture System (CSEA-NIMH, 1995). Seven additional threatening images were generously provided by our colleagues S.F. Taylor and I. Liberzon (Taylor et al., 2000). Based on published arousal and valence ratings (Lang et al., 1995), pictures were selected to fall into a category of either neutral (low arousal, medium valence) or aversive (high arousal, negative valence). For example, neutral pictures included: people boarding an airplane; a man sitting at a computer terminal; and a fish. Aversive pictures included scenes depicting bodily mutilation, disease and violence.

Scrambled pictures were created from the neutral, aversive, and additional pictures by systematically rearranging the pixels into a colored ‘swirl’ that had no recognizable content. CorelDRAW7 software (Version 7, Corel Corporation, 1996) was used to first ‘blur’ the images (Gaussian filter, radius = 30) and then ‘swirl’ the blurred images (five rotations, 90° additional angle).

The pictures were presented in blocks, similar to the design of many fMRI experiments. The order of initial picture block (aversive or neutral) was counterbalanced between subjects. The aversive and neutral pictures were shown in 16 second blocks of four pictures each, while the scrambled pictures were shown in 32 second blocks of eight images. The scrambled picture blocks were extended in order to allow a sufficient period of time for the emotional response to diminish.

The pictures were presented full screen on a 15-inch monitor via a personal computer (Dell Dimension XPS R400 Pentium II equipped with a 16 MB Graphics card) using ACDSee 32 software (version 2.3, ACD Systems, Ltd.). The monitor was positioned approximately 60 cm from the subject’s eyes.

2.1.3. Procedure

The Negative Emotional State (NES) rating scale was introduced during a training session. The NES scale was created by the authors to allow for quick, repeated ratings of the intensity of the current negative feelings. In order to obtain data on a temporal scale comparable to fMRI, only 4 s were allowed for each rating. Thus, only a single measure could be taken. Negative emotion was chosen as the rating dimension because the intensely aversive pictures were predicted to elicit primarily unpleasant affective responses.

The anchored NES scale ranged from 0 to 10, where ‘0’ corresponded to ‘no negative feelings’ and the descriptors ‘calm, indifferent, neutral’. A rating of ‘5’ was associated with ‘moderately negative feelings’ and the descriptors ‘uncomfortable, uneasy, bothered’. A rating of ‘10’ indicated ‘extremely negative feelings’ and a description of ‘upset, shocked, queasy’. The subject practiced using the ratings to verbally report the intensity of her current negative feelings during the viewing of a sample set of neutral, aversive and scrambled pictures. The subject was explicitly instructed to rate the intensity of her current negative feelings, whether or not the feelings had been elicited by the current picture, a previous picture, or her own thoughts and memories. The pictures were then presented on the computer as a continuous series, without a ‘gap’ or blank screen between pictures. Each picture was shown for 4 s. This stimulus duration is similar to that used in previous fMRI and PET studies of emotion (Taylor et al., 1998; Lane et al., 1999; Canli et al., 1998; Irwin et al., 1996). The subject verbally reported her emotional state rating during the time that each picture was shown (e.g. one rating every 4 s).

After the presentation was complete, the investigator asked each subject how she had made her ratings. As described above, one subject was excluded after indicating that she had rated the content of each picture, rather than rating her emotional state.

2.2. Results

2.2.1. Subject variables

Subjects were debriefed after the experiment, and all reported that they tolerated the procedure without significant difficulty or emotional distress.

2.2.2. Time course of emotional response

To evaluate changes in negative emotional state over time, NES ratings were averaged across subjects at each time point and plotted as a function of time for comparison with the pattern of stimulus presentation. Fig. 1 shows the averaged changes in NES ratings over the course of the experiment. Qualitatively, it is clear that the negative emotional response to the aversive pictures continued well beyond the end of the aversive picture block, as shown by the shaded area under the curve.

A repeated measures analysis of variance (ANOVA) was performed to determine if the average ratings in the aversive picture blocks were significantly different from the average ratings in the subsequent scrambled picture blocks. For this analysis, the scrambled picture blocks following the aversive pictures were divided into two blocks, AS1 (the first four ratings) and AS2 (the last four ratings). This allowed us to compare blocks with equal numbers of data points, and also to determine if ratings in the first half of the scrambled block differed from those in the second half. Similarly, ratings in the scrambled picture blocks following the neutral picture blocks were divided into two blocks, NS1 (first four data points) and NS2 (last four data points). A repeated measures ANOVA showed a significant effect of picture block ($F_{5,45} = 85.69$, $P < 0.0001$). Pairwise comparisons of the individual picture blocks (aversive, AS1, AS2, neutral, NS1, NS2) showed significantly lower ratings in the AS1 block compared with the aversive block, and in the AS2 block compared with the AS1 block. Therefore, ratings declined after the aversive block, and then continued to decline significantly after the end of the first half of the scrambled block. However, there was no change in ratings in the neutral block compared with the following scrambled picture blocks (NS1 and NS2).

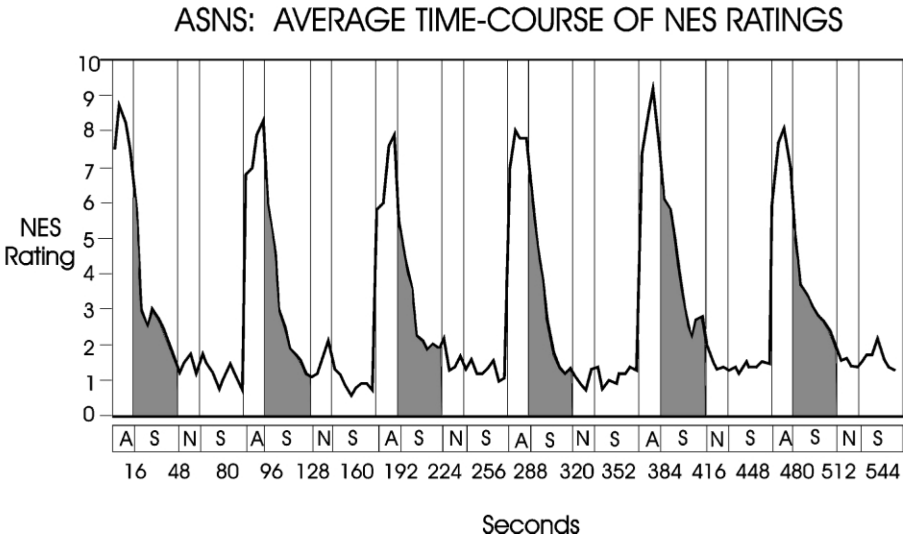

Fig. 1. Negative Emotional State (NES) ratings for the ASNS design over the course of the experiment, averaged across 10 subjects. The shaded area highlights the 32-s scrambled picture block following the threat pictures, when ratings are decreasing slowly rather than immediately. A = aversive picture block (16 s); S = scrambled picture block (32 s); N = neutral picture block (16 s).

2.2.3. Decline of ratings over time

To obtain quantitative information about the rate of decline of the NES ratings, percent of decline curves were created. For the purposes of analysis, a cycle was defined as a series of four consecutive picture blocks, or ASNS. Therefore, the entire picture presentation consisted of six cycles (for example, ASNS ASNS ASNS ASNS ASNS ASNS). For each subject, NES ratings at each time point of the cycle were averaged across the six cycles to obtain a mean response. For example, the NES ratings from the first time point in each of the six aversive picture blocks were averaged to yield the first mean time point in the aversive block.

The following values were then defined, based on the mean cycle for each subject: The final aversive rating (Rfa) = NES rating during the final aversive picture of the average cycle; and the baseline rating (Rb) = the final NES rating during the final scrambled picture for the mean cycle. This rating was obtained just before each new block of aversive pictures began (80 s after Rfa) and serves as our best estimate of the baseline from which NES ratings increased during each new aversive picture block. Range-adjusted percent decline scores for each subject were calculated for each time point (Ri) in the remainder of the cycle:

$$\text{Percent decline (i)} = 100 * (\text{Rfa} - \text{Ri})/(\text{Rfa} - \text{Rb})$$

Fig. 2 shows the average percent of decline of NES ratings over the 80-s period from the end of the mean aversive block to the end of the mean cycle. On average, ratings have declined only 30% during the first picture following the threat picture block. This is quite unlike an fMRI analysis vector that, in spite of corrections for hemodynamic effects, assumes a rapid offset of neural responding after stimuli offset. In fact, 8 s are required for a decline of 57%, and 16 s are required for ratings to decline 74%.

3. Experiment II

A second experiment was then conducted to determine if the emotional response would decline more quickly if subjects viewed neutral rather than scrambled images immediately following the aversive images. We hypothesized that the neutral images may have more of a calming

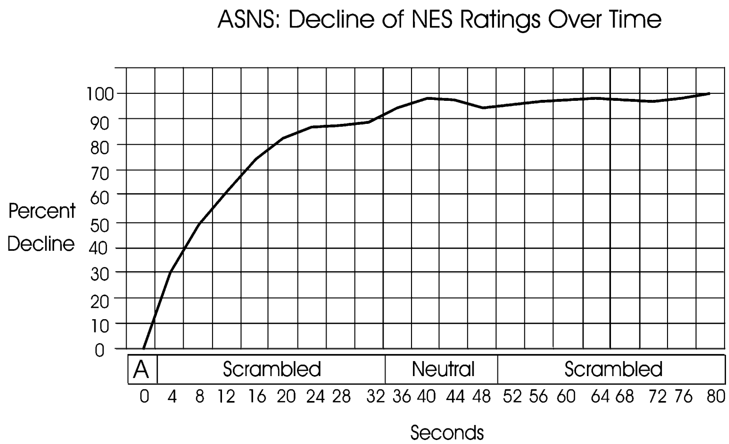

Fig. 2. Percent Decline of Negative Emotional State (NES) ratings for the ASNS design during a mean response relative to the final rating in the scrambled block. Note that a 74% decline in ratings is reached approximately 16 s after the end of the aversive picture block. A = aversive picture block.

or distracting effect on negative emotion than the scrambled pictures. For example, previous studies have shown that positive films speed recovery from the cardiovascular effects of fear-eliciting films (Fredrickson and Levenson, 1998). Also, fMRI experiments commonly present neutral images directly after emotional pictures.

3.1. Methods

3.1.1. Subjects

A total of nine female subjects were recruited and screened as described for the first experiment. One subject was excluded for improper use of the rating scale (as described in Section 2). The remaining eight subjects ranged in age from 24 to 51 (mean = 35). They had acquired a mean of 15 years of education. Seven reported that they were right-handed. Five were native English speakers, and the remaining two had been speaking English as a primary language for 10 and 45 years. The sample included five Caucasians; one African American, one Hispanic, and one Asian.

3.1.2. Materials and procedure

The same pictures were used for this experiment as for the first experiment. The pictures were presented in blocks with the order ANS (aversive, neutral, scrambled). Four pictures of each type were shown, at 4 s per picture. All other details of picture presentation are the same as described for Experiment I.

3.2. Results

3.2.1. Subject variables

All of the subjects were debriefed and they reported that they had tolerated the procedure without significant difficulty or emotional distress. The subject groups in Experiment I and II were compared and found to have no differences in age ($t_{16} = 0.48$ $P > 0.05$) or education ($t_{16} = 0.71$, $P > 0.05$).

3.2.2. Time course of emotional response

The group average time course for the ANS design was computed as described for the first experiment, and is shown in Fig. 3.

A repeated measures ANOVA for the effect of picture block was performed as described above for the ASNS design. The picture blocks included the aversive (four ratings), neutral (four ratings) and scrambled (four ratings). Ratings during the picture blocks differed significantly ($F_{2,14} = 46.53$, $P < 0.0001$). Pairwise comparisons showed a significant difference between the aversive and neutral blocks and between the neutral and scrambled blocks. Thus, similar to the ASNS design,

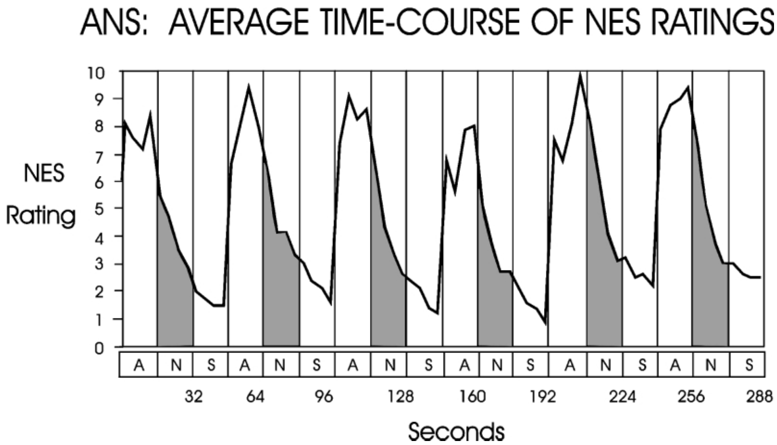

Fig. 3. Negative Emotional State (NES) ratings for the ANS design over the course of the experiment, averaged across eight subjects. The shaded area indicates the 16-s neutral picture block following the aversive pictures, when ratings are slowly decreasing. A = aversive picture block (16 s); N = neutral picture block (16 s); S = scrambled picture block (16 s).

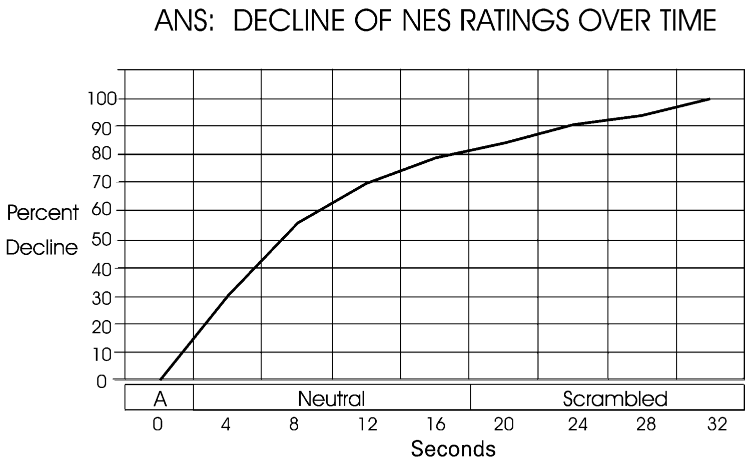

Fig. 4. Percent Decline of Negative Emotional State (NES) ratings for the ANS design during an average cycle relative to the final rating in the scrambled picture block. Note that approximately 16 s are required for the ratings to decline 80% following the aversive picture block. A = aversive picture block.

ratings after the end of the aversive picture block continued to decline significantly after the end of the neutral picture block.

3.2.3. Decline of ratings over time

Percent decline of ratings was also computed as described for the first experiment, and the results are shown in Fig. 4. The results of the second experiment using the ANS design were very similar to those found in the first experiment using the ASNS design. The average time course (Fig. 3) shows that the NES ratings remain elevated after the end of the threatening picture block. The rate of decline over the 32 s following the end of the threat picture block (Fig. 4) is also similar to that for the ASNS design. Approximately 16 s are required for an 80% decline in the range-adjusted scores. Thus, the NES ratings follow similar patterns whether the aversive picture block is followed by neutral pictures or by abstract colored images.

As a final analysis, we examined the magnitude of NES ratings during aversive picture blocks for both experiments (18 subjects) to determine if responses to the aversive pictures changed over the course of the entire experiment. For each subject, the four ratings collected during each block of aversive pictures were averaged to obtain one mean NES rating for each of the six cycles of the experiment. An analysis of variance showed that the NES ratings during the aversive picture blocks changed significantly, although slightly, over the course of the experiment ($F_{5,17} = 2.94$, $P = 0.02$). Follow-up comparisons showed that this effect was due entirely to lower ratings in the first aversive picture block.

3.3. Discussion

This study was designed to investigate the duration of the subjective response to intensely emotional stimuli for application to the design and analysis of fMRI experiments. The results show that, for female subjects, the average negative emotional state ratings following the viewing of a 16-s block of aversive pictures require an additional 16 s to show a 74–80% decline, based on range-adjusted values. The decline was similar whether the aversive pictures were followed by scrambled images or by neutral images. This period of time is much greater than has typically been incorporated into fMRI studies of emotion (Irwin et al., 1996; Maddock and Buonocore, 1997; Lang et al., 1998; Phillips et al., 1997, 1998; Canli et al., 1998; Teasdale et al., 1999; Whalen et al., 1998). In addition, self-reported ratings during the aversive pictures did not decline over the course of the experiment, suggesting that negative emotional responses did not habituate.

These data suggest that fMRI studies that use intensely aversive stimuli to study subjective emotion should allow for an extended duration of the subjective response. FMRI studies of emotion that do not allow the emotional response to subside before the presentation of neutral stimuli may incorrectly assume that the subject has returned to a neutral emotional state. If so, at least part of the subsequent control or comparison epoch will contain the effects of the remaining emotional response. In addition, the lack of reduction in the average NES ratings during the aversive picture blocks over the course of the experiment suggests that the subjective response to non-repeated aversive pictures does not habituate. This is unlike the habituation of the BOLD response of the amygdala reported by Breiter et al. (1996), although the latter study used repeated presentations of less intense emotional stimuli (emotionally valenced facial expressions).

Taking into account the duration of the emotional response may increase statistical power. By collecting data during a comparison condition that is free from lingering emotional response, variance in the comparison condition is decreased, thus increasing the probability of detecting significant differences between the emotional and comparison conditions. As an illustration, the behavioral ratings from Experiment I were examined for differences in t values before and after taking into account the duration of the emotional response. When comparing the 24 NES ratings from the aversive picture block with the 24 ratings from the first half of the scrambled picture block, t values averaged 6.34 (range = 1.94–9.84; d.f. = 23). However, when comparing ratings in the aversive block with ratings in the second half of the scrambled picture block, which is when the emotional response has significantly declined, t scores averaged 12.28 (range = 5.21–20.11; d.f. = 23). Thus, allowing for the emotional response to decline increased the difference in behavioral ratings between the emotional and neutral conditions. Similarly, this method may also prove effective in reducing variance and increasing statistical power in detecting brain activation in fMRI studies of emotion.

In this study, we studied the duration of the emotional response following a block of four aversive pictures presented for 4 s each. The observed recovery period of an additional 16 s may be specific to the temporal pattern of picture presentation used in this study. Thus, longer blocks of aversive pictures may require longer recovery times. On the other hand, single pictures or rapidly presented pictures, as used in event-related fMRI designs, may be followed by more rapid recovery. The duration of the emotional response should be investigated for specific study designs. Previous studies have recorded the intensity of the emotional response after the entire experiment is complete. That method does not inform the issue of the duration of that response during the course of the experiment.

The current study is limited in that the results are only applicable to female subjects. Future studies are needed to determine if male subjects exhibit the same pattern of decline in negative emotional ratings following aversive pictures. Another limitation is that the behavioral laboratory environment differs from that of the MRI scanner in several ways, including the distance between the picture screen and the subject, and the loud noises and solitary environment of the MRI scanner. These variables may change the magnitude or the duration of the negative emotional response to the aversive pictures. Therefore, future behavioral studies of the duration of the emotional response could be performed in the MRI scanner.

It is important to consider that the index of emotional response may be a key factor in measuring the duration of the response. In the current study, subjective report was used as the primary measure in order to track changes in the experience of emotion. However, other studies measuring physiological indices of emotion have shown varying temporal characteristics depending on what was measured. For example, the augmentation of the startle response has been shown to decay significantly within 500 ms after the offset of unpleasant pictures (Bradley et al., 1993). However, corrugator facial electromyographic

(EMG) responses to unpleasant pictures were shown to persist at least 6 s in one study (Bradley et al., 1996) and to persist at least 60 s after the end of a negative mood induction procedure (Sirota et al., 1987). These studies suggest that different measures of the emotional response may show different patterns of decay over time. Lang (1993) pointed out that various levels of emotional expression (self-report, behavior, physiology) may function partially independently, with interaction and control at the brain level. Therefore, to identify the brain regions associated with some component of the emotional response, it is important to first define the time course of that particular response, whether it is EMG, heart rate, or subjective emotional state.

Another factor that may affect the results of this study is the possibility that attending to the subjective emotional state may augment its intensity. Previously, Lane et al. (1997) used PET to show that cerebral blood flow patterns in response to affective pictures changed depending on whether subjects attended to their subjective emotional state or spatial aspects of the pictures. In the current study, focusing on the intensity of the negative emotional state may have increased the intensity and duration of the experience. Therefore, neuroimaging studies of emotion using tasks that direct attention away from emotional content may observe more rapid declines in subjective emotional arousal.

The results of this study indicate that fMRI studies of emotion should take into account the duration of the subjective emotional response to the stimuli used in that particular study. By considering the time course of the emotional response, imaging studies will more clearly discern brain areas of activity associated with the emotional stimulus condition from those associated with the control condition.

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