Neural Representation of Anxiety and Personality During Exposure to Anxiety-Provoking and Neutral Scenes from Scary Movies

Thomas Straube,^{1*} Sandra Preissler,¹ Judith Lipka,¹ Johannes Hewig,¹
Hans-Joachim Mentzel,² and Wolfgang H.R. Miltner¹

¹*Department of Biological and Clinical Psychology, Friedrich-Schiller-University of Jena,
Am Steiger 3 // 1, D-07743 Jena, Germany*

²*Institute of Diagnostic and Interventional Radiology, Friedrich-Schiller-University of Jena,
Bachstr. 18, D-07740 Jena, Germany*

Abstract: Some people search for intense sensations such as being scared by frightening movies while others do not. The brain mechanisms underlying such inter-individual differences are not clear. Testing theoretical models, we investigated neural correlates of anxiety and the personality trait sensation seeking in 40 subjects who watched threatening and neutral scenes from scary movies during functional magnetic resonance imaging. Threat versus neutral scenes induced increased activation in anterior cingulate cortex, insula, thalamus, and visual areas. Movie-induced anxiety correlated positively with activation in dorsomedial prefrontal cortex, indicating a role for this area in the subjective experience of being scared. Sensation seeking-scores correlated positively with brain activation to threat versus neutral scenes in visual areas and in thalamus and anterior insula, i.e. regions involved in the induction and representation of arousal states. For the insula and thalamus, these outcomes were partly due to an inverse relation between sensation seeking scores and brain activation during neutral film clips. These results support models predicting cerebral hypoactivation in high sensation seekers during neutral stimulation, which may be compensated by more intense sensations such as watching scary movies. *Hum Brain Mapp* 31:36–47, 2010. © 2009 Wiley-Liss, Inc.

Key words: emotion; fMRI; horror; sensation seeking; threat

INTRODUCTION

“Aliens” (Cameron, 1986), “The Shining” (Kubrik, 1980), “The Silence of the Lambs” (Demme, 1991), and several other so-called horror movies evoke feelings of fear and anxiety in the observer [Hewig et al., 2005; Weaver and Tamborini, 1996]. The most important psychological dimension of such movies seems to relate to anxiety regarding some uncertain and often supernatural threat of existential nature [Weaver and Tamborini, 1996]. Nevertheless, horror movies are commercially very successful, since many people spend a significant amount of time and money enjoying such movies. Obviously, it is entertaining to be scared and to experience a specific level of threat-related, arousing stimulation. There are several theoretical

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*Correspondence to: Thomas Straube, Department of Biological and Clinical Psychology, Friedrich-Schiller-University of Jena, Am Steiger 3 // 1, D-07743 Jena, Germany.
E-mail: straube@biopsy.uni-jena.de

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accounts for the role of individual differences in the preference for horror movies [Weaver and Tamborini, 1996; Zuckerman, 1979, 1996a,b]. Zuckerman [1979, 1996b] proposed that subjects scoring high on the personality dimension of sensation-seeking might be especially attracted to horror movies due to the increased level of sensation these movies provide. In line with this assumption, several studies reported positive correlations between scores on Zuckerman's Sensation Seeking Scale (SSS) and self-reported enjoyment of frightening entertainment and horror movies [Edwards, 1984; Litle and Zuckerman, 1986; Slater, 2003; Sparks, 1986; Tamborini et al., 1987].

The trait variable sensation seeking relates to the search for risky, varied, novel, complex, and intense sensations and experiences [Zuckerman, 1994]. High, as compared to low, sensation seekers seem to anticipate less negative affect concerning challenging situations and to experience more positive affect during such situations [Zuckerman, 1994]. In his early proposals Zuckerman [1979] conceptualized sensation seeking as being dependent on cortical arousal. He hypothesized a low, by the organism as "sub-optimal" perceived arousal level in high sensation seekers during sensations of low intensity, leading to compensatory search for stronger sensation and increased arousal. Later, Zuckerman also proposed a role of subcortical areas and specific neurotransmitter systems for the understanding of differences in sensation seeking; an idea which received partial support by experimental findings [Zuckerman and Kuhlman, 2000]. Furthermore, based on electrophysiological studies, it has also been suggested that high, as compared to low, sensation seekers exhibit increased cerebral arousability in response to strong sensory input [Zuckerman, 1990]. Accordingly, studies using electroencephalography (EEG) showed a stronger increase in the amplitude of event-related potentials with increasing intensity of sensory stimulation in high as compared to low sensation seekers [Brocke et al., 2000; Hegerl et al., 1995; Zuckerman, 1990]. Although studies with scalp-recorded EEG found some evidence for the association between cortical activity and sensation seeking, functional brain imaging methods, such as functional magnetic resonance imaging (fMRI), provide an unique possibility to investigate in detail both magnitude and topography of cortical and sub-cortical brain activation during sensory stimulation. However, corresponding imaging studies testing the arousal model of the sensation seeking trait are lacking yet.

The aim of the current fMRI study was to investigate in detail the relation between brain activation, experienced anxiety, and sensation seeking in subjects who were exposed to clips from commercially successful scary movies. First, we explored generally differential brain activation in response to threatening versus neutral scenes of scary movies. Furthermore, we aimed to identify brain regions in which activation correlates with subjectively experienced anxiety during exposure to the movie clips. Main effect and correlation analysis were conducted in visual areas and in brain regions known to be involved in

threat processing and anxiety, such as the dorsomedial prefrontal cortex (DMPFC), the anterior insula, the anterior cingulate cortex (ACC), the thalamus, and the amygdala, even though these activations are strongly dependent on task conditions and experimental designs [Kalisch et al., 2006; Phan et al., 2002; Reiman et al., 1997; Straube et al., 2004, 2006a,b, 2007a,b, 2009].

Most importantly, we tested the aforementioned model that inter-individual differences in the sensation seeking trait are associated with differences in cerebral arousal. Based on the assumption of higher arousability, high as compared to low sensation seekers should exhibit a stronger increase of brain activation to threatening versus neutral movie scenes in cortical areas involved in visual processing of movie clips. In addition, we explored whether a similar relation between brain activation and sensation seeking would also be found in areas that are associated with the induction and representation of arousal states, such as the anterior insula, the ACC, and the thalamus [Anders et al., 2004; Craig, 2002; Critchley et al., 2002; Porro et al., 2003; Reiman et al., 1997; Straube et al., 2006a,b]. To assess the specificity of the results concerning the association between brain activation and sensation seeking, we also analyzed the relationship between brain activation and other personality factors that are correlated with sensation seeking.

Finally, we analyzed whether an increased cerebral arousability to threat vs. neutral stimulation might partially be associated with decreased activation during exposure to neutral movie clips. As described above, neural models of sensation seeking suggest a deficit in cerebral arousal during low intense stimulation. Thus, sensation seeking should negatively correlate with brain activation during low intense stimulation such as the neutral scenes from scary movie clips. In contrast, this inverse relation between brain activation and sensation seeking should not be observed during high intense stimulation such as the threat scenes from scary movie clips. This activation pattern would support the hypothesis that intense sensations, such as those provided by scary movies, compensate a deficit in cerebral arousal in high sensation seekers during less intense stimulation.

MATERIALS AND METHODS

Subjects

Forty healthy, Caucasian volunteers (20 woman and 20 men; mean age: 22.55 years, range: 19–26 years) participated in this study. Subjects were not preselected according to sensation seeking scores, but represent the full spectrum of this trait (see below). All participants had normal or normal-to-corrected vision. All participants were university students and each received 10 EUR for participating in this study. Participants were recruited within the university student population via public announcement and all were required to be right-handed, as determined

by the Edinburgh Handedness Inventory [Oldfield, 1971]. All subjects provided informed consent to participate in the study. The experimental procedure was approved by the Ethics Committee of the University of Jena.

Questionnaires

All subjects completed the SSS Form V [German version: Beauducel et al., 2003; Zuckerman, 1979]. The SSS V is a 40-item forced-choice questionnaire measuring individual differences in stimulation and arousal preferences. The SSS V consists of four 10-item subscales (thrill and adventure seeking, experience seeking, disinhibition, boredom susceptibility) and was shown to relate to the trait of subjects to need varied, novel, and complex sensations and experience, and the willingness to take physical and social risks for the sake of such experiences [Zuckerman, 1979]. The discriminability of the factor structure of the SSS V in the German population is uncertain [Beauducel et al., 2003]. In contrast, the total sum score of the SSS V has a high reliability and validity in different populations [Beauducel et al., 2003; Zuckerman, 1979; Zuckerman and Kuhlman, 2000]. All subjects also completed the NEO-FFI Personality Inventory [German version: Borkenau and Ostendorf, 1993; Costa and McCrae, 1992]. The German version of the NEO-FFI is a 60-item self-rating questionnaire based on the five-factor model of personality of Costa and McCrae [Costa and McCrae, 1992]. It measures the factors neuroticism, extraversion, openness for new experiences, agreeableness, and conscientiousness on five scales consisting of 12 items each. Sum scores of each scale were used for the analysis.

Stimuli

Subjects were exposed to scenes from horror movies which were commercially very successful. The movies were preselected based on internet user ratings from the international movie database (IMDB, <http://www.imdb.com>). The 10 most successful movies from the genre “horror,” which were rated by at least 10,000 users (using 10 point Likert scales), were selected for a prestudy (see Supporting Information Table SI). In this prestudy with an independent sample of subjects ($n = 29$; mean age: 23.72 years; SD: 2.73 years; range: 18–29), 64 threatening scenes (duration between 30 and 90 s) from the following movies were shown: *Alien* (Scott, 1979), *Aliens* (Cameron, 1986), *Jaws* (Spielberg, 1975), *Psycho* (Hitchcock, 1960), *The Exorcist* (Friedkin, 1973), *The Shining* (Kubrick, 1980), *The Silence of the Lambs* (Demme, 1991), *The Others* (Amenábar, 2001), *Rosmarys Baby* (Polanski, 1968), and *Young Frankenstein* (Brooks, 1974). Only scenes with predominantly uncertain threat, which is the most prominent psychological dimension in horror movie clips [Weaver and Tamborini, 1996], were selected. Scenes, which were clearly aggressive, disgusting, or shocking were excluded. This reduced variance in movie complexity and induced emotions. It also pre-

vented shock-induced movements made by participants in the MRI scanner while watching the movie clips. All sequences were shown with music, as it seems an essential attribute for inducing the emotional effects of scary movies [Weaver and Tamborini, 1996]. During the prestudy, the subjects used a nine-point Likert scale (0 = “not at all” to 8 = “most intensive”) to rate scenes according to the following emotions: sadness, anxiety, and disgust. Furthermore, subjects were asked whether scenes contained sudden shocking elements and these scenes were consequently excluded. From the remaining 41 scenes, the four scenes with the highest anxiety ratings and relatively low sadness and disgust ratings were chosen for the experiment proper (see Supporting Information Table SI). These scenes were from *Aliens* (1986), *The Shining* (1980), *The Silence of the Lambs* (1991), and *The Others* (2001). Clip duration was 67 s (*Aliens*), 83 s (*The Shining*), 54 s (*The Silence of the Lambs*), and 41 s (*The Others*). A brief description of the content of each scene can be found in Supporting Information Table SII. The four neutral clips were selected from the same movie as the corresponding threatening movie excerpt. Each was matched according to overall duration of the corresponding clip and duration of speech and music, as well as number of actors (see Supporting Information Table SII). Neutral clips were rated by a subsample ($n = 15$; mean age: 23.72 years; SD: 2.73 years; range: 20–28 years) of the 29 subjects who had rated the threatening scenes. Results indicate that the neutral scenes did not induce anxiety or other negative emotions (see Supporting Information Table SI).

Experimental Paradigm

During scanning, subjects were presented with the four selected neutral and four selected threatening sequences in pseudorandomized order. Between movie sequences a fixation cross was shown for 16 s. There were two versions of order of the movie clips that were balanced across subjects. One version started with a threatening, the other with a neutral movie clip. Scenes from the same movie were not presented in direct sequence, and no more than two clips of the same category (threat, neutral) succeeded each other. Visual stimuli were shown via a back-projection screen onto an overhead mirror. The auditory part of the movie was presented binaurally via MRI suited headphones (Commander XG MRI audio system, Resonance Technology, Northridge, USA). Subjects were informed that scenes from horror movie clips would be shown but they were not informed whether scenes would be neutral or threatening. After the fMRI-session, participants were shown parts of each sequence again and they were asked to rate the anxiety that was felt during the presentation of the particular movie clip in the scanner. For rating, a 9-point Likert scale (0 = “not at all” to 8 = “most intensive”) was used. Furthermore, all participants judged the familiarity of the movie clips. Behavioral data were

analyzed using SPSS (Version 12; SPSS, Chicago). Data are expressed by mean $\pm$ SEM (standard error of means).

FMRI Data Acquisition and Analysis

In a 1.5-T magnetic resonance scanner (Magnetom Vision plus, Siemens, Medical Systems, Erlangen, Germany), one run of 161 Vol. was measured using a T2*-weighted echo-planar sequence (TE = 50 ms, flip angle = 90°, matrix = 64 $\times$ 64, FOV = 192 mm, TR = 3,900 ms). Each volume comprised 40 axial slices (thickness = 3 mm, in plane resolution = 3 $\times$ 3 mm²), acquired with a tilted slice orientation [Deichmann et al., 2003]. Additionally, a high-resolution T1-weighted anatomical volume was recorded. Preprocessing and analysis of functional data was performed using the software Brain Voyager QX (Version 1.7; Brain Innovation, Maastricht, The Netherlands). The volumes were realigned to the first volume to minimize effects of head movements. Further data preprocessing included spatial [8-mm full-width half-maximum isotropic Gaussian kernel (FWHM)] as well as a temporal (low-trend removal) smoothing. Anatomical and functional images were coregistered and normalized to the Talairach space [Talairach and Tournoux, 1988]. Statistical analysis was performed by multiple linear regression of the signal time course at each voxel. The expected blood oxygen level-dependent (BOLD) signal change for each event type (= predictor) was modeled by a canonical hemodynamic response function (modified gamma function; $\delta = 2.5$, $\tau = 1.25$). Within-group statistical comparisons were conducted using a mixed effect analysis, which considers inter-subject variance and permits population-level inferences. First, voxelwise statistical maps were generated and the relevant, planned contrasts of predictor estimates (β -weights) were computed for each individual. Second, a random effects group analysis of these individual contrasts was performed. Statistical parametric maps resulting from the voxelwise analysis were considered significant for statistical values that survived a cluster-based correction for multiple comparisons, as implemented in Brain Voyager. This is based on a 3D extension of the randomization procedure described by Forman et al [1995]. Voxel-level threshold was initially set at $P < 0.005$ (uncorrected). Thresholded maps were then submitted to a region of interest (ROI)- or whole brain-based correction criterion, which was based on the estimate of the map's spatial smoothness and on an iterative procedure (Monte Carlo simulation) used to estimate cluster-level false-positive rates. After 1,000 iterations, the minimum cluster size threshold that yielded a cluster-level false-positive rate of 5% was applied to the statistical maps. For exploratory analysis, threshold was set at $P < 0.05$, family wide corrected across the whole brain (cluster threshold: four voxel). According to our previous studies [Straube et al., 2004, 2006a,b, 2007a,b], the following ROIs were defined *a priori* using Talairach daemon software (<http://ric.uthscsa.edu/projects/talairachdaemon.html>):

DMPFC, anterior insula, ACC, amygdala, and, as separate ROIs, Brodman areas 17, 18/19, and 37 corresponding to striate and different parts of extrastriate ventral visual cortex.

The analytic strategy of data analyses was as follows: First, we analyzed main effects of movie category on brain activation by contrasting BOLD responses during threatening versus neutral scenes. In the next step, we analyzed correlations between anxiety ratings (individual differential scores for threat minus neutral scenes) with the relevant differences of parameter estimates (difference: threat minus neutral). Then, we analyzed correlations between activation to threat vs. neutral (difference of parameter estimates) and sensation seeking scores, to investigate the assumed general arousability effect that should be associated with the sensation seeking trait. In the last step, we investigated, at the coordinates found in the previous analysis, the association between each predictor (threat or neutral; this means in each case activation in contrast to the low level fixation baseline) and sensation seeking and explored by means of a step wise regression the contribution of each factor to the prediction of sensation seeking scores. This analysis explored whether the arousability effect is partly due to a negative correlation between sensation seeking and brain activation during low intense stimulation such as the neutral scenes from scary movie clips. This would suggest that high sensation seekers show decreased cerebral arousal during less intense stimulation, which is compensated by intense sensations, such as those provided by scary movies. It has to be noted that this activation is of course also a differential BOLD response from a fixation cross to scary and neutral clips. This difference clearly is not a measure of basal activity but of differential reactivity. Thus, we cannot make any conclusion regarding basal activation differences in high vs. low sensation seekers. Investigation of basal differences requires other MRI strategies or measures of regional cerebral blood flow or alternatively glucose metabolism at rest.

RESULTS

Questionnaire Data

Table I lists the descriptive statistics for the (SSS) Form V [German version: Beauducel et al., 2003; Zuckerman, 1979], including mean, standard deviation, and normative means of a German sample [Beauducel et al., 2003]. The total sensation seeking sum score (TS), which is the relevant psychometric variable for this study (see Methods), was normal-distributed across subjects (KS-t = 0.457, $P > 0.25$). There were no significant differences between men and women in TS (men: 20.53 $\pm$ 6.59; range: 6–36; women: 20.85 $\pm$ 7.43; range: 8–30; $t = -0.14$, $P > 0.05$). The TS correlated with the factors neuroticism and extraversion of the NEO-FFI [German version: Borkenau and Ostendorf, 1993; Costa and McCrae, 1992]. There was a negative

TABLE I. Scores of the SSS-V (mean, standard deviation, normative means)

Score	Males		Females	
	Mean (STD)	Normative mean	Mean (STD)	Normative mean
Total sum score	20.53 (6.58)	20.15	20.85 (7.43)	22.10
Thrill and adventure seeking	6.11 (2.70)	6.05	5.80 (2.62)	6.55
Experience seeking	5.42 (1.74)	6.35	6.45 (2.50)	6.05
Disinhibition	4.36 (2.15)	3.85	3.90 (2.88)	5.05
Boredom susceptibility	4.63 (2.14)	3.85	4.70 (2.31)	4.45

Note: Normative mean: 396 men, 396 women [16-29 years; Beauducel et al., 2003].
STD, Standard deviation.

correlation with neuroticism ($r = -0.46$; $P < 0.01$) and a positive one with extraversion ($r = 0.54$; $P < 0.001$). No significant relations were found between the other factors of the NEO-FFI and TS (conscientiousness: $r = 0.22$; agreeableness: $r = 0.12$; openness to experience: $r = 0.34$; all $P > 0.01$). However, there was an additional significant correlation between “openness to experience” and the SSS subscale “experience seeking” ($r = 0.45$; $P < 0.01$), a finding which supports the validity of our measurements.

Analysis of subjects’ mean post-scanning ratings of experienced anxiety revealed increased scores for threatening, as compared to neutral clips (3.86 ± 2.22 vs. 1.23 ± 1.19 ; $t = 9.55$; $P < 0.05$). Neither anxiety ratings of threat scenes nor anxiety ratings of neutral scenes correlated significantly with the total sensation seeking score ($r = -0.27$ and $r = -0.28$, both $P > 0.05$), though a tendency of generally decreased anxiety ratings in high vs. low sensation seekers was observed (for both the above correlations: $P < 0.1$). However, anxiety ratings of threat scenes and, to a lesser extent, also of neutral scenes were significantly correlated with the neuroticism score of the NEO-FFI ($r = 0.55$; $P < 0.001$ and $r = 0.38$; $P < 0.01$).

Furthermore, in the post-scanning ratings session, subjects were also asked whether they already knew the scenes. Only a minority of subjects (between 6 and 15 subjects per scene; see Supporting Information Table SIII) confirmed being familiar with some of the scenes. There was no association between familiarity ratings and rated anxiety or the total sensation seeking score (see Supporting Information Table SIII, which displays the correlation coefficients and P values). Finally, there was also no significant difference in absolute frequency of positive familiarity ratings between all threat and all neutral scenes (44 vs. 42; $\chi^2 = 0.05$; $P > 0.05$).

FMRI Data

Main effect of movie clip category

We analyzed main effects of movie category on brain activation by contrasting BOLD responses during threatening versus neutral scenes. ROI analysis indicated that threat vs. neutral movie excerpts led to increased activation bilaterally in the ACC, the anterior insula, thalamus,

and areas of the visual cortex (see Table II for coordinates and statistics). Figure 1 indicates cluster of activation within the ROIs and displays plots of the mean of parameter estimates. There were no significant differences in activation to threat vs. neutral clips in the amygdala or the DMPFC (see Supporting Information Fig. S1 for activation time course in the ROIs). Furthermore, there was no significantly increased activation to neutral compared to threatening clips in the ROI analysis.

Exploratory analysis outside regions of interest revealed increased activation to threat vs. neutral movie clips in left and right precentral gyrus, in right inferior frontal gyrus, in bilateral precuneus, and bilaterally in lateral inferior parietal cortex (see Table II for coordinates and statistics). There was no significantly enhanced activation to neutral compared to threat clips in the exploratory analysis.

TABLE II. Brain activation to threat vs. neutral movie clips

Region	Side	Size	x	y	z	t value
<i>ROI</i>						
Thalamus	R	73	7	-28	4	6.04
	L	81	-9	-19	10	6.31
Anterior insula	R	84	39	20	13	5.60
	L	52	-33	17	10	4.81
ACC	R/L	63	4	6	39	4.73
Visual areas: BA 17	R	11	8	-81	10	5.13
Visual areas: BA 18/19	R	273	51	-58	-5	10.27
	L	195	-9	-85	28	6.64
Visual areas: BA 37	R	112	53	-57	-5	10.27
	L	101	-54	-57	-5	6.58
<i>Exploratory</i>						
Superior parietal cortex	R	10	27	-52	43	6.66
	L	183	-21	-52	46	9.84
Inferior parietal cortex	R	111	48	-37	28	8.17
	L	62	-63	-31	22	7.68
Inferior frontal and precentral gyri	R	81	45	2	31	7.57
Precentral gyrus	L	18	-30	-13	55	7.49

Note: x-, y-, z-values represent Talairach-coordinates of the neuro-anatomical region’s peak voxel (activation threshold: $P < 0.05$, corrected; size: number of $3 \times 3 \times 3$ mm³ voxels). BA, Brodmann area; ROI, Region of interest; R, right; L, left.

Figure 1.

Increased brain activation to threatening vs. neutral movie clips. Activation is displayed for (A) the ACC, (B) the insula, (C) the thalamus, and (D) the visual areas. Statistical parametric maps are overlaid on a T1 scan (A: $x = 4$; B: $z = 10$; C: $z = 10$; D: $z = -5$; radiological convention: left = right).

Correlation with subjective anxiety

Anxiety ratings (individual differential scores for threat minus neutral scenes) correlated with brain activation to threat minus neutral scenes in the DMPFC [$r = 0.50$; Talairach coordinates of peak voxel (x, y, z): 3, 53, 21] but not in any other region. There was no other significant correlation in the brain using the a priori defined threshold, neither in nor outside the ROIs. Figure 2 displays the cluster in the DMPFC that significantly correlated with anxiety. This is also indicated in the corresponding scatter plot. The scatter plot also reveals a relatively greater activation in the most

anxious subjects, whereas low anxious subjects showed a relative deactivation. This pattern supports the findings of previous studies on anticipatory anxiety [Kalisch et al., 2006; Simpson et al., 2001; Straube et al., 2007a].

Correlation of activation to threat vs. neutral clips with personality

We analyzed the relation between sensation seeking and differential activation to threat vs. neutral movie clips. A positive correlation would indicate increased cerebral

Figure 2.

Positive correlation between subjects' anxiety ratings and brain activation to threatening vs. neutral movie clips. Subjects' anxiety ratings correlated positively with brain activation to threatening vs. neutral movie clips in the DMPFC. Statistical parametric maps are overlaid on a T1 scan ($x = 3$; radiological convention: left = right). The scatter plot shows the relationship between contrasts of parameter estimates (threat vs. neutral clips) and subjective anxiety.

Figure 3.

Positive correlation between sensation seeking scores and brain activation to threatening vs. neutral movie clips. Significant positive correlations were found in **(A)** the right fusiform gyrus, **(B)** the right insula, and **(C)** the right thalamus. Statistical para-

metric maps are overlaid on a T1 scan (A: $z = -11$; B: $z = 4$; C: $z = 4$; radiological convention: left = right). The scatter plots show the relationship between contrasts of parameter estimates (threat vs. neutral clips) and sensation seeking.

arousability to threat vs. neutral movie clips in high as compared to low sensation seekers. In the ROIs, this analysis revealed a significant positive correlation in the ventral stream of the extrastriate visual cortex, the right fusiform gyrus in BA 37 [$r = 0.55$; coordinates of peak voxel (x, y, z): 30, -50, -11]. Furthermore, significant positive correlations were detected in the right anterior insula [$r = 0.52$; coordinates of peak voxel (x, y, z): 42, 11, 4], and in right thalamus [$r = 0.67$; coordinates of peak voxel (x, y, z): 12, -13, 4]. Scatter plots and clusters of brain activation corre-

lating with sensation seeking are displayed in Figure 3. There were no negative correlations between sensation seeking and brain activation to threat vs. neutral movie excerpts. Significant positive or negative correlations between sensation seeking and brain activation were not detected outside the ROIs.

We also investigated whether the personality traits extraversion and neuroticism, which were associated with sensation seeking (see Questionnaire Data section), correlate with brain activation to threat vs. neutral movie clips.

Figure 4.

Negative correlation between sensation seeking scores and brain activation to neutral movie clips. Significantly negative correlations between sensation seeking scores and brain activation were found in the insula and thalamus during neutral movie clips. The scatter plots show the relationship between parameter estimates (neutral clips) and sensation seeking for **(A)** the right insula and **(B)** the right thalamus for the peak voxel shown in Figure 3.

This analysis revealed a cluster in the left fusiform gyrus (BA 18), where activation correlated positively with extraversion [$r = 0.51$; talairach coordinates of peak voxel (x, y, z): $-29, -78, -10$]. There were no further significant correlations between extraversion scores and brain activation. In addition, there were no clusters of brain activation that correlated with neuroticism. Thus, the relationships between sensation seeking and activation in the right insula, right thalamus, and right fusiform gyrus were specific for this personality trait.

Association between each predictor (threat or neutral) and sensation seeking

In a further step, we analyzed the association between sensation seeking and each condition separately at the coordinates found in the previous analysis. In particular, we tested whether a negative correlation with sensation seeking would be found for neutral movie clips, supporting a deficit model of cerebral arousal.

Activation of the right fusiform gyrus did not show a clear relation with sensation seeking for either category of movie clips (neutral scenes: $r = -0.15$; threatening scenes: $r = 0.17$; each correlation: $P > 0.05$). Thus, in extrastriate visual cortex, increased cortical activation to threat vs. neutral movie clips in high sensation seekers does not seem to be based on a specific association between sensation seeking and either predictor.

In contrast to the visual areas, but in accordance with a model assuming decreased brain activation during low intense stimuli, a significantly negative correlation between brain activation and sensation seeking was found in the right insula ($r = -0.40$; $P < 0.01$) and right thalamus ($r = -0.49$; $P < 0.01$) during the neutral scenes. Scatter plots for the correlation between brain activation and sen-

sation seeking are displayed in Figure 4. There was no significant correlation between sensation seeking and brain activation during threatening scenes in either region (insula: $r = -0.03$; thalamus: $r = -0.10$; both correlations: $P > 0.05$). Yet, a subsequent stepwise regression analysis showed that both predictors (threat, neutral) contributed significantly to the prediction of sensation seeking scores. This indicates that, besides activation differences during neutral movie clips, a general arousability effect leads to the association between sensation seeking and brain activation to threat vs. neutral movie clips. For the insula, activation during neutral movie clips explained 16% of the variance ($R^2 = 0.16$; $P < 0.01$). Inclusion of the threat predictor explained 36% of the variance. The increase in R^2 was significant ($P < 0.01$). For the thalamus, activation during neutral movie clips explained 24% of the variance ($R^2 = 0.24$; $P < 0.01$). Inclusion of the threat predictor explained 51% of the variance. Again, this change in explained variance was significant ($P < 0.01$).

DISCUSSION

The present study explored the neural correlates of being scared when watching scary movies, and the association between the personality trait sensation seeking and brain activation during scary movie clips. The study yielded three main results related to effects of movie category, experienced anxiety, and personality, all of which are discussed in the subsequent paragraphs.

Movie Category and Brain Activation

ACC, insula, thalamus, and visual areas were strongly activated during the threatening than during the neutral

scenes of scary movies. The finding for the visual areas suggests increased visual processing during the threatening movie clips. This outcome is consistent with previous studies, which showed stronger activation in visual regions in response to aversive and generally emotional, as compared to neutral movie clips [Goldin et al., 2005; Lane et al., 1998; Paradiso et al., 1997; Reiman et al., 1997; Stark et al., 2005; Straube et al., 2006a,b]. The insular cortex and midline frontal regions, such as the DMPFC or the ACC, have been implicated in the general awareness of own emotional responses [Critchley, 2004; Critchley et al., 2002; Kalisch et al., 2006; Phan et al., 2002; Straube et al., 2004, 2006a,b, 2007a,b]. In particular, the insula and ACC were proposed to be involved in the representation and generation of arousal states, which seem to contribute to the experience of emotional feelings [Craig, 2002; Critchley et al., 2003, see below]. The thalamic activation observed in the present study confirms the results of previous studies, which reported increased activation of the thalamus during anxiety states and emotional arousal in general [e.g. Anders et al., 2004; Karama et al., 2002; Porro et al., 2003; Straube et al., 2006b, 2007a, see below]. Noteworthy, we found no activation of the amygdala, which is in accordance with most studies on sustained anxiety [Hasler et al., 2007; Straube et al., 2006b, 2007a, 2009]. As discussed elsewhere, the amygdala is strongly activated during automatic evaluation and implicit processing of threat signals and seems to be more important for cue-induced, immediate fear, rather than for sustained anxiety [Hasler et al., 2007; Straube et al., 2004, 2006a,b, 2007a,b]. Even though there are suggestions that the left amygdala might be involved in more detailed threat processing of threat-related stimuli [e.g., Straube et al., 2006a], the current study did not find amygdala activation in either hemisphere. Thus, it seems more likely to reveal amygdala activation in response to sudden changes in the film clips or specific threat-related effects, which was not the focus of the current study.

Experienced Anxiety and Brain Activation

Compared to the main effect analysis, the correlation analysis between experienced anxiety and BOLD response allows stronger conclusions concerning the functional relevance of brain activation for the magnitude of subjective emotion. This analysis might also reveal activations not seen with the main effect analysis. Such effects may be found, if there is a main factor that rather prevents the activation of a region. For example, automatic attention to sensory input seems generally to lead to a decrease of pregenual medial prefrontal activation [e.g., Bishop et al., 2004; Simpson et al., 2001; Straube et al., 2007a, 2009]. However, the extent of appraisal processes and individual emotional involvement might nevertheless be associated with individual differences in activation of the medial prefrontal cortex [Simpson et al., 2001; Straube et al., 2007a].

These differences can be detected in the correlational analysis. In line with the latter possibility, the only area which showed a positive correlation with subjective anxiety was the DMPFC. A relation between anticipatory anxiety and activation in the DMPFC has been described in previous studies [e.g., Kalisch et al., 2006; Simpson et al., 2001; Straube et al., 2007a]. This brain region is implicated in high-level appraisal processes and has been shown to be involved in the general assessment of the emotional significance of stimuli and situations [Gusnard et al., 2001; Hornak et al., 2003; Kalisch et al., 2006; Phan et al., 2002; Simpson et al., 2001; Straube et al., 2004]. In particular, activation in the pregenual and DMPFC has been implicated in self-referential processing and subjective emotional experience [Hornak et al., 2003; Phan et al., 2002]. The activation in the DMPFC suggests that this area is involved in the subjective experience of being scared, at least for movie scenes that are characterized by high uncertainty regarding the nature and occurrence of the threatening event [i.e. the most relevant psychological dimension of horror movies, see Weaver and Tamborini, 1996].

Sensation Seeking and Brain Activation

A particularly relevant aspect of the current study was the test of theoretical models predicting a relation between sensation seeking and brain activation. It has been suggested that, during neutral stimulation, sensation seekers are characterized by decreased cerebral arousal levels leading to a search for sufficient sensations [Zuckerman, 1979, 1994]. In this sense, horror movies provide a specific kind of strong sensation and lead to increased cerebral arousal [Zuckerman, 1996a]. If the assumption is correct, that sensation seeking relates to some kind of "suboptimal" arousal during neutral stimulation, subsequently intense stimulation should be coupled with a stronger increase in brain activation in high, as compared to low sensation seekers. Studies using event-related potentials provided some evidence for this idea by showing, for example, augmentation of visually evoked potentials with increasing stimulus intensity in high but not in low sensation seekers [Siegel, 1997; Zuckerman, 1990]. Noteworthy, there were also effects in visual areas in the present study. High sensation seekers showed a pronounced relative increase of activation. However, there was no negative association between sensation seeking and neutral stimulation suggesting that there is no general tendency of less activation in visual cortical areas in high vs. low sensation seekers during less intense stimulation.

Besides the increase of activation in visual areas, we also detected a strong and trait-specific relation between sensation seeking and brain activation in the right thalamus and the right anterior insula. However, in both regions, the positive correlation between sensation seeking scores and activation to threat versus neutral film clips was associated with less activation in high, as compared

to low, sensation seekers during the neutral movie clips. Furthermore, we did not find any relation between sensation seeking and activation during threatening movie clips. The findings for these regions support a model predicting (1) less cerebral arousal during less intense stimulation in high as compared to low sensation seekers, (2) a partial compensation for this reduced activation during intense sensations as, for example, provided by scary movie scenes, and (3) generally stronger cerebral arousability with increased stimulation.

The correlation between sensation seeking and activation in the thalamus suggests that sensation seeking is coupled with activation differences in sub-cortical brain areas. The thalamus is involved in the control of cortical arousal [Parvizi and Damasio, 2001; Van der Werf et al., 2002]. The midbrain reticular formation seems to extend into the intra-laminar and midline nuclei of the thalamus [Krout et al., 2002; Parvizi and Damasio, 2001; Van der Werf et al., 2002]. These thalamic nuclei project to diverse cortical, but also subcortical, areas and seem to tonically activate the cortex [Parvizi and Damasio, 2001]. Functional imaging has repeatedly shown a relation between arousing stimulation and thalamic activation [e.g. Anders et al., 2004; Porro et al., 2003; Straube et al., 2006a,b, 2007a]. Furthermore, the thalamic cluster of activation in the current study covered most of the thalamus proper including the midline/intralaminar nuclei of the thalamus. Thus, in the case of sustained stimulation of low intensity, high sensation seekers seem to be characterized by relatively decreased activity of the thalamic arousal centers. This finding indicates that differences in the sensation seeking trait are represented on the subcortical level. This might also indicate a highly automatic differential activity associated with different levels of sensation seeking.

The thalamus is also strongly connected with the anterior insula [Craig, 2002]. The insular cortex represents arousal states of the organism and the right anterior insula, in particular, seems to integrate interoceptive information [Craig, 2002]. This area might assist the assessment of danger and provide a warning centre, due to the perception of arousal states [Craig, 2002; Paulus and Stein, 2006]. Thus, a relation between insular hyperactivity, increased awareness of bodily states, and anxiety proneness has been suggested [Craig, 2002; Critchley, 2004; Paulus and Stein, 2006; Straube et al., 2004, 2006a,b, 2007a,b]. Furthermore, insula activation during anxiety-provoking paradigms has been repeatedly shown [e.g. Critchley, 2004; Straube et al., 2006a, 2007a]. Given this function of the insula, the present findings suggest hypoarousal in high sensation seekers during low intense stimulation. In low sensation seekers, relatively enhanced insula activation during less intense stimulation might signal potential danger and limit the search for further challenge. In contrast, high sensation seekers are generally supposed to anticipate less danger [Zuckerman, 1996b]. Furthermore, decreased insula activation in high sensation seekers might be below the optimal homeostatic level of interoceptive

sensation. Risky and intense situations increase interoceptive signals and insula activation and may thus be preferred by high sensation seekers [Critchley et al., 2002; Paulus and Stein, 2006; Zuckerman, 1994]. Based on this homeostatic account and the suggested role of interoception and insula activation for self-awareness [Craig, 2002], high sensation seekers may need more intense sensations to feel themselves and to just feel comfortable. However, this hypothesis has to be tested by additional behavioral data in future studies.

CONCLUSION

In summary, the present study showed that threat, as compared to neutral scenes of scary movie clips, lead to increased activation in the ACC, anterior insula, thalamus, and visual areas. Movie-induced anxiety correlated positively with activation in the DMPFC, suggesting that this area plays a role in being scared by horror movies. Most importantly, sensation seeking scores were positively correlated with brain activation to threat versus neutral scenes in visual areas, as well as in regions known to be involved in induction and representation of arousal states: right thalamus and right anterior insula. The outcomes for the latter two regions were associated with an inverse relation between sensation seeking and brain activation during the neutral condition. These results suggest decreased cerebral arousal in high, as compared to low sensation seekers, in specific brain regions during low intense stimulation. This hypoactivation seems to be compensated by intense sensations as provided, for example, by threat scenes in scary movies.

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