THESIS

OPTICAL IMAGING OF EMOTIONAL RESPONDING TO SENSATIONAL STIMULI IN HIGH AND LOW RISK-SEEKING INDIVIDUALS

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ABSTRACT

OPTICAL IMAGING OF EMOTIONAL RESPONDING TO SENSATIONAL STIMULI IN HIGH AND LOW RISK-SEEKING INDIVIDUALS

Sensation seeking is a reward-based personality construct linked to engagement in risky behavior. A neural and conceptual overlap between emotion and reward suggests there is an emotional component to sensation seeking. The current study sought to assess the theorized emotional component of sensation seeking by measuring a distinct pattern of visual cortex activation that accompanies the induction of emotion via visual stimuli.

Undergraduate participants were recruited based on a prescreening personality assessment. Thirty-five participants were sorted into groups with either high or low scores on risk seeking (a facet of sensation seeking) and exposed to emotional, sensational, and neutral video stimuli. Participants rated their emotional response and reward valuation following each video. Activation in the primary visual cortex was measured using functional near-infrared spectroscopy (fNIRS). Activation during the sensational conditions was assessed for similarity to the emotional conditions and compared between risk seeking groups.

Imaging results revealed no significant differences between conditions or groups. Participant responses to stimuli indicated that individuals high in risk seeking experienced a more positive emotional response to sensational videos than individuals low in risk seeking. Participant responses to stimuli also indicated that individuals high in risk seeking endorsed a stronger approach response to sensational stimuli.

The study encountered methodological challenges, which limited its statistical power and ability to measure the hypothesized effects. Stimulus response data, however, provided preliminary support for the role of emotional processes in risky behavior amongst individuals high in sensation seeking. These findings suggest that targeting emotion regulation processes in individuals who are high in sensation seeking may be an effective approach to reducing engagement in risky behavior.

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Optical Imaging of Emotional Responding to Sensational Stimuli in High and Low Risk Seeking Individuals

Introduction

Sensation seeking has been identified as a significant risk factor for engagement in a variety of health risk behaviors (Roberti, 2004). To date, attempts to integrate individual differences in sensation seeking into a treatment approach have been largely unsuccessful. On the other hand, emotion regulation strategies have a rich history as primary intervention targets in a number of psychotherapeutic treatment modalities (Beck, 2011; Hayes, Strosahl, & Wilson, 1999; Linehan, 2014). If inroads can be made into understanding the emotional processes involved in sensation seeking, then its viability as a target of intervention may be improved.

Sensation seeking was originally defined by Zuckerman, Bone, Neary, Mangelsdorff, and Brustman (1972), who described it as an individual's desire for new and stimulating experiences accompanied by a willingness to take risks in order to achieve its fulfillment. Individuals low in sensation seeking exhibit higher levels of fear and anxiety in response to risky situations, as well as stronger aversive reactions to both predictable and unpredictable threat cues (Lissek et al., 2005). Individuals high in sensation seeking, however, are biased towards the perception of greater potential benefits in risky situations (Zimmerman, 2010). In fact, risk itself is a potential reward for individuals high in sensation seeking (Conner & Henson, 2011). Given greater perception of reward and diminished fear response, those high in sensation seeking often find themselves in situations of a risky nature. Similarly, they have increased risk for a wide variety of health risk behaviors including non-suicidal self-injury, substance use, risky sexual behaviors, gambling, and physically dangerous activities (Knorr, Jenkins, & Conner, 2013; Roberti, 2004).

Sensation seeking has been traditionally conceptualized as a reward-based trait (Bardo, Donohew, & Harrington, 1996). Genetics research has highlighted the critical role of dopamine in the reward processes that contribute to sensation seeking (Hamidovic, Dlugos, Skol, Palmer, & DeWit, 2009). The mesolimbic dopaminergic system (ML DA) appears to be the primary site for this dopaminergic variability (Bardo et al., 1996). The ML DA is a collection of neural structures involved in a number of functions, including: reward/motivation; arousal; "approach" behaviors in response to positively valenced stimuli; "withdrawal" behaviors in response to negative valenced stimuli; and, sensation seeking (Alcaro, Huber, & Panksepp, 2007). The ML DA interacts with several structures in the midbrain, diencephalon, basal forebrain, and higher forebrain (Alcaro et al., 2007).

Many key components of the ML DA are responsible for processes related to emotion as well as reward, including the amygdala (Bzdok, Laird, Zilles, Fox, & Eickhoff, 2013), nucleus accumbens (Floresco, 2015), anterior cingulate cortex (Bush et al., 2001; Ochsner & Gross, 2005), and orbitofrontal cortex (Ochsner & Gross, 2005; Hänsel & van Känel, 2008). In a review of emotional circuits in the brain, LeDoux (2000) made the case that emotion researchers must move beyond describing emotions in terms of subjective feelings and focus on the largely unconscious processes that form the foundation of emotion. Rolls (2000) argued effectively that emotions are, ultimately, states elicited by reinforcing signals. Indeed, it is common for experimental psychologists to define emotion and affect in terms of appetitive "approach" and aversive "withdrawal" behaviors (Cardinal, Parkinson, Hall, & Everitt, 2002). This neural and conceptual overlap between reward and emotion suggests the presence of an emotional component of sensation seeking.

The amygdala plays a critical role in emotionally motivated stimulus-response learning by associating a perceived stimulus with representations of its reward value (Cardinal et al., 2002; Louilot & Besson, 2000). When an aversive or desirable stimulus has been identified, the amygdala affects behavioral response by modulating dopamine levels in the ventral striatum, one of the key nodes in the ML DA system associated with sensation seeking (Alcaro et al., 2007; Louilot & Besson, 2000). This effect is then propagated behaviorally via cortico-striatal-thalamo-cortical loops loops (Alcaro et al., 2007). Additionally, the amygdala receives input from various sensory modalities, including vision, and plays a key role in the emotional processing of salient visual stimuli (Bzdok et al., 2013; Sabatinelli, Lang, Bradley, Costa, & Keil, 2009). This processing occurs recursively within an extensive reentrant network between the amygdala and ventral visual cortex (Sabatinelli, Lang, Bradley, Costa & Keil, 2009).

Due to the interactive processing of emotionally salient visual stimuli by the amygdala and ventral visual cortex, a characteristic pattern of activation is produced in early visual cortex areas (V1 and V2) (Herrmann et al., 2008; Lane et al., 1997b; Plichta et al., 2011). In a review of 55 neuroimaging studies, Phan, Wagner, Taylor, and Liberzon (2002) found that this distinct activation pattern was present regardless of the valence of the emotions that were induced and was independent of the purely visual aspects of the stimuli. If, as theorized, individuals high in sensation seeking perceive stimuli representing risky behavior as emotionally salient objects, this pattern of activation should be present.

These processes may contribute to the engagement in health risk behaviors by individuals high in sensation seeking. Figure 1 illustrates a theorized model of this phenomenon:

(i) A perceived stimulus has previous associations with the experience of reward;

(ii) It is identified as emotionally salient via connections between the amygdala and ventral visual cortex;

(iii) The visual cortex exhibits a pattern of enhanced activation; and,

(iv) The individual's behavior is mediated by amygdalar control of dopamine in the ventral striatum.

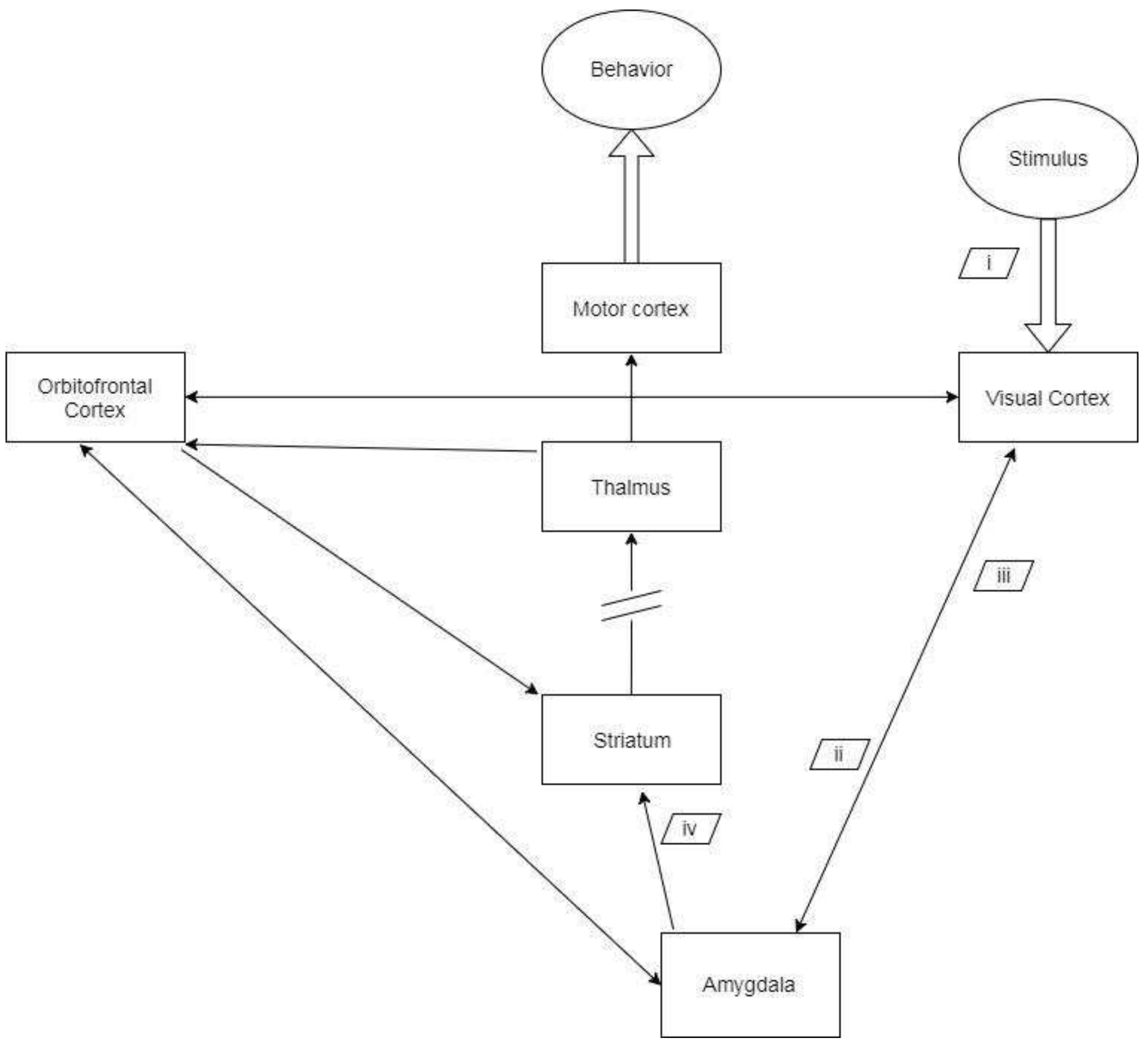

Figure 1. Visual Induction of Emotion and Behavioral Response in RS Individuals

Previous studies have measured increased visual cortex activation following visual induction of emotion using multiple imaging modalities, including functional magnetic resonance imaging, positron emission tomography, and near-infrared spectroscopy (Phan, Wagner, Taylor, and Liberzon, 2002; Plitcha et al., 2007). However, most fNIRS studies of emotion have used still images rather than video as stimuli. A recent review (Bendall, Eachus, & Thompson, 2016) did not identify any such studies as using video stimuli. Beyond those reviewed by Bendall, Eachus, and Thompson (2016), only one fNIRS study located used video to induce emotion (Leon-Carrion et al., 2006). Furthermore, hemodynamic response to the emotional video stimuli in this study was only compared to baseline, not a control condition consisting of emotionally-neutral video stimuli (Leon-Carrion et al., 2006). In their review, Bendall et al. (2016) highlighted the variability in comparisons amongst fNIRS studies investigating emotion (i.e., comparing to baseline vs. comparing to a control condition) and the effect such comparisons have on findings. Thus, using video stimuli to induce emotion and making comparisons against a video control condition is a novel and relatively unexplored approach.

The current study seeks to contribute to the field of neuroimaging of sensation seeking by testing this novel methodology. This is an important examination because no imaging paradigm for sensation seeking currently exists. Furthermore, individuals high in sensation seeking are drawn to intense visual stimuli (Palmgreen, Donohew, Lorch, Hoyle, & Stephenson, 2001) and are more likely to be engaged by video than by still images. Therefore, existing imaging paradigms that use still images are likely ill-suited to the study of individuals high in sensation seeking traits. The current study also expands the literature by attempting to clarify whether individuals high in sensation seeking experience an emotional reaction when exposed to sensational (novel, risky, or potentially rewarding) stimuli. The study focuses on risk seeking (RS), a facet of sensation seeking associated with maladaptive risk-taking behavior (Conner & Henson, 2011). Rewarding and emotional stimuli are processed through multiple sensory modalities (Rolls, 2000). However, as neuroimaging research reveals a distinct pattern of primary visual cortex activation in response to emotionally salient stimuli, this study focuses on the visual processing of such stimuli (Herrmann et al., 2008; Phan et al., 2002). This led to the following hypotheses, which test paths identified as i-iii in Figure 1 (above)

Hypothesis 1:

When exposed to sensational visual stimuli and emotionally salient visual stimuli, individuals high in RS would display similar patterns of increased visual cortex activation, which are distinct from patterns of visual cortex activation elicited by exposure to neutral visual stimuli.

Hypothesis 2:

When exposed to sensational stimuli and neutral visual stimuli, individuals low in RS would display similar patterns of visual cortex activation, which are distinct from patterns of visual cortex activation elicited by exposure to emotionally salient visual stimuli.

Method

Stimuli

Participants were presented video clips from a sensational condition, an emotional condition, and a neutral control condition. Each condition was comprised of six individual videos that were all 30 seconds long. Several open-source online videos were evaluated for their emotional and sensational content. Eighteen were selected to match condition criteria and edited to 30 seconds in length. To control for the effect of music, which might elicit an emotional response, all videos contained natural audio, but no music (Juslin & Västfjäll, 2008).

Sensational stimuli. Individuals high in sensation seeking have been found to show increased physiological reaction to novel and intense stimuli, including sexually explicit and violent images (Joseph, Liu, Jiang, Lynam, & Kelly, 2009). The current study included videos in the sensational condition that correspond to known correlates of high risk seeking. These were intended to represent stimuli that were potentially rewarding for high RS individuals. The videos included two portrayals of heavy substance use (alcohol and marijuana), two portrayals of extreme sports (shark diving and tower climbing), and two portrayals of risky driving (automobile street racing and motorcycle lane splitting).

Emotional stimuli. Six video clips were selected that contained strong emotional content such as joy, despair, and grief. Because the hypothesized pattern of visual cortex activation has been found with both positively and negatively valenced emotional stimuli (Herrmann et al., 2008; Phan et al., 2002), 50% of the selected videos contained positive emotional content and 50% contained negative emotional content. The final set of negatively-valenced videos portrayed a boy saying goodbye to his dog, a woman's account of gun violence, and a man's description of being homeless. The final set of positively-valenced videos portrayed a celebrating basketball player, a girl receiving a puppy as a gift, and a girl reunited with her father.

Neutral stimuli. To serve as a control condition, six neutral clips were selected which contained very little emotional or sensational content. The final set of control videos depicted a math lesson, a history lecture, a minivan test drive, a tour of a nondescript apartment, a field of barley swaying in the wind, and pedestrians walking on a city street.

Instruments

Sensation seeking. Trait sensation seeking was measured via the Sensation Seeking Personality Type (SSPT) scale developed by Conner and Henson (2011). The SSPT contains 14 items, which form two subscales: risk seeking and experience seeking. The SSPT has favorable psychometric properties, with a .83 test-retest reliability. Previous psychometric data indicate that risk seeking and experience seeking have Cronbach's alphas of 0.85 and 0.77, respectively (Conner & Henson, 2011).

Stimulus response items. Participants were asked to respond to queries immediately following the presentation of each stimulus. To assess their emotional response, participants responded to the item:

> *Please evaluate your emotional response to this video. (Did you experience positive or negative feelings?)*

The questionnaire utilized a 7-point Likert scale (1 = entirely negative; 4 = neither positive nor negative; 7 = entirely positive). To assess for participants' reward valuation of stimuli, the study used the item:

> *Please rate the extent to which you agree with the following statement: I would like to participate in the activities depicted in this video.*

Again, the questionnaire utilized a 7-point Likert scale.

Functional near-infrared spectroscopy. Primary visual cortex activation of participants was measured via functional near-infrared spectroscopy (fNIRS). Similar to functional magnetic resonance imaging (fMRI), fNIRS determines neural activation through measurement of cerebral hemodynamic response. However, fNIRS imaging is much less invasive and cost intensive than fMRI (Lloyd-Fox, Blasi, & Elwell, 2010). It utilizes differential absorption of infrared light by tissues in the body, specifically oxygenated hemoglobin (HbO) and deoxygenated hemoglobin

(Hb), to derive an indicator of neural activity (Tak & Ye, 2014). Examining this differential absorption with an array of optical emitters and detectors makes it possible to calculate concentration changes of HbO and Hb using modified Beer-Lambert law, providing a blood oxygen level dependent signal (Ferrari & Quaresima, 2012; Zhu et al., 2015). Compared to other neuroimaging methods, fNIRS allows for excellent temporal resolution, due to its rapid data acquisition rate, and adequate spatial resolution (Lloyd-Fox et al., 2010; Tak & Ye, 2014). The current study employed a tight-fitting cap containing an array of photodetectors and light emitters that covered the entire cortical surface. Placement of the cap was standardized between subjects by using the international 10-20 system. The location of the Fpz site was established at 10% of the total distance between nasion and inion for each participant.

Participants

Three samples were examined over the course of the study. To test the primary hypotheses, neuroimaging data were collected from a sample of 35 individuals who were recruited based on personality scores (the “experimental sample”). To verify the success of sampling and recruitment, previously-collected data from a large psychometric study of the SSPT were analyzed (the “self-report comparison sample”). Finally, to corroborate participants’ responses to the experimental stimuli, data were collected from a concurrent validation study (the “stimulus validation sample”). Participant characteristics for each sample are provided here, and their roles are defined in the analysis plan, below.

Experimental sample. Participants in the experimental sample were recruited from the undergraduate psychology research pool at Colorado State University. Participants completed an online prescreening measure for research credit in psychology courses. Risk seeking scores were calculated from the prescreening data, and individuals whose RS scores were greater than or equal to one standard deviation above the mean were selected for recruitment. These individuals were emailed an invitation to participate in the study for additional research credit. Participants taking any psychoactive medications at the time of data collection were excluded, but received credit for participating in the study. In total, 38 participants completed data collection. Data from these participants were analyzed for signal quality, as described below. Participants whose data were compromised due to poor signal quality were excluded from analysis, leaving a final sample of 35 individuals. The participants were majority male (53.6%) and white (92.6%), with an average age of 20.0 (sd = 2.2).

Self-report comparison sample. SSPT data in the experimental sample were compared to a large (n = 1,902) sample of undergraduates from Colorado State University. Participants in this sample were recruited to participate in a psychometric study of the SSPT between the fall semester of 2013 and the fall semester of 2014. Participants in this sample were majority female (70.8%) and white (79.5%), with an average age of 19.6 (sd = 2.2).

Stimulus validation sample. Participants' responses to stimuli in the experimental sample were compared to a sample of undergraduates recruited from psychology courses at Colorado State University (n = 795). Participants in this sample were exposed to the same stimuli and responded to the same items as the experimental sample, but neuroimaging data were not collected. Participants in the stimulus validation sample were majority female (62.5%) and white (87%), with an average age of 19.7 (sd = 2.6).

Procedures

Prescreened participants in the experimental sample were re-administered the SSPT to confirm their RS scores. A median split was used to assign participants to the low-RS group or high-RS group. They were fitted with an fNIRS cap containing the array of photo emitters and detectors and seated in front of a computer monitor. Researchers used the tip of a cotton swab to move any hair and expose the participants' scalp at the site of each emitter and detector. Clear ultrasound gel was applied to each site to ensure adequate optical transmission. Participants were instructed to remain as motionless as possible during data collection to minimize motion artifacts.

To obtain baseline fNIRS data, participants were instructed to close their eyes and relax for two minutes. Participants were then presented with the video stimuli. To prevent any ordering effects, the presentation of videos was pseudorandomized. Four sequences of stimuli were defined such that no two stimuli from the same condition were presented consecutively. Participants were randomly assigned to one of these sequences. After each stimulus presentation, participants were asked to complete the stimulus response queries. This procedure was repeated until all stimuli had been presented. All fNIRS measurements were completed using a NIRX NIRScout system. The Colorado State University's Institutional Review Board approved this study.

Analysis Plan

Self-report. SSPT results from participants in the experimental group were analyzed to confirm group membership. An independent samples t-test was performed to compare mean RS scores between the low- and high-RS groups. SSPT results from participants in the self-report comparison sample were analyzed similarly. Ninety-five percent confidence intervals for mean RS scores were calculated for groups in both samples. Confidence intervals for the low- RS and high-RS groups were compared across samples. All test statistics and confidence intervals were computed from 1,000 bootstrapped samples. Differences between two group means are considered statistically significant when the confidence intervals for the means do not overlap.

Comparisons of group means against 0, or some other benchmark value, are considered statistically significant when the confidence interval for the mean does not contain 0 or the specified value.

Stimulus response. Stimulus responses from participants in the experimental group were analyzed to confirm that all stimuli produced the intended effect. Since videos in the emotional condition were intended to induce reactions that were both positively and negatively valenced, emotional responses to the emotional and control conditions were recoded to reflect magnitude only. The resulting variable had a range of 0 to 3 (0 = no response, 3 = strong response). Ninety-five percent confidence intervals for mean emotional response were calculated for the emotional and control conditions across all participants. These confidence intervals were examined to confirm that the emotional stimuli were producing a measurable reaction, and that the control stimuli were producing no reaction. Emotional responding to sensational stimuli was expected to be more positive for individuals in the high-RS group, so emotional responses to sensational stimuli were not recoded, rather for these the subjects' original 7-point Likert scores were used. An independent samples t-test was conducted to assess any differences in emotional responding to sensational stimuli between the low- and high-RS groups.

Participants' reward valuation of stimuli was analyzed for the sensational and control conditions. A 95% confidence interval for mean reward response across all participants was calculated for the control condition to confirm that their reward valuation was neutral. An independent samples t-test was conducted to test the assumption that participants in the high-RS group would evaluate stimuli in the sensational condition as more rewarding than those in the low-RS group.

Responses from the stimulus validation sample were analyzed similarly, and confidence intervals were examined to assess for differences between the samples. All confidence intervals and test statistics were computed from 1,000 bootstrapped samples.

Validity of sensational stimuli. In order to test the predictive validity of participant response to sensational stimuli, a series of regression analyses were conducted in the stimulus validation sample to predict various risky behaviors from average emotional response and reward valuation to videos in the sensation condition. Risky driving was assessed by asking participants, "In general how many miles per hour do you drive over the speed limit?" Responses to this item were continuous and normally distributed. Extreme values were winsorized at 20 miles per hour. Simple linear regression was used to predict risky driving. Risky sex was operationalized as a count of unprotected vaginal or anal sexual encounters in the last 12 months. Binge drinking was operationalized as a count of the number of drinking episodes involving the consumption of five or more drinks for males and four or more for females in the last 30 days. Extreme sports were operationalized as a count of the number of different extreme sports an individual had tried in his/her/their lifetime, including activities such as skydiving, bungee jumping, and kite surfing. Risky sex, binge drinking, and extreme sports were all non-normally distributed count variables and were modelled using negative binomial regression.

fNIRS. Analysis of neuroimaging data was conducted using statistical parametric mapping (SPM) for fNIRS (Ye, Tak, Jang, Jung, & Jang, 2009). Data were collected from an array of fNIRS sensors that covered the entire cortical surface (Figure 2).

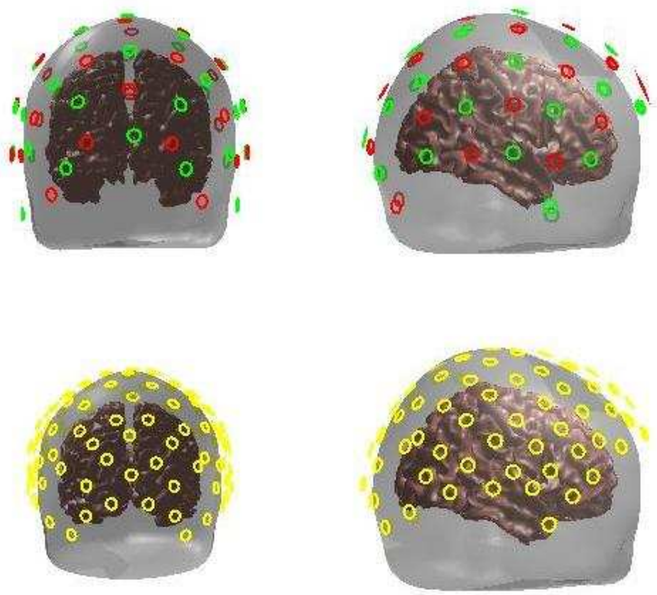

Figure 2. Full fNIRS Sensor Array

Note. Full Array: fNIRS sources (red), fNIRS detectors (green), and fNIRS channels for analysis (yellow).

To evaluate data quality, a region of interest was specified that was centered over the primary visual cortex (V1). The sensors deployed over this region comprised 18 channels (Figure 3). Data for channels with gain settings greater than 7 were interpolated from adjacent channels. As interpolation required adequate signal quality in at least two neighbors (i.e., gain < 7), those channels without at least two usable adjacent channels were considered lost and excluded from analysis. An *a priori* cutoff of no more than six lost channels was established (1/3 of channels in the array). Participants whose data did not meet this cutoff were excluded from analysis.

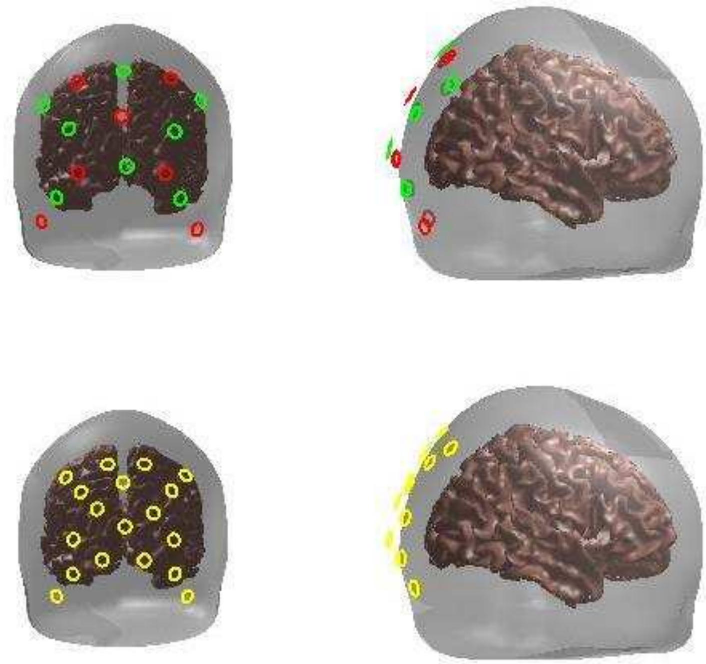

Figure 3: fNIRS Region of Interest Sensor Array

Note. Region of Interest: fNIRS sources (red), fNIRS detectors (green), and fNIRS channels for analysis (yellow).

To remove physiological noise, the raw fNIRS data were passed through a moving filter with an 8s window and a 0.01 HZ high-pass filter. Motion artifacts were removed from the data by an integrated SPM fNIRS function that utilizes moving standard deviation and spline interpolation (Ye et al., 2009). Modified Beer-Lambert law was applied to calculate hemodynamic states, expressed in hemoglobin concentration changes, which formed a time series for each channel (Cope & Delpy, 1988).

As with fMRI, fNIRS data is typically analyzed in a multi-level process (Bullmore et al., 1996; Tak & Ye, 2014). For a given channel at the first level (within subjects) of SPM analysis, the canonical hemodynamic response function (HRF) was used to model hemodynamic response. This was convolved with the specified stimulus function to produce a design matrix. The time series for each channel was regressed on the design matrix, and the resulting model was used to calculate contrasts between conditions. The emotional and sensational conditions were contrasted with the control condition and each other, providing a metric of differential activation. At the second level of analysis, the contrast estimates were averaged within groups (low- and high-RS). Statistical significance of the averaged contrasts for the whole sample and differences between groups for each contrast were tested with one sided t-tests. This process was repeated for all channels in the sensor array. To control for multiple comparisons, the false discovery rate was fixed at .05 (Benjamini & Hochberg, 1995).

Results

Self-Report Results

Participants in the experimental sample were re-administered the SSPT at the time of final data collection to determine group membership. Two groups were formed by splitting high RS scores and low RS scores at the median. The low-RS group (n = 18) had RS scores that ranged from 10 to 21, with a mean score of 15.7 (95% CI: [14.1, 17.2]). The high-RS group (n = 17) had RS scores ranging from 22 to 40, with a mean score of 29.8 (95% CI: [27.7, 32.1]). A bootstrapped independent samples t-test confirmed that these groups had a difference in mean RS score of 14.2 ($t = 10.0$, $df = 33$, $p < .001$, $d = 3.4$, 95% CI: [11.5, 17.2]).

These groups were compared against the self-report comparison sample. To reflect the originally intended sampling method, RS groups were formed in the self-report comparison sample by assigning participants with RS scores greater than one standard deviation below the mean to a low-RS group and participants with RS scores greater than one standard deviation above the mean to a high-RS group. The low-RS group in the self-report comparison sample (n = 295) had RS scores that ranged from 8 to 18, with a mean score of 15.6 (95% CI: [15.3, 15.8]). The high-RS group in the self-report comparison sample (n = 295) had RS scores that ranged from 31 to 41, with a mean score of 33.4 (95% CI: [33.2, 33.7]). A bootstrapped independent samples t-test was conducted to test the difference between groups (t = 95.0, df = 588, p < .001). The difference in mean RS score between the high-RS and low-RS groups was 17.8 (t = 95.0, df = 588, p < .001, d = 7.8, 95% CI: [17.4, 18.2]).

Table 1

Risk Seeking Descriptive Group Statistics

	Experimental Sample			**Comparison Sample**		
	Statistic	Lower Bound	Upper Bound	Statistic	Lower Bound	Upper Bound
Low RS Mean	15.7	14.1	17.2	15.6	15.26	15.84
High RS Mean	29.8	27.7	32.2	33.4	33.2	33.7
Group Mean Difference	14.2	11.5	17.2	17.8	17.4	18.2

Note. RS groups in current and self-report comparison sample. All results are based on 1,000 bootstrapped samples.

Stimulus Response Results

Experimental sample. Immediately following the presentation of each stimulus video, participants were asked to evaluate their emotional response. To assess the effect of stimuli in the emotional condition, responses were scored to reflect the magnitude of response but not valence, resulting in values that ranged from 0 (no response) to 3 (extreme response). Emotional responses for all videos in the condition were averaged within subjects. This value was averaged across all participants. A bootstrapped one-sample t-test indicated that this value was significantly different from zero (M = 2.2, t = 22.7, df = 33, p < .001, d = 3.9, 95% CI: [1.9, 2.4]).

To assess the emotional effect of stimuli in the control condition, responses were scored as above and all stimuli in the condition were averaged within subjects. A bootstrapped one-sample t-test was conducted comparing mean emotional response to control condition videos to zero (M = 0.80; $t = 10.4$, $df = 33$, $p < .001$, $d = 1.8$, 95% CI: [0.67, 0.96]). Reward valuation of control condition videos was tested by examining the extent to which participants would enjoy participating in the events depicted (1 = strongly averse to participation, 4 = neutral, 7 = strong desire to participate). A bootstrapped one-sample t-test was conducted comparing the average reward valuation for control condition stimuli to neutral (M = 3.9, $t = .84$, $df = 33$, $p = .408$, $d = -0.14$, 95% CI: [3.6, 4.1]).

To assess whether stimuli in the sensational condition represented potentially rewarding stimuli for individuals high in RS, participants were asked to rate the extent to which they would like to participate in the events depicted. All videos in the sensational condition were averaged within subjects. The mean response for the low-RS group was 2.0 (95% CI: [1.8, 2.3]). The mean response for the high-RS group was 3.3 (95% CI: [2.6, 3.9]). A bootstrapped independent samples t-test was conducted to test the difference between high-RS and low-RS groups ($t = 3.7$, $df = 32$, $p = .001$, $d = 1.3$). The difference in mean reward valuation of sensational videos between high-RS and low-RS groups was 1.2 (95% CI: [0.56, 1.9]).

To assess emotional response to sensational videos, a bootstrapped independent samples t-test was performed. Emotional response was scored on a scale from 1 (extremely negative) to 7 (extremely positive). Participants in the high-RS group (M = 3.6) had a more positive response than those in the low-RS group (M = 2.5) ($t = 3.1$, $df = 32$, $p = .004$, $d = 1.1$). The difference in mean emotional response to sensation videos between groups was 1.0 (95% CI: [0.5, 1.7]).

Stimulus validation sample. Data on response to stimulus videos were collected from a large sample of undergraduates (n = 795) in a concurrent validation study. To assess the effect of stimuli in the emotional condition, responses were scored to reflect magnitude of response but not valence, resulting in values that ranged from 0 (no response) to 3 (extreme response). Emotional responses to all videos in the condition were averaged within subjects and across all participants in the sample. A bootstrapped one-sample t-test was conducted comparing this value to zero (M = 2.15, $t = 106.3$, $df = 748$, $p < .001$, $d = 3.9$, 95% CI: [2.11, 2.19]).

To assess for the emotional effect of stimuli in the control condition, responses were scored as above, and all stimuli in the condition were averaged within subjects. A bootstrapped one-sample t-test was conducted comparing the mean emotional response to zero (M = 0.85, $t = 43.3$, $df = 750$, $p < .001$, $d = 1.5$, (95% CI: [0.81, 0.89]). Reward valuation of control condition videos was tested by examining the extent to which participants would enjoy participating in the events depicted (1 = strongly averse to participation, 4 = neutral, 7 = strong desire to participate). A bootstrapped one-sample t-test was conducted comparing average reward valuation for stimuli in the control condition to neutral (M = 3.39, $t = 20.8$, $df = 750$, $p < .001$, $d = -0.76$ (95% CI: [3.33, 3.44]).

To assess whether stimuli in the sensational condition represented potentially rewarding stimuli for individuals high in RS, participants were asked to rate the extent to which they would like to participate in the events depicted. Responses ranged from 1 (strong aversion to participating) to 7 (strong desire to participate). Responses to all videos in the sensational condition were averaged within subjects. The mean response for the low-RS group was 2.0 (95% CI: [1.8, 2.1]). The mean response for the high-RS group was 4.3 (95% CI: [4.1, 4.5]). A bootstrapped independent samples t-test was conducted to test the difference between high-RS and low-RS groups ($t = 19.2$, $df = 251$, $p < .001$, $d = 2.5$). The difference in mean reward valuation of sensational videos between high-RS and low-RS groups was 2.3 (95% CI: [2.1, 2.6]).

To assess emotional response to sensational videos, a bootstrapped independent samples t-test was performed. Emotional response was scored on a scale from 1 (extremely negative) to (7 extremely positive). Participants in the high-RS group (M = 4.3, 95% CI: [4.1, 4.5]) had a more positive response than those in the low-RS group (M = 2.5, 95% CI: [2.4, 2.7]). The difference between mean emotional response to sensation videos was 1.8 ($t = 15.6$, $df = 251$, $p < .001$, $d = 2.5$, 95% CI: [1.6, 2.0]).

Validity of Sensational Stimuli

Risky driving was predicted by reward valuation of sensational stimuli ($b = 0.746$, $p<.001$) but not by emotional response to sensational stimuli ($b = -0.04$, $p = .88$). Binge drinking was predicted by reward valuation of sensational stimuli ($b = 0.257$, $e^b = 1.29$, $p < .001$) but not by emotional response to sensational stimuli ($b = 0.004$, $p = .961$). Engagement in extreme sports was not predicted by reward valuation of sensational stimuli ($b = 0.113$, $p = .064$) or emotional response to sensational stimuli ($b = 0.004$, $p = .961$). Risky sex was predicted by reward valuation of sensational stimuli ($b = 0.668$, $e^b = 1.95$, $p = .01$) and negatively associated with emotional response to sensational stimuli ($b = -0.798$, $e^b = 0.45$, $p = .003$). Emotional response to sensational stimuli and reward valuation of sensational stimuli were significantly correlated with one another ($r = 0.832$, $p < .001$

fNIRS Results

Whole-sample comparisons. A series of comparisons that utilized the entire experimental sample was conducted to contrast cortical activation within the region of interest between the various conditions. Cortical activation at the channel level contrasted for every channel within the region of interest. Differential cortical activation was assumed when a channel's statistical contrast was significant after correcting for multiple comparisons. Contrasts were calculated between the sensational and control conditions, the emotional and control conditions, and the sensational and emotional conditions. Following correction for multiple comparisons, no channels within the region of interest remained significant for any of these contrasts.

Between-groups comparisons. A series of between-groups tests was conducted to compare the contrasts detailed above between RS groups. After correcting for multiple comparisons, no channels were significantly different between RS groups for the sensational and control conditions contrast; the emotional and control conditions contrast; or, the sensational and emotional conditions contrast.

Effect size mapping. Since the initial between-groups comparisons were conducted using Student's t-test to compare activation at each channel; Cohen's *d* was calculated at each channel to visualize effect size. Effect sizes were then plotted on a cortical surface for selected between-groups comparisons. Between-groups effect size plots were examined for sensational condition compared to control condition (See Figure 4, Image a), sensational condition compared to resting baseline (See Figure 4, Image b), emotional condition compared to control condition (See Figure 4, Image c), and emotional condition compared to resting baseline (See Figure 4, Image d). In general, magnitude of effect sizes in the occipital region was small and directionality was mixed.

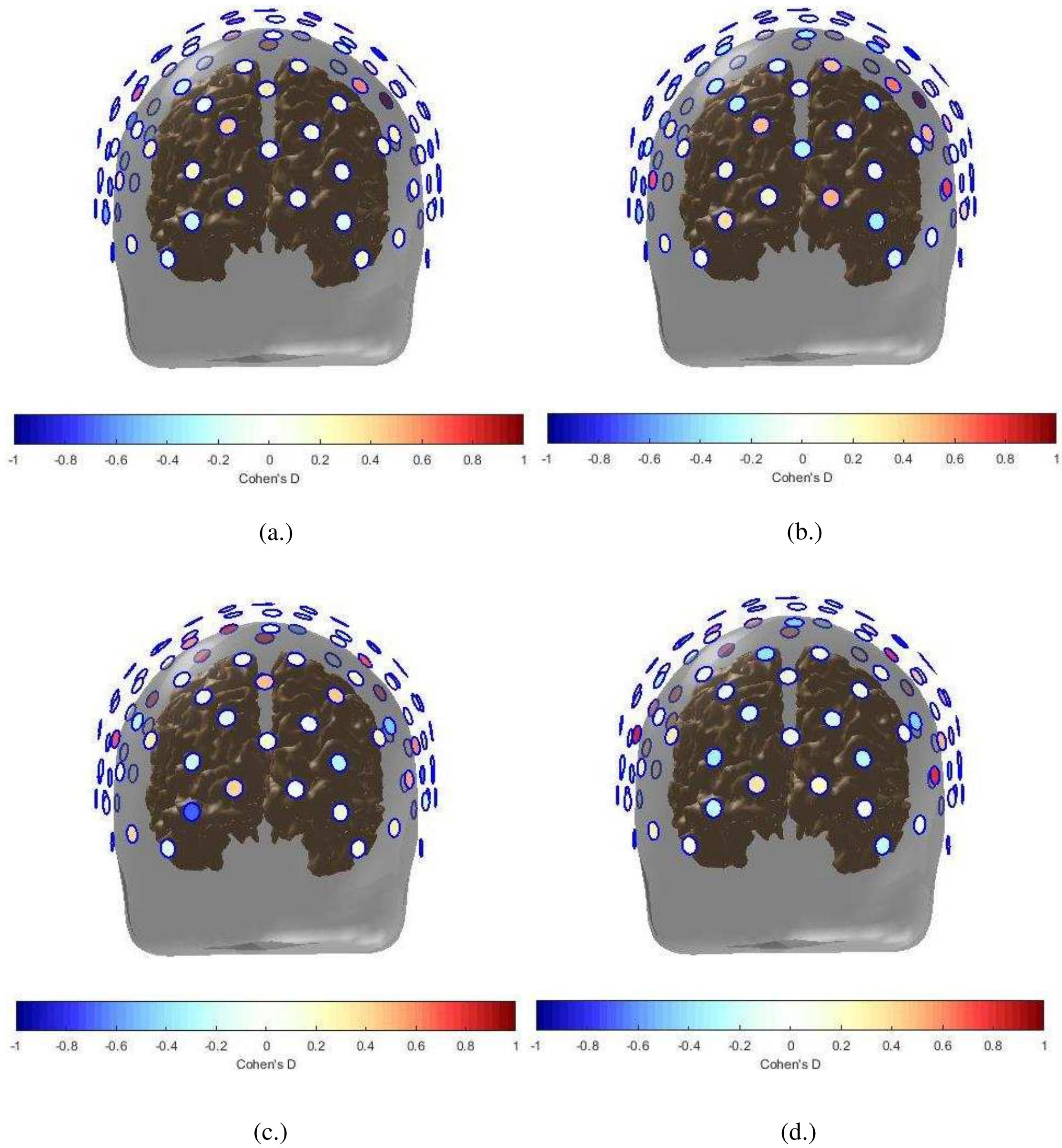

Figure 4. Between-Groups Effect Size Plots

Note. Between-Groups Effect Size Plots: (a) sensational condition – control condition, (b) sensational condition – resting baseline, (c) emotional condition – control condition, and, (d) emotional condition – resting baseline.

Discussion

In order to test the hypotheses, participants were first recruited to form two groups, a group of individuals with high RS scores and a group with low RS scores. The current experimental sample was compared to a large comparison sample containing self-report RS data to validate the high-RS and low-RS groups. RS groups in the experimental sample were significantly different from one another, as were RS groups in the self-report comparison sample. However, the groups in the self-report comparison sample were separated by a larger mean difference. Examination of the confidence intervals showed that the low-RS groups in each sample were not significantly different, but the high-RS group in the self-report comparison sample had significantly higher scores than the high-RS group in the experimental sample. This finding was unexpected: participants were recruited who scored one standard deviation or more above or below the mean of risk seeking on a prescreening measure, and RS groups in the self-report comparison sample were created using the same criteria.

The reduced difference between the high- and low-RS groups in the experimental sample appears to be the result of regression to the mean. In the high-RS group, participants' final RS scores were 1.2 points lower on average than their scores during prescreening. In the low-RS group, participants' final RS scores were 1.0 points higher on average than their scores during prescreening. It is likely that this reduced difference between groups served to reduce the power of the experiment by limiting the size of the effect being measured. This is particularly relevant because the stimulus materials were selected with individuals high in sensation seeking in mind, a group that was not adequately sampled. This sampling failure presents one of the primary limitations of the study.

Next, participants viewed a series of video stimuli that fell into three conditions: emotional, sensational, and control. Participants were asked to rate their emotional response to each video, as well as their desire to participate in the events depicted in each video. A study was conducted concurrently to provide a validation sample wherein participants responded to the same videos and queries. Because the predicted pattern of cortical activation was the same for both positive and negative emotions, the valence of stimuli in the emotional condition was balanced so that half would elicit positive emotions and half would elicit negative emotions. When participants' emotional responses were analyzed, the videos in this condition performed as expected. On average, they elicited a response that was moderate in magnitude, regardless of valence. This was true for both the experimental sample and stimulus validation sample.

Sensational stimuli were selected to represent risky behaviors of the type that have been linked to sensation seeking in previous research. The sensational condition consisted of videos depicting substance use, extreme sports, and risky driving. The reward valuation of the videos was assessed by asking participants to rate the extent to which they would like to participate in the events shown. These responses were compared between high-RS and low-RS groups. In the experimental sample, the high-RS group rated the videos in the sensational condition as more rewarding than did the low-RS group. However, the mean response for the high-RS group was slightly below neutral. Thus, the high-RS group, on average, found the behaviors portrayed in the stimuli less aversive than did the low-RS group. In the stimulus validation sample, the high-RS group rated the videos in the sensational condition as more rewarding than the low-RS group. In this sample, mean response for the high-RS group was slightly above neutral. This discrepancy is likely due to the sampling limitations described previously. Nevertheless, participants' responses in both samples were lower than expected. This may be due to the nature of the risky behaviors depicted. While it is true that individuals high in RS are more likely to engage in risky behaviors, such behaviors are still relatively rare events. In other words, the probability that an individual high in RS would exhibit such behavior is small, even if it is greater than that of an individual low in RS.

The hypothesized pattern of cortical activation in response to sensational stimuli assumed that such stimuli produce an emotional response in individuals high in RS. To test this assumption, participants' subjective rating of their emotional responses to videos in the sensational condition was compared between RS groups. The results were similar to those for participants' rating of reward valuation. In the experimental sample, participants in the high-RS group rated their emotional response more positively than those in the low RS condition. However, the mean response for the RS group was slightly below neutral. In the stimulus validation sample, the high-RS group also rated their emotional response as more positive, this time slightly above neutral. Again, it is likely that the discrepancy between the two samples is due to sampling limitations. It is also likely that the lower than expected responses are due to the relative rarity of engaging in the behaviors depicted. This pattern of findings represents another critical limitation of the study: the direction of the effects for the emotional and reward responses was as hypothesized, but the magnitude of the effects was significantly depressed.

Finally, videos were selected for the control condition that contained neither emotional nor sensational content. Emotional response to control condition stimuli was analyzed by magnitude, irrespective of valence. On average, participants in both the experimental and stimulus validation samples endorsed an emotional response to videos in this condition that was slight, but stronger than neutral. Because the hypothesized cortical activation was tested by comparing conditions to one another, the larger than expected emotional effect of the control condition served to further limit the power of the study. Reward responses to stimuli in this condition were neutral for the experimental sample and slightly averse for the stimulus validation sample.

Predictive validity of Sensational Stimuli was assessed by regressing various risky behaviors (risky driving, unprotected sex, binge drinking, and extreme sports) onto participants' emotional response to sensational stimuli and reward valuation of sensational stimuli. Engagement in extreme sports was not significantly associated with either emotional response or reward valuation. The remaining risky behaviors were all significantly predicted by reward valuation of sensational stimuli. The effect of emotional response was less consistent: it was negatively associated with risky sexual behavior, and not significantly related to risky driving or binge drinking. Nevertheless, emotional response and reward valuation were correlated with one another, suggesting that emotional response may be involved in interactive or indirect effects on risky behavior.

The hypothesized patterns of visual cortex activation were tested by measuring hemodynamic response via functional near-infrared spectroscopy. Hemodynamic states were converted to activation levels at each channel in the region of interest and averaged across conditions within subjects. These activation levels were then contrasted between conditions and between RS groups. As a manipulation check, the emotional condition was contrasted with the control condition across all participants. The pattern of activation that was hypothesized for sensational videos has been found in previous research following visual induction of emotion, and is independent of regular visual processing. Therefore, it was expected to be present for all participants when contrasting the emotional and control conditions. However, after correcting for multiple comparisons, no channels in the region of interest indicated significant activation.

Similarly, when the sensational condition was contrasted with the control condition across all participants, no channels remained significant following multiple comparison correction.

The current study's primary hypothesis predicted that participants high in RS would exhibit a pattern of visual cortex activation in response to sensational stimuli that was like the pattern displayed in response to emotional stimuli. To test this hypothesis, contrasts were performed on activation at each channel between the sensation and control conditions, as well as between the emotional and control conditions. These contrasts were then analyzed for differences between the low-RS and high-RS groups. After correcting for multiple comparisons, no significant between groups difference at any channel in the region of interest was observed for the sensational-control contrast or for the emotional-control contrast. Given the results of the whole-sample comparisons, it can be inferred that no between-group differences were observed due to a lack of significant effect for either group.

Magnitude of the between-groups effect sizes for comparisons of the sensational and emotional conditions to the control condition suggest that the fNIRS analyses were underpowered. In addition to other threats to statistical power discussed previously, the presence of an active control condition may have caused further decrement in power. Previous studies either used still images or used baseline recordings to make comparisons. Indeed, the magnitude of effect sizes for comparisons to baseline in the current study was generally greater than magnitude of effect sizes for comparison against the control condition. It is possible that the effect of the control condition in the current study was strong enough to mask the hypothesized visual cortex signal.

The current study presents with several limitations. First, the sampling targets were not met. Despite recruiting participants with RS scores greater than one standard deviation away from the mean, the final experimental sample consisted of groups that were more similar to each other in RS scores, thus reducing the magnitude of any between-groups effects that might have been present. Furthermore, the effects of stimuli in the sensational condition on both emotional response and reward valuation were smaller than anticipated. This is perhaps due to the rarity of the risky behaviors that were depicted. This limitation could have been avoided if experimental stimuli were formally tested *a priori*, rather than concurrently with the study. Furthermore, it might be the case that the presence of a video control condition masked any experimental effects that may have been present. Taken together, these limitations suggest that the current study was likely underpowered.

Despite these limitations, the current study produced some results which suggest promising directions for future research, researchers, and clinicians. For example, it was found that individuals high in RS are more likely to report a desire to participate in risky behaviors presented as visual stimuli. It was also found that individuals high in RS rate their emotional response to such stimuli as more positive than individuals low in risk seeking. It may prove germane for future research to investigate the nature of the relations between personality, emotional response to sensation stimuli, reward valuation of sensational stimuli, and engagement in risk taking behavior. For example, it is possible, using the self-report and stimulus response data generated, to test the hypothesis that the effect of sensation seeking on engagement in risk behavior is mediated by emotional response to sensational stimuli. Since sensation seeking personality traits are generally enduring and stable across lifespan, they are unlikely targets for clinical intervention. However, if a link between sensation seeking and emotion is validated empirically, it affords clinicians an additional avenue for intervention to prevent health risk behavior. Techniques for improving emotion regulation are prevalent in a variety of psychotherapeutic modalities, including cognitive behavioral therapy, acceptance and commitment therapy, and dialectical behavioral therapy. If these techniques can be applied to the emotional response that mediates engagement in risky behavior, they may prove effective for improving clinical outcomes in individuals high in sensation seeking traits.

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