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Sensation Seeking and the Aversive Motivational System

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Sensation seeking (SS) has traditionally been viewed as a phenomenon of the appetitive motivational system. The limited SS research exploring contributions from the aversive motivational system reveals greater anxious reactivity to dangerous activities among low sensation seekers. The present study extends this line of work by comparing levels of fear and anxiety during anticipation of predictable and unpredictable aversive stimuli across high- and low-SS groups. Low sensation seekers displayed greater fear-potentiated startle (FPS) to predictable aversive stimuli, and only those low on SS showed FPS and skin conductance response effects during experimental contexts in which aversive stimuli were delivered unpredictably. Findings implicate enhanced apprehensive anticipation among those low on SS as a potential deterrent for their participation in intense and threatening stimulus events.

Keywords: sensation seeking, anxiety, fear, startle, psychophysiology

Sensation seeking (SS) is a dimension of personality that has been defined by the need for varied, novel, complex, and intense sensory stimulation and the level of risk taken in an effort to satisfy the desire for such stimulation (Zuckerman, 1994). High SS has been associated with participation in a variety of intense, anxiogenic stimulus events such as viewing horror movies (Zuckerman & Litle, 1986), parachuting (Hymbaugh & Garrett, 1974), hang gliding (A. M. Wagner & Houlihan, 1994), auto racing (Straub, 1982), whitewater rafting (Campbell, Tyrrell, & Zingaro, 1993), breaking the law (Arnett, 1996), unsafe sexual behavior (M. K. Wagner, 2001), and reckless automobile driving (Furnham & Saipe, 1993). Of central importance to the SS construct are the specific motivational forces underlying the approach and avoidance of such activities among those high and low on SS.

Zuckerman (1994, p. 385) maintains that high sensation seekers experience appetitive arousal and "approach" behavioral tendencies in response to these types of intense, novel, and often dangerous situations by way of increased dopaminergic activity in the mesolimbic (positive arousal; Duvauchelle, Levitin, MacConell, Lee, & Ettenberg, 1992) and nigrostriatal areas (motor output; Carli, Evenden, & Robbins, 1985). These rewarding consequences are thought to account for high sensation seekers' willingness to endure substantial risk for the sake of intense sensory stimulation. According to Zuckerman, low sensation seekers experience little or no positive affect from these types of stimulus events, leaving them with little motive to endure the risks associated with such activity.

Although Zuckerman (1994) views SS as a phenomenon of the appetitive motivational system, there is reason to believe that high and low sensation seekers differ in terms of their aversive motivational tendencies as well. More specifically, low sensation seekers may avoid intense and dangerous sensory experiences because of increased apprehensive anticipation (e.g., fear/anxiety of injury or other negative consequences). Conversely, reduced anxious anticipation among high sensation seekers may both facilitate their decision to participate in intense, risky activities and allow them to enjoy the rush of sensations free from anxious apprehension.

Support for this view comes from multiple studies associating low SS with both greater self-reported anxious reactivity to physically risky situations (Blankstein, 1975; Breivik, Roth, & Jorgensen, 1998; Burkhart, Schwartz, & Green, 1978; Franken, Gibson, & Rowland, 1992; Kilpatrick, Sutker, & Smith, 1976; Maneno & Lykken, 1973; Mellstrom, Cicala, & Zuckerman, 1976; Segal, 1973) and higher risk appraisals of dangerous behaviors (Furnham & Saipe, 1993; Heino, van der Molen, & Wilde, 1992; Zuckerman, 1979). Zuckerman (1994) notes such relations but maintains that low sensation seekers display elevated anxious reactivity and perceived danger to risky situations because they self-select out of these activities, leaving them little opportunity to habituate or gain a sense of mastery over such experiences. Although this explanation seems plausible, it is inconsistent with data demonstrating greater anxious reactivity among low sensation seekers to threatening events, to which high and low sensation seekers have equal exposure. For example, threatening images from the International Affective Picture System (Lang, Öhman, & Vaitl, 1988) presented

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with equal frequency to high and low sensation seekers evoke startle potentiation in low- but not high-SS individuals (Lissek & Powers, 2003). Additionally, several studies demonstrate greater anxiety and maladjustment among low versus high sensation seekers who endured physically threatening events such as the Vietnam War (Orr et al., 1990), military captivity (Solomon, Ginzburg, Neria, & Ohry, 1995), and sports-related injury (Smith, Ptacek, & Smoll, 1992). It is thus unlikely that relations between SS and anxious reactivity are attributable to differential exposure to risk. Additionally, such data provide further support for the involvement of the aversive motivational system in the SS trait.

The present study applies a fear-potentiated startle (FPS) paradigm to assess the relationship between SS and apprehensive anticipation of intense and aversive audiovisual stimuli. *FPS* refers to the increase in startle magnitude reliably evoked by cues marking the possible onset of aversive events such as electric shocks, blasts of air, and loud white noises (Grillon, Ameli, Woods, Merikangas, & Davis, 1991; Grillon, Dierker, & Merikangas, 1998; Skolnick & Davidson, 2000). Because startle potentiation is blocked following damage to amygdala-based "fear" circuits in both animal (Hitchcock & Davis, 1986) and human studies (Angrilli et al., 1996; Pissiota et al., 2003), and because incremental increases in the anxiogenic quality of experimentally presented stimuli produce linear increases in startle magnitude (Grillon, Ameli, Goddard, Woods, & Davis, 1994; Morgan, Grillon, Southwick, Davis, & Charney, 1995; Pole, Neylan, Best, Orr, & Marmar, 2003), FPS in humans is thought to reflect states of anxious arousal.

Because in the present study we examine apprehensive anticipation via FPS to novel auditory stimuli to which both groups are equally exposed, Zuckerman's (1994) position would predict similar levels of potentiation across high and low sensation seekers. This contrasts the aversive motivational position that predicts greater FPS among low versus high sensation seekers.

An additional goal of the present study was to examine the separate effects of SS on fear- and anxiety-like states. M. Davis (1998) has proposed a distinction between fear and anxiety whereby *fear* is conceptualized as a short-term, phasic response to explicit threat cues, and *anxiety* is proposed as a sustained apprehension to diffuse or contextual (unpredictable) threat cues. This distinction may have important implications, as discrete neurobiological loci are associated with fear (central nucleus of the amygdala) and anxiety (bed nucleus of the stria terminalis), and each emotion may contribute to the pathogenesis of different types of anxiety disorders (Grillon, 2002b; Kandel, 1983). Importantly, unpredictable aversive events promote contextual anxiety (Baker, Mercier, Gabel, & Baker, 1981; Grillon & Davis, 1997; Odling-Smee, 1975) and have been applied to evoke anxiety-like reactions in the laboratory setting (Grillon, Baas, Lissek, Smith, & Milstein, 2004; Grillon & Davis, 1997). In the present study, we apply an experimental paradigm, designed by our group (Grillon et al., 2004) to measure emotional reactivity to predictable (signaled by a cue) and unpredictable (nonsignaled) threat of aversive events in order to test associations between SS and both fear and anxiety. Of note, the term *apprehensive anticipation,* as used in the present article, denotes general aversive activation (i.e., either *fear* or *anxiety*) accompanying the expectation of an imminent unpleasant event.

Evidence of decreased phasic fear responses to a physical threat among high sensation seekers supports an inverse SS by predictable threat association, but the SS-by-unpredictable threat relationship is less clear. On the one hand, those high on SS are boredom susceptible and are proposed to display greater appetitive arousal to novel and less predictable sensory stimulation (Zuckerman, 1994). Because mutually inhibitory effects have been found between appetitive and aversive motivational states (Albert & Ayers, 1997; Bull, 1970; H. Davis & Kreuter, 1972; Dickinson & Pearce, 1977), appetitive reactions to unpredictability among high sensation seekers may dampen the amount of aversive (anxious) arousal they experience during anticipation of unpredictable stimuli. This first possibility affords the prediction that those high relative to low on SS will show less anxiety during anticipation of an unpredictable threat. A different prediction regarding reactivity to unpredictable aversive stimuli is supported by documented correlations between self-reported anxiety and SS. Such correlations reveal negative relationships between SS and phasic fear to specific threats of physical harm but no relationship between SS and free-floating, persistent anxiety traits (Zuckerman, 1979). It is thus possible that high and low sensation seekers will display equal levels of diffuse anxiety-like reactivity to the unpredictable threat of aversive stimuli. These two competing predictions regarding the SS-by-anxiety association are tested in the present study along with the primary hypothesis that those high relative to low on SS will show less phasic anticipatory fear to predictable threat cues.

Method

Participants

Participants were 34 healthy volunteers divided into high- (11 men and 6 women) and low- (5 men and 12 women) sensation-seeking groups, with equivalent mean age and average scores on state and trait measures of anxiety (see Table 1). The Sensation Seeking Scale-Form V (SSS-V; Zuckerman, 1994) was used to determine each participant's level of SS. A median-split method yielded a high-SS group ($n = 17$; SSS-V $M = 26.41$, $SD = 4.11$) and a low-SS group ($n = 17$; SSS-V $M = 15.35$, $SD = 3.86$), with average SS scores falling in the 76th and 7th percentiles, respectively, of Zuckerman's normative sample. A complete description of the study was given prior to participation, and participants gave written informed consent that had been approved by the National Institute of Mental Health Human Investigation Review Board. Inclusion criteria included (a) no past or current psychiatric disorders, as per the Structured Clinical Interview for *DSM–IV* (SCID; First, Gibbon, Spitzer, & Williams, 2001); (b) no medical condition that interfered with the objectives of the study; and (c) no use of drugs or psychoactive medications, as per self-report.

Stimuli and Physiological Responses

Stimulation and recording were controlled by a commercial system (Contact Precision Instruments, London, England). The physiological measures included eyeblink electromyography (EMG) (startle reflex) and skin conductance (SC). Startle in each participant was elicited with either acoustic or airpuff probes as part of a separate effort to study the effects of probe type on startle responding. The results of this comparison are reported elsewhere (Lissek et al., 2005). Preliminary analyses indicated that the results from the present study were not influenced by probe type. Probe type was found to be unrelated to levels of baseline startle, $t(32) = 0.03$, $p > .97$, and FPS, $t(32) = 0.90$, $p > .37$. In addition, probe type was well represented in both high-SS (nine white noise, eight airpuff) and

Table 1
Means, Standard Deviations, and Paired Samples t Tests for Demographics and Self-Report Measures Across Groups

	Group					
	Low SS (n = 17)		High SS (n = 17)			
Measure	*M*	*SD*	*M*	*SD*	t(32)	*p*
Age	27.1	7.9	26.7	5.6	0.18	*ns*
% Male	29.4	46.9	64.7	49.2	2.14	< .05
SS-Total	15.4	3.9	26.4	4.1	8.09	< .001
SS-TAS	5.2	2.3	8.0	1.7	4.05	< .001
SS-ES	4.8	1.8	7.4	1.9	4.13	< .001
SS-DIS	3.8	1.9	7.1	1.2	6.15	< .001
SS-BS	1.6	1.5	3.9	2.2	3.62	< .01
STAI-Trait	32.3	12.3	28.9	7.3	0.12	*ns*
STAI-State	29.0	10.5	26.3	5.5	0.05	*ns*

Note. SS = sensation seeking; TAS = Thrill and Adventure Seeking; ES = Experience Seeking; DIS = Disinhibition; BS = Boredom Susceptibility; STAI = State–Trait Anxiety Inventory.

low-SS groups (eight white noise, nine airpuff). Finally, SS scores are uncorrelated with probe type, $r(35) = -.01$, $p > .97$.

The acoustic startle stimulus was a 40-ms duration, 102 dB(A) burst of white noise, with a near instantaneous rise time presented binaurally through headphones.

The airpuff startle probe was a 40-ms 3-psi puff (measured at the level of the regulator) of compressed room air delivered to the center of the forehead through a polyethylene tube (2.0 foot long [0.61 m], 1/8 in. [.20 cm] inside diameter) affixed 1 cm from the skin by way of a headpiece worn by the participant. This airpuff probe setup was the same as the setup shown to work effectively in a previous FPS study in our lab (Grillon & Ameli, 1998), except that the startle probe intensity was reduced from 15 psi to 3 psi in the present study. The 3-psi airpuff probe was chosen because pilot data demonstrated similar blink magnitudes when using the 3-psi airpuff and a 102dB white-noise probe.

For both probe types, the eyeblink reflex was recorded with two 6-mm tin cup electrodes placed under the right eye, and the amplifier bandwidth was set to 30–200 Hz.

The left palmar SC was recorded from the index and middle finger of the left hand according to published recommendations (Prokasy & Ebel, 1967).

Experimental Design

High- and low-SS groups underwent identical experimental procedures. The primary experiment consisted of three conditions: neutral (N), predictable (P), and unpredictable (U), lasting 2 min each. In the N condition, no unpleasant events were delivered. In the P condition, unpleasant events were administered predictably, that is, only in the presence of a threat cue. In the U condition, unpleasant events could be delivered at any time (see below). Unpleasant events consisted of four different 3-s duration, 95dB aversive noises: (a) white noise, (b) high-pitch tone (2kHz), (c) smoke alarm (Pizzagalli, Greischar, & Davidson, 2003), and (d) human female scream (the human scream was accompanied by a briefly presented picture of a fearful woman). In each condition (N, P, and U), an 11-s duration cue was presented twice. The cues were colored shapes, which varied in color and shape by condition (e.g., blue circle for N and green square for U). The cues signaled the possibility of receiving an aversive stimulus only in the P condition, but they had no signal value in the N and U conditions. For the duration of each 2-min N, P, and U condition, a computer monitor apprised participants of the current condition by displaying the following information: "no unpleasant event" (N), "unpleasant event only during shape" (P), or "unpleasant event at any time" (U). During each predictable and unpredictable condition, two different unpleasant events were administered, and each of the four unpleasant events were given equally often in the P and U conditions. The unpleasant events were delivered at cue offset in the predictable conditions and in the absence of the cues in the unpredictable conditions. Startle stimuli were delivered (a) 4–6 s following the onset of each cue and (b) during intertrial intervals (ITI) between cues every 20–40 s. Startle magnitudes elicited in the three conditions in the absence of cues (i.e., during ITIs) were measured to assess anxious arousal during the N, P, and U contexts. Throughout this article, *condition* refers to the N, P, and U conditions regardless of the presence or absence of the cue. *Context*, however, refers to the period of time in each condition when no cue is present (i.e., ITI).

Prior to the start of the threat experiment, participants received nine startle probes to habituate the startle reflex. The threat experiment consisted of two recording blocks, with a 5–10 min rest between blocks. Each block began with four habituation trials and consisted of three N, two P, and two U conditions in one of the following two orders: P N U N U N P or U N P N P N U. Each participant was presented with the two orders, with half the participants starting with the P condition.

Procedure

Participants underwent a screening session that consisted of a SCID, a physical exam, and the completion of the SSS-V (Zuckerman, 1994) and the State–Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Within 2 weeks of screening, participants returned for the testing session. This session started with the presentation of nine startle stimuli delivered every 18–25 s to assess the baseline startle reflex prior to the threat study. Participants were then given an explanation of the study, including explicit instructions regarding the conditions under which they would and would not receive an unpleasant event. Following this instruction, the experiment was conducted.

At the end of the experiment, participants were asked to retrospectively rate their overall subjective anxiety to the cue and context in the N, P, and U conditions on an analog scale ranging from 1 (*not at all*) to 10 (*extremely*). Participants used a similar 10-point scale to report "how intense," "how unpleasant," and "how anxiety provoking" the unconditioned stimuli were during the experiment. Finally, participants indicated the degree to which they would prefer to avoid further exposure to the aversive stimuli using a 10-point scale (1 = *definitely*, 10 = *definitely not*).

Data Analysis

Startle EMG was rectified and then smoothed (20-ms moving window average). The onset latency window for the blink reflex was 20–100 ms, and the peak magnitude following the onset up to 120 ms was determined. Additionally, the average baseline EMG level for the 50 ms immediately preceding delivery of the startle stimulus was subtracted from the peak magnitude. Skin conductance responses (SCR) to the contexts, cues, and aversive stimuli were required to have an onset within a 1- to 5-s latency window of presentation of such stimuli. SCRs were calculated by subtracting the SC level at onset from the peak SC level of the response wave. SCR scores underwent a square-root transformation to attain statistical normality. Additionally, SCRs were range corrected (Lykken & Venables, 1971) to reduce the influence of between-subjects variability unrelated to psychological processes.

For each physiological variable, the data were averaged for context and cue for each condition across blocks. The magnitude of the eyeblink was also analyzed after standardization using within-subjects *t* scores. Because similar results were obtained with the raw scores and with the *t* scores for within-subjects comparisons, only results of the *t*-scored data are presented. The data were analyzed with a Block (1 or 2) x Condition (N, P, or U) x Cue (Cue on or off) x Group (High SS or Low SS) x Gender multivariate analysis of variance, with repeated measures. Multivariate analyses of variance were computed using Wilks's lambda and were followed by paired samples *t* tests to examine a priori predicted differences across groups. Although only one dependent variable was included in each analysis, multivariate analysis of variance was chosen because it affords protection against sphericity without performing the univariate correction (Tabachnick & Fidell, 1996). Alpha was set at .05 for all statistical tests. Additionally, given the limited sample size, power analyses were conducted for inferential statistics testing a priori predictions resulting in *p* values less than .40. Such power analyses will allow the reader to interpret results with the probability of Type II errors in mind for nonsignificant but more substantial effects. Of note, analyses of SS subscales were conducted, and results are available as supplemental materials on the Web at http://dx.doi.org/10.1037/1528-3542.5.4.396.

Operationalizing responses to predictable and unpredictable threat. For startle data, potentiations to predictable and unpredictable threat for each group were tested by comparing startle magnitudes with the predictable cue versus predictable context and unpredictable context versus neutral context, respectively. Similarly for self-reported anxiety, enhanced anxiety to the predictable and unpredictable threat for each group was examined through comparisons between reported anxiety to the predictable cue versus predictable context and unpredictable context versus neutral context, respectively.

Although SCRs to unpredictable threat were also analyzed by way of a comparison between unpredictable and neutral contexts, reactions to predictable threat were analyzed slightly differently. SCRs to the context were phasic responses to the onset of each context and could not serve as a baseline with which to compare SCRs with the predictable cue. Startle during the predictable context, however, is an appropriate baseline because it was measured at different points during each context and thus reflected ongoing levels of anxious arousal that preceded anxious arousal to the predictable cue. SCR responses to predictable threat were thus tested by comparing SCRs with the predictable cue with SCRs to the neutral cue.

In the present paradigm, predictable threat models phasic fear to a discrete threat cue, whereas unpredictable threat models sustained anxiety to diffuse contextual cues. The link between unpredictability and anxiety stems from animal and human studies implicating unpredictable aversive events as important antecedents of contextual anxiety (Bouton, 1984; Fanselow, 1980; Grillon & Davis, 1997).

Of note, no EMG activity was detectable for 1 participant in the low-SS group and was dropped from analyses (i.e., there were originally 18 participants in the low-SS group). Additionally, no detectable SCR was present for 4 participants (3 low SS; 1 high SS), leaving data for 15 low-SS and 16 high-SS participants for SCR analyses.

Results

Table 1 displays means and standard deviations for demographics and self-report inventories across groups. As can be seen, trait and state anxiety scores for low-SS (trait = 32.3; state = 29.0) and high-SS groups (trait = 28.9; state = 26.3) did not differ significantly (both *p*s $>$ .36). Groups differed on total SS scores as well as on the Thrill and Adventure Seeking, Experience Seeking, Disinhibition, and Boredom Susceptibility subscales (all *p*s $<$ .01). Groups also differed on gender, χ^2 (1, $N = 34$) = 4.25, $p = .04$, with significantly more men in the high-SS group (low SS = 30% male; high SS = 65% male). As such, the moderating effect of gender was accounted for in all relevant analyses.

Startle Reflex

Figure 1 displays mean startle magnitudes for each group across contexts and cues. Inferential analyses revealed significant main effects of both condition, $F(2, 28) = 32.45$, $p < .001$, and cue, $F(1, 31) = 52.94$, $p < .001$; as well as Condition × Cue, $F(2, 28) = 10.78$, $p < .001$; and Group × Condition × Cue interactions, $F(2, 28) = 4.84$, $p = .016$.

Group × Predictable Threat. Although the predictable cue potentiated startle in both low-, $t(16) = 8.24$, $p < .001$, and high-SS groups, $t(16) = 2.86$, $p = .011$, the effect size for the low-SS group (Hedge's $g = 1.90$) was significantly larger than that for the high-SS group (Hedge's $g = 0.66$), as indicated by Johnson's (Johnson, 1989) Q_b statistic ($Q_b = 5.24$, $p = .022$; see Figure 2). The relationship between SS and FPS to the predictable cue was further supported by a significant FPS-by-raw SS score correlation, whether FPS was calculated as a predictable cue over context proportion, $r(34) = -.47$, $p = .005$, or as a predictable cue minus context difference score, $r(34) = -.48$, $p = .004$ (see Figure 3). These correlations were not attributable to gender differences among high- and low-SS groups, as this SS × FPS relationship remained significant after controlling for gender whether using difference scores, $pr(31) = -.55$, $p < .001$, or proportions, $pr(31) = -.54$, $p < .001$.

Group × Unpredictable Threat. Those low on SS displayed enhanced startle to the unpredictable versus neutral context, $t(16) = 2.39$, $p = .03$, whereas those high on SS did not, $t(16) = 1.35$, $p = .20$, power = .34 (see Figure 2). Effect sizes for this unpredictability effect for low (Hedge's $g = 0.55$) and high sensation seekers (Hedge's $g = -0.31$) did not significantly differ ($Q_b = 0.24$, $p > .62$), and continuous SS scores were unrelated to FPS to the unpredictable context whether computing FPS as an unpredictable versus neutral context proportion, $r(34) = -.190$, $p = .28$, power = .29, or difference score, $r(34) = -.189$, $p = .28$, power = .29. After controlling for gender, both correlations dropped to $-.01$ (both *p*s $>$ .94).

As can be seen above, power analyses revealed a high probability (66%) of a Type II error for the null result of unpredictability among those high on SS. Such results attenuate the conclusion that startle potentiation is not elicited by unpredictable aversive events among those high in SS.

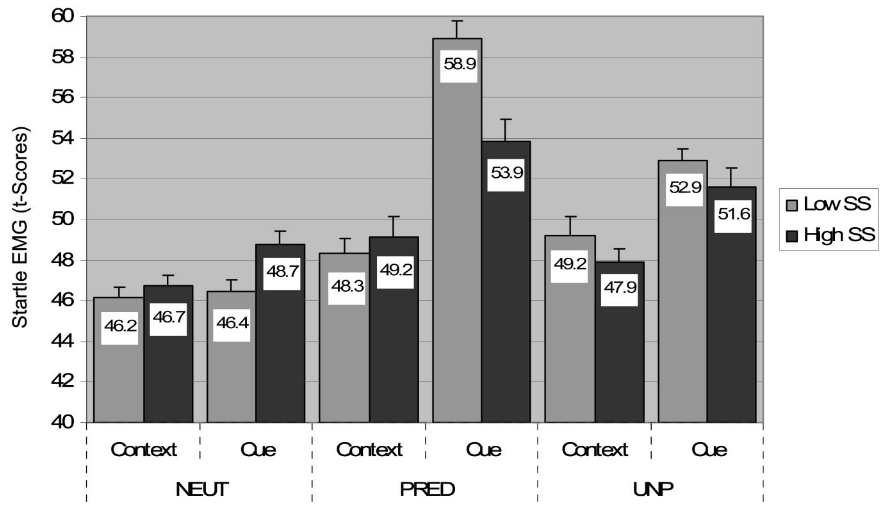

Figure 1. Average standardized eyeblink electromyography (EMG) (*t*-scores) across neutral (NEUT), predictable (PRED), and unpredictable (UNP) cues and contexts by high- and low-sensation-seeking (SS) groups. Error bars display standard errors of the means.

SCR

Average SCR magnitudes are displayed in Figure 4. Inferential statistics revealed that SCR varied by condition, $F(2, 26) = 4.28$, $p = .025$, but not by cue, $F(1, 27) = 1.69$, $p = .21$; and a Condition × Cue interaction was present, $F(2, 26) = 3.63$, $p = .04$. Additionally, gender did not interact with condition or cue (both *p*s > .58), and no Gender × Condition × Cue interaction was found ($p > .43$).

The main effect of group was significant whether analyzing raw SCR data, $F(1, 27) = 5.09$, $p = .04$, or range-corrected data, $F(1, 27) = 5.21$, $p = .03$, indicating that those low on SS generally displayed stronger SCRs to all cues and contexts. The Group × Condition × Cue interaction was not significant, $F(2, 28) = 2.14$, $p = .14$, yet follow-up comparisons were computed to test a priori predicted differences in SCR across groups.

Group × Predictable Threat. Larger SCRs to the predictable versus neutral cue were found among low sensation seekers, $t(14) = 2.41$, $p = .03$; and a trend for this effect was found among those high on SS, $t(15) = 1.99$, $p = .07$, power = .56. Additionally, no between-group difference was found for SCR

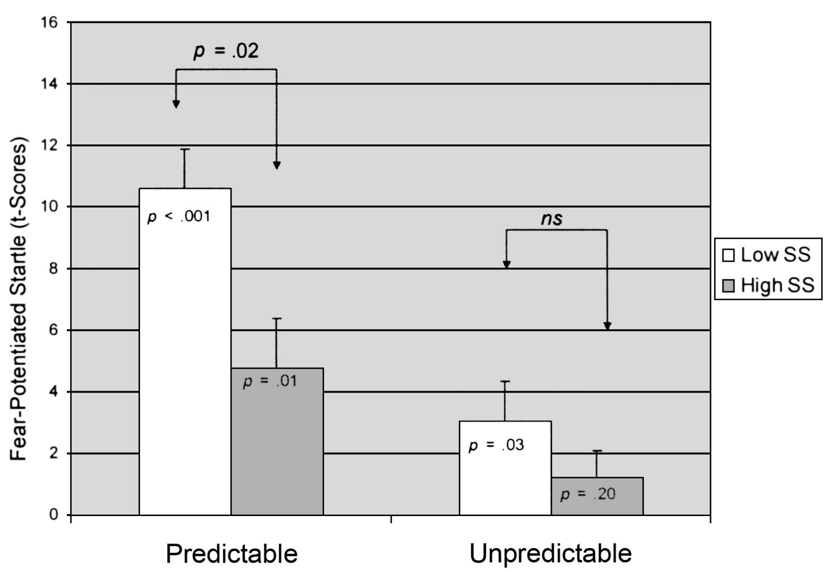

Figure 2. Fear-potentiated startle (FPS) to predictable and unpredictable threat of aversive audiovisual stimuli across high- and low-sensation-seeking (SS) groups. *Predictable FPS* defined as predictable cue minus predictable context. *Unpredictable FPS* defined as unpredictable context minus neutral context. *ns* = nonsignificant. Error bars display standard errors of the means.

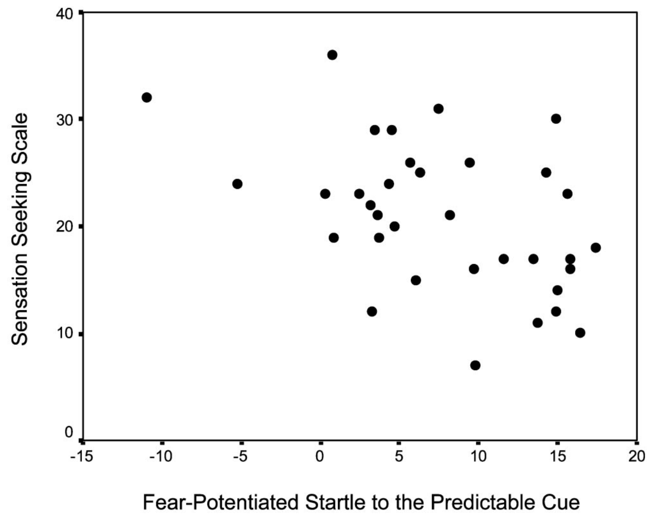

Figure 3. Scatter plot displaying the association between sensation seeking (*y* axis) and fear-potentiated startle to the predictable cue (*x* axis). Startle potentiation was calculated by subtracting standardized startle magnitudes elicited by the predictable context from those elicited by the predictable cue. Scores on the Sensation Seeking Scale range from 0 to 40. $r = -.48$, $p = .004$.

to the predictable cue, $t(29) = 0.95$, $p = .35$, power = .24; and the correlation between continuous SS scores and SCR to the predictable cue was nonsignificant, $r(31) = -.18$, $p = .33$, power = .25, even after controlling for gender, $pr(28) = -.25$, $p = .19$, power = .39. As can be seen from power analyses, the probability of missing a group effect for SCRs to the predictable threat cue ranges from 61% to 76%. It is thus possible that group differences exist but could not be detected with the present level of power.

Group × Unpredictable Threat. Greater SCR to the unpredictable versus neutral context was found for low, $t(14) = 3.77$, $p = .002$, but not high sensation seekers, $t(15) = 0.26$, $p = .80$; and a trend for larger SCR to the unpredictable context among those low on SS was found, $t(29) = 1.87$, $p = .07$. Additionally, the zero-order correlation between continuous SS scores and SCR to the unpredictable context fell short of significance, $r(31) = -.28$, $p = .13$, power = .48 (see Figure 5), but became significant after controlling for gender, $pr(28) = -.40$, $p = .029$.

SCR to the unpleasant events. In the present study, range corrections were computed by dividing each SCR for a given individual by that individual's maximum SCR. Because SCRs to the unpleasant events were usually the largest, range correction of SCRs to the unpleasant event would yield scores approaching 1.0 regardless of the absolute SCR levels. For this reason, SCR data used to test arousal to unpleasant events across groups were square rooted but not range corrected. No group differences in square-rooted SCR were found for any of the four unpleasant events tested separately (all ps $> .18$) or as an aggregated average, $t(29) = 1.10$, $p = .28$, power = .29. The failure to find group differences in SCRs to the unpleasant events may be because of a lack of power, as there is a 71% chance of Type II error for this between-group *t* test.

Self-Reported Anxiety

Mean levels of reported anxiety by cue and condition are listed across groups in Table 2. Significant main effects were found for condition, $F(2, 27) = 28.79$, $p < .001$, and cue, $F(1, 28) = 11.40$, $p = .002$; and the Condition × Cue interaction was significant, $F(2, 27) = 23.66$, $p < .001$. An examination of the effects of gender on self-reported anxiety resulted in no Gender × Condition, Gender × Cue, or Gender × Condition × Cue interactions ($p > .49$).

A main effect of group was found at the level of a trend, $F(1, 32) = 3.26$, $p = .08$. Although no Condition × Cue × Group interaction was present, $F(2, 27) = 0.60$, $p > .55$, follow-up contrasts were computed to test a priori hypotheses.

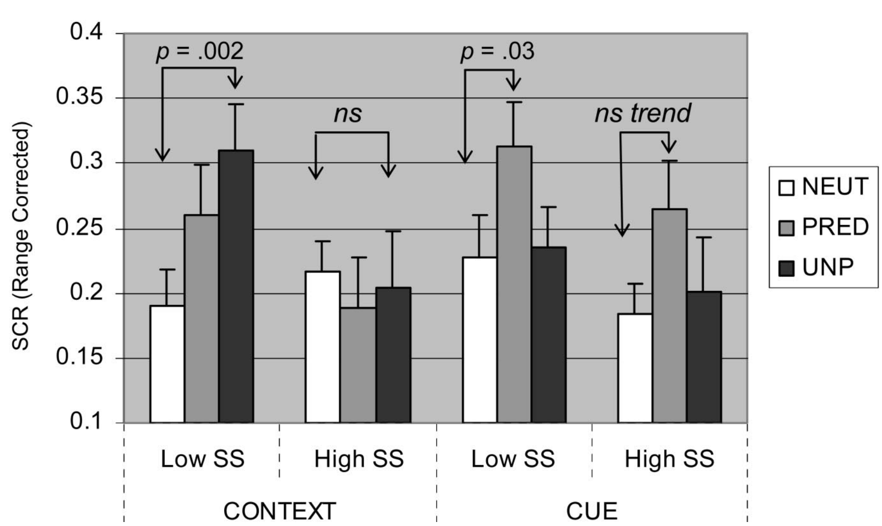

Figure 4. Range-corrected skin conductance responses (SCRs) to the neutral (NEUT), predictable (PRED), and unpredictable (UNP) cues and contexts by high- and low-sensation-seeking (SS) groups. *ns* = nonsignificant. Error bars display standard errors of the means.

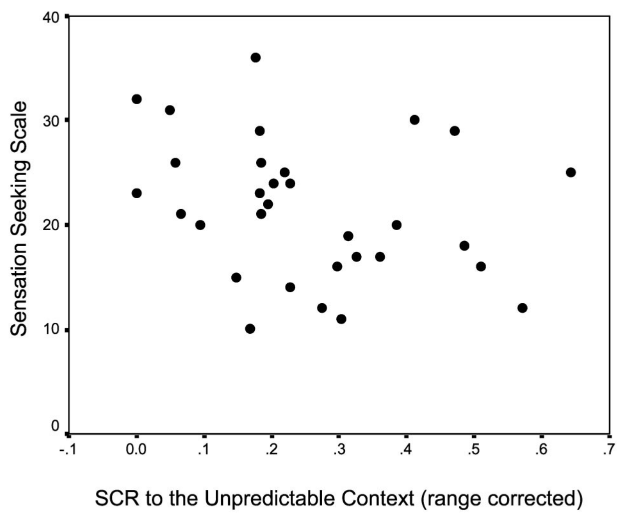

Figure 5. Scatter plot displaying the association between sensation seeking (y axis) and skin conductance responses (SCRs) to the unpredictable context (x axis). Reactions to the unpredictable threat were calculated by subtracting SCRs elicited by the neutral context from those elicited by the unpredictable context. Scores on the Sensation Seeking Scale range from 0 to 40. $r = -.28$, $p = .13$.

Group × Predictable Threat. Increases in reported anxiety from predictable context to cue were identified for low-SS, $t(16) = 6.18$, $p < .001$, and high-SS groups, $t(16) = 4.83$, $p < .001$; and no group difference in these increases was found, $t(32) = 1.31$, $p = .20$, power = .35. This nonsignificant group difference should be interpreted cautiously, as a power analysis revealed a 65% probability of Type II error for this comparison. Of note, raw levels of reported anxiety to the predictable cue were greater among those low versus high in SS, $t(32) = 2.40$, $p = .02$, and the lack of a differentially larger increase from predictable context to cue among those low on SS may be attributable to the trend for greater anxiety to the predictable context among those low on SS, $t(32) = 1.88$, $p = .07$. No correlations between continuous SS scores and elevations in reported anxiety to the predictable cue were found whether analyzing difference or proportion scores, before or after controlling for gender (all ps > .63).

Group × Unpredictable Threat. Increases in anxiety from neutral to unpredictable contexts were reported by both low-SS, $t(16) = 7.55$, $p < .001$, and high-SS groups, $t(16) = 5.28$, $p < .001$; and no group effect on difference scores in reported anxiety (unpredictable vs. neutral context) was found, $t(32) = 0.99$, $p = .33$, power = .24. Again, this nonsignificant group difference should be interpreted with caution, as a power analysis revealed a 76% probability of Type II error for this effect. Additionally, no correlations were found between SS and raw or change scores for reported anxiety to the unpredictable context with or without controlling for gender (all ps > .55).

Reported Reactions to Unpleasant Events

As can be seen in Table 3, no group differences were found for subjectively rated intensity ($p = .80$), unpleasantness ($p = .23$, power = .32), and anxiety provocation ($p = .62$) of unpleasant events, and both groups expressed an equal interest in avoiding further exposure to the unpleasant stimuli ($p = .38$, power = .21).

Discussion

Low- relative to high-SS groups displayed more FPS in response to the predictable threat cues. Additionally, those low on SS displayed enhanced SCR to the predictable threat cue, whereas this effect was at the level of a nonsignificant trend for the high-SS group. Although increases in reported anxiety elicited by the predictable threat cue versus context were equal across groups, those low versus high on SS displayed larger raw levels of anxiety while exposed to the predictable threat cue. With regard to effects of unpredictable threat, those low but not high on SS displayed startle potentiation and enhanced SCRs to the context in which intense, unpleasant events were delivered unpredictably, though levels of reported anxiety to the unpredictable context were equal across groups. Though male participants were overrepresented in the high-SS group, the above results were found after controlling for gender.

Table 2
Means, Standard Deviations, and Independent Samples t Tests for Self-Reported Anxiety Across Neutral (NEUT), Predictable (PRED), and Unpredictable (UNPR) Contexts and Cues

	Group					
	Low SS (n = 17)		High SS (n = 17)			
Experimental condition	*M*	*SD*	*M*	*SD*	$t(32)$	*p*
NEUT-Context	2.29	1.29	1.85	1.17	1.05	.30
NEUT-Cue	2.26	1.24	1.91	1.41	0.78	.44
PRED-Context	4.32	2.20	3.14	1.37	1.88	.07
PRED-Cue	6.47	2.42	4.68	1.90	2.40	.02
UNPR-Context	5.97	2.36	4.79	2.38	1.45	.16
UNPR-Cue	5.32	2.42	4.44	2.01	1.15	.26
Average all	4.44	1.71	3.47	1.41	1.81	.08

Note. Anxiety reported on a 10-point scale where 1 = *no anxiety* and 10 = *extreme anxiety.* SS = *sensation seeking*.

Table 3
Means, Standard Deviations, and Independent Samples t Tests for Self-Report and SCR Responses to Unpleasant Events

Response	Group: Low SS *M*	*SD*	*n*	High SS *M*	*SD*	*n*	*t*	*p*
Self-report								
Intense[a]	7.11	1.45	17	7.00	1.23	17	0.26	.80
Unpleasant[a]	7.53	1.56	17	6.85	1.66	17	1.23	.23
Anxiety provoking[a]	6.15	2.09	17	5.78	2.14	17	0.51	.62
Avoidance[b]	8.53	1.31	17	8.07	1.66	17	0.89	.38
SCR[c]	1.39	0.60	15	1.16	0.58	16	1.10	.28

Note. SCR = skin conductance response; SS = sensation seeking.
[a] Subjective ratings reported on a 10-point scale where 1 = *not at all* and 10 = *extremely*. [b] Participants asked whether they would be interested in experiencing the unpleasant event again and answered on a 1–10 scale where 1 = *definitely yes* and 10 = *definitely not.* [c] Square-rooted microS.

The present results suggest less fear and anxiety during anticipation of predictable and unpredictable aversive stimuli among low versus high sensation seekers, supporting the involvement of the aversive motivational system in the SS trait. That startle potentiations to predictable threat cues correlated with continuous SS scores further supports the linear association between SS and apprehensive anticipation of intense unpleasant stimuli. Zuckerman's (1994) differential exposure account of the SS × Anxiety relationship cannot explain the present results, as high and low sensation seekers experienced an equal number of aversive stimulus presentations.

The present results are consistent with the notion that low sensation seekers avoid intense and risky activities such as skydiving and reckless driving because of increased anxiety during anticipation of such stimulus events. Results also suggest that the decision to participate in risky activities among high sensation seekers may be facilitated by the relative absence of apprehensive anticipation. This explanation of the differential participation in dangerous activities among those high and low on SS contrasts Zuckerman's explanation, which focuses exclusively on differences in the appetitive motivational system (i.e., those high but not low on SS are appetitively motivated to approach intense and risky sensory experiences).

Of note, several of the null relations found in the present study should be interpreted with caution, given the limited statistical power afforded by the size of the study sample. More specifically, the null results for group differences in both SCR increases to predictable threat and reported anxiety to the predictable and unpredictable threat may be because of Type II errors that may be avoided by increasing the size of the present sample.

Both Aversive and Appetitive Systems Are Likely to Contribute to SS

We are not arguing against the contribution of the reward system to the SS trait in the present article, but rather we are proposing the involvement of both the aversive and appetitive systems. The mutually inhibitory relation between aversive and appetitive states (Albert & Ayers, 1997; Bull, 1970; H. Davis & Kreuter, 1972; Dickinson & Pearce, 1977) lends plausibility to the involvement of both systems in the generation of motivational antecedents of risky behaviors. More specifically, enhanced appetitive arousal in response to intense and risky stimulus events among high sensation seekers may dampen levels of anxiety associated with exposure to physical danger, leaving them with mostly positive arousal during these sensory experiences. Conversely, stronger anxiety elicited during the anticipation and actual experience of intense and risky activities among low sensation seekers may prevent positive arousal (e.g., excitement) that may otherwise accompany participation in such activities, leaving them with mostly aversive experiences of these stimulus events.

SS and Trait Anxiety

The aversive motivational component of SS is not the equivalent of trait anxiety but may rather serve as a latent predisposition for anxiety that manifests only in the presence of stress. This conception of SS is consistent with the fact that relations between anxiety and SS are not found when using broad trait anxiety scales and emerge only when using measures of anxious reactivity to situations involving physical threat (for a review, see Zuckerman, 1979). Similarly, in the present results as well as in the results of Lissek and Powers (2003), trait anxiety did not differ across low- and high-SS groups, yet low-SS groups displayed greater phasic fear responses (i.e., FPS) to unpleasant stimuli.

The null association between broad trait anxiety and SS may result from the fact that low sensation seekers organize their lives in ways that protect them from physical risk and sensory overload. For example, individuals low on SS choose low-risk recreation, such as jogging (McCutcheon, 1981), golf, and bowling (Kerr & Svebak, 1989); more conventional lifestyles with predictability and order (Schenk, 1996); and low-risk vocations (Oleskiewicz-Zsurzs, 1982), such as bookkeeping (Van den Berg & Feij, 1988), accounting, and editorial assisting (Schenk, 1996). Thus, in day-to-day living, low sensation seekers may have normative levels of trait anxiety because they self-select a lifestyle they find comfortable. Nevertheless, low sensation seekers display greater anxiety or maladjustment in response to unavoidable stress from a variety of sources, including unemployment, divorce, death of a loved one (Jorgensen & Johnson, 1990; R. E. Smith, Johnson, & Sarason, 1978), sports-related injury (R. E. Smith et al., 1992), military combat (Orr et al., 1990), and being a prisoner of war (Solomon et al., 1995). Thus, low SS may function as an underlying diathesis for anxious states that is activated by stressful experiences but remains latent in the absence of psychological stress.

SS and Fear Versus Anxiety

The present results provide evidence for both enhanced phasic fear responses to predictable threat and more sustained anxiety to contexts in which aversive stimuli are presented unpredictably, among low versus high sensation seekers. Less anxious reactivity to unpredictability among those high on SS is consistent with their tendency toward boredom susceptibility and enjoyment of novel, less predictable sensory stimulation (Zuckerman, 1994). Given that unpredictable threat may elicit sustained (trait) anxiety as opposed to phasic fear (Grillon, 2002a), the group effect for unpredictable threat is inconsistent with evidence pointing to equal levels of broad trait anxiety among those low and high on SS (Zuckerman, 1979). Further psychophysiological exploration of phasic fear versus sustained anxiety across high and low sensation seekers is needed to clarify whether the relationship between SS and the aversive motivational system is either limited to phasic fear responses or extends to sustained levels of "free floating" anxiety.

FPS Versus SCR Effects for Predictable and Unpredictable Threat

Whereas continuous SS scores were correlated with FPS to predictable but not unpredictable threat, the opposite was true for SCR after controlling for gender (i.e., SS correlated with SCR to unpredictable but not predictable threat). Disparate FPS and SCR results for predictable threat may be because of differences in the valence specificity of these measures. Whereas FPS reflects activation in the aversive but not appetitive motivational system (e.g., Skolnick & Davidson, 2000), SCR may reflect activity in either system (e.g., Bradley, Codispoti, Cuthbert, & Lang, 2001). Although the present results demonstrate equal SCR increases to the predictable cue across groups, such increases may have been the result of arousal of different valences among high versus low sensation seekers. More specifically, the imminent onset of intense sensory stimulation signaled by the predictable cue may have elicited SCRs reflecting positive arousal (excitement) and negative arousal (fear) for high and low sensation seekers, respectively. As such, increased appetitive arousal among those high in SS may have masked group differences in aversive arousal. With regard to FPS, the significant group effect for predictable threat may have resulted from the valence specificity of FPS that afforded greater sensitivity to detect group differences in aversive arousal.

Disparate FPS and SCR results for unpredictable threat may be because of methodological factors. Because phasic SC activity cannot be measured in the absence of a phasic stimulus event, phasic SC to the context was operationalized as the SCR to the onset of neutral, predictable, or unpredictable contexts. FPS to the context, by contrast, was assessed with startle probes delivered during ITI periods in each context. SCR to the unpredictable context thus reflects levels of arousal elicited by the switch from neutral to unpredictable context, whereas FPS reflects levels of tonic aversive arousal during the unpredictable condition. Given a significant relationship between continuous SS scores and unpredictable context for SCR but not FPS, it is plausible that those low versus high in SS experienced more anxious arousal to the onset of the condition in which aversive events would be presented unpredictably but displayed levels of anxious arousal equal to those high in SS once anxiety to the onset of the unpredictable condition subsided.

Using the SS Trait to Study the Neurobiology of Anxiety

In the present study, FPS to explicit threat cues was found to increase linearly with decreases in SS. Given the central role played by amygdaloid "fear circuits" in the fear potentiation of startle in both animal (e.g., Hitchcock & Davis, 1986) and human studies (Angrilli et al., 1996; Pissiota et al., 2003), such results indirectly implicate a continuous association between SS and fear-circuit reactivity. Studying SS in normative samples may allow for the assessment of individual differences in amygdala excitability free from the cost and effort associated with studying clinical samples. This may result in larger amounts of available data through increases in both sample size and the number of published studies.

Although trait anxiety may be an obvious choice for studying the continuous-fear-by-amygdala relationship, trait anxiety, as measured with standardized measures (e.g., State–Trait Anxiety Inventory; Spielberger et al., 1983; Penn State Worry Questionnaire; Meyer, Miller, Metzger, & Borkovec, 1990, has not been found to moderate levels of FPS (Grillon, Ameli, Foot, & Davis, 1993; Nitschke et al., 2002). Additionally, the SS scale may provide psychometric advantages. As opposed to most measures of trait anxiety in which sensitive, personal questions likely to elicit social-desirability distortion are posed (e.g., "I worry too much over something that really does not matter"; "I feel inadequate"), the SS scale does not elicit personally revealing information but rather assesses an individual's preferences and attitudes with respect to a variety of intense sensory experiences ("I would like to try parachute jumping"; "I think I would enjoy the sensations of skiing very fast down a high mountain slope"). Thus, SS relative to more traditional self-report indices may capture interindividual variation in anxious reactivity with less distortion from impression management.

Past Findings Relevant to the Present Study

Although no past studies have explored relations between SS and FPS during anticipation of aversive events, the present results are consistent with reduced emotional enhancement of startle during exposure to threatening visual stimuli among high versus low sensations seekers (Lissek & Powers, 2003). Taken together, these findings suggest a blunted fear response during both anticipation of and exposure to aversive stimulus events among those high in SS.

The present findings may also be consistent with the lack of emotionally enhanced startle among psychopaths (e.g., Herpertz et al., 2001; Patrick, 1994; Patrick, Bradley, & Lang, 1993), a group found to be high on the SS personality trait (Harpur, Hare, &

Hakstian, 1989; Zuckerman, 2002). It is, however, uncertain whether the same underlying trait is responsible for blunted potentiation of startle among psychopaths and high sensation seekers, as the lack of potentiation among psychopathic individuals is largely associated with the emotional detachment factor (Factor 1) of psychopathy (for a review, see Patrick & Lang, 1999), whereas SS is more related to the antisocial behavior component (Factor 2; Harpur et al., 1989; Zuckerman, 2002). That effects of psychopathy on emotionally enhanced startle are largely driven by a factor of psychopathy (Factor 1) unrelated to SS supports the idea that present findings derive from a component of SS that does not overlap with psychopathy.

The notion that dampening effects of psychopathy and SS on emotionally enhanced startle stem from the same latent construct assumes that blunted aversive reactions to negative events associated with both psychopathy and SS serve as the common source for such effects. Nevertheless, there is reason to believe that the blunted emotion found in psychopathy is qualitatively distinct from that found in SS. Whereas psychopathy (Factor 1) tends to be related to reduced negative affect in response to the misfortune of others (lack of remorse, guilt, and empathy; callously manipulative, pathological lying; Hare, Harpur, Hakstian, Forth, & Hart, 1990), high SS is most related to blunted emotional reactivity to potential threats to the self (reduced fear of physical injury). Thus, even though blunted aversive reactivity is associated with both SS and psychopathy, the nature of such blunted affect may be dissociable. Future research could test this idea by separately assessing startle potentiation to stimuli representing physical injury to self (e.g., images of pointed weapon) and others (e.g., images of mutilated body) and correlating such potentiations with levels of SS and psychopathy. Alternatively, startle investigations of SS could collect continuous measures of psychopathy that would allow for the assessment of the unique and combined contributions of SS and psychopathy on emotionally enhanced startle.

In summary, the present results provide further support for the involvement of the aversive motivational system in the SS trait. Those low on SS displayed greater anxious arousal during anticipation of predictable and unpredictable aversive audiovisual stimuli. Heightened apprehensive anticipation to intense and threatening sensory experiences may deter low sensation seekers from participation in dangerous stimulus events, whereas blunted anticipatory apprehension may facilitate participation in such activities among those high in SS. SS is proposed as a useful trait for the study of individual differences in the neural circuitry underlying fear reactivity to physical threat.

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