THESIS

ASSESSMENT OF SENSATION SEEKING PERSONALITY TYPE USING BEHAVIORAL AND FUNCTIONAL NEUROIMAGING MEASURES

Submitted by

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ABSTRACT

ASSESSMENT OF SENSATION SEEKING PERSONALITY TYPE USING BEHAVIORAL AND FUNCTIONAL NEUROIMAGING MEASURES

Sensation seeking personality type, in which an individual has the propensity to engage in risky behaviors while searching for an optimal level of stimulation, is associated with a variety of negative health outcomes, such as higher rates of substance misuse, gambling, and self-harm. It is important to develop methods to identify those at higher risk of engaging in such health risk behaviors. Historically, sensation seeking has been primarily measured using self-report surveys. Providing additional measures of sensation seeking, such as through behavioral assessment or biomarkers, would aid our measurement of the sensation seeking personality type. The present work sought to create a new behavioral measure of sensation seeking personality type, the Sensation Seeking Dot Probe Task (SSDP), that measures an individual's attentional bias towards sensation seeking imagery. Further, the SSDP task was combined with functional Near Infrared Spectroscopy, which utilizes the spectral differences of hemoglobin in the brain to measure neural activity, to identify neural correlates of attention to sensation seeking imagery and relate them to the Sensation Seeking Personality Type scale. I hypothesized that the SSDP would be as effective in identifying sensation seeking as the self-report scale, and that attention to sensation seeking images would correlate with changes in neural activity in the prefrontal cortex and orbitofrontal cortex (regions associated with executive control and decision making) that would be greater in high sensation seeking individuals. While the SSDP did not find significant differences in accuracy or reaction time, the typical measures used in attentional bias dot-probe tasks, there was a significant difference in selection of sensation seeking imagery when paired with neutral control imagery. There were also significantly different changes in activity during sensation seeking congruent tasks in areas of the lateral prefrontal cortex for high sensation seeking individuals. These results suggest functional and behavioral differences measurable in high sensation seekers, and future tasks can use these findings to lead to a greater understanding of the personality type.

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INTRODUCTION

Sensation Seeking Personality Type

Sensation seeking is a distinct personality trait defined as an individual's propensity to pursue novel and excessively stimulating experiences despite potential risks (Zuckerman et al., 1972; Arnett, 1994; Roberti, 2004). Expression of the trait is related to the dopaminergic midbrain and factors in reward-based cognitive decision making (Zuckerman, 1994; Noël et al., 2011; Norbury, 2015). This results in greater motivation and preference for highly stimulating activities, such as substance misuse, extreme sports and highly exciting or risky occupations, as well as decreased goal-directed behavior when alternative sensational stimuli are present (Lawson et al., 2012; Roberti, 2004; Norbury, 2015). The increased motivation towards sensation providing stimuli can lead to decreased risk appraisal, which could impact normal avoidance of dangerous or risky situations (Roberti, 2004; Lissek et al. 2005). Sensation seeking is often associated with related constructs such as novelty seeking, which leads to behavioral differences similar to addiction such as changes in craving and risk perception (Bardo et al., 1996; Zimmermann, 2010).

Novelty seeking is a construct closely related to sensation seeking, in which individuals have greater motivation towards unknown, novel stimuli compared to known, familiar stimuli (Wittmann et al., 2008; Wingo et al., 2016). Some preference towards novelty is expected in behavior as it aids in the exploration of unknown information, seen in studies finding an inherent reward response due to novelty of stimuli (Daw et al. 2006; Wittmann et al., 2008). This uncertainty and "informational reward" tie the related constructs of novelty, sensation seeking, exploration, and curiosity together (Kidd & Hayden, 2015; Kolling et al., 2012; Koster et al., 2016; Morris et al., 2016). This behavior can lead to similar results as (and is often coexisting with) sensation seeking in leading towards health-risk behaviors (Bardo et al., 1996; Büchel et al., 2017).

There are distinct behavioral differences found between individuals measured as either high or low in sensation seeking. Low sensation seeking individuals tend to be risk-averse and report greater levels of anxiety in response to risk and threat (Lissek et al., 2005). Meanwhile, high sensation seeking individuals are biased toward risky situations and may view them as more intrinsically rewarding or overvalue them (Zuckerman et al., 1972; Conner & Henson, 2011; Huskey et al., 2018). This bias along with a motivation to seek out highly stimulating situations can result in those high in sensation seeking showing preference towards certain activities, such as extreme sports (Norbury & Husain, 2015). The exact mechanism causing this difference between trait values is not definitively known, however it is possibly heritable due to genetic changes affecting the dopaminergic midbrain (Hamidovic et al., 2009).

Several distinct decision-making behaviors are affected by sensation seeking and novelty seeking, including approach-avoidance and explore-exploit decision making (Norbury et al., 2015; Wittmann et al., 2008; Abram et al., 2016; Sweis et al. 2018). Approach-avoidance is the decision an individual makes between engaging with a stimulus or avoiding it, while explore-exploit is the decision between trying to find a more valuable stimuli (explore) or to continue with the stimuli you have available (exploit). These decisions may factor in potential reward, expected danger, cost, and other considerations.

Approach-avoidance decision making can be seen in foraging behavior in an animal. A specific example being the choice of whether or not to approach food which it highly values while a predator's scent is also present. The interplay between value of the food and the risk of harm from the apparent predator affect the decision made. An animal with high sensation seeking may overvalue the food or underappreciate the risk (Norbury et al., 2015; Wittmann et al., 2008).

Explore-exploit decision making can be seen as an economic decision made in order to maximize reward. An example would be a situation such as a person deciding to watch a movie that they know and like versus the deciding to try watching something they hadn't seen before, which could be better or worse. This results in a decision between something with a known value or risking finding something better, but potentially finding something worse and being a waste of time. This decision would be partially determined by the individual's level of sensation seeking personality trait (Abram et al., 2016; Sweis et al. 2018). Novelty seeking affects approach-avoidance decision making as well, giving preference to new or unknown stimuli, though not necessarily highly stimulating ones (Daw et al., 2006; Krebs et al., 2009).

Due to the motivation those high in sensation seeking have towards stimulating outcomes, those high in sensation seeking have an increased risk for several behaviors such as substance misuse, gambling, risky sexual behavior, and non-suicidal self-injury (Knorr, Jenkins, & Conner, 2013; Palmgreen et al., 2001; Quinn & Harden, 2013; Steinberg, 2008). Further understanding of sensation seeking and implementation of individual differences into clinical treatments would improve outcomes in therapies concerned with these behaviors.

Measures of sensation seeking

Sensation seeking as a trait has been primarily studied using self-report surveys. The first scale created was the Sensation Seeking Scale (SSS) developed by Zuckerman and colleagues (1972), and now is in its fifth iteration, the SSS-V. This scale attempted to validate its content through self and peer reported behaviors as well as theoretical behavioral measures (Roberti, 2004). The SSS-V categorizes sensation seeking as a whole through four subcomponents: thrill and adventure seeking, experience seeking, disinhibition and boredom susceptibility. However, these subscales have had concerns in terms of their reliability, particularly in samples of children and adolescents (Roberti, 2004). To address these, other scales have been made attempting to further parse out the particular intricacies of sensation seeking, such as separating novelty and risk (Arnett, 1994) and experiential versus risk seeking behaviors (Conner, 2020). Risk seeking entails a tendency to engage in risk behaviors that can endanger health and well-being, whereas experience-seeking is a tendency to engage in novel and intense experiences that are not necessarily associated with risk to health (Conner, 2020). By incorporating the differences in these subscales with other related constructs such as novelty seeking, a clearer understanding of the connections and separation of these traits can be made.

Neural Bases of Sensation Seeking and its Effects on Decision Making

Decision making relies on interactions between multiple neural systems, including the reward-based circuitry found in the dopaminergic midbrain (Alcaro et al., 2007; Gershman & Tsovaras, 2018). The classic mesolimbic path consists of the ventral tegmental area's (VTA) dopaminergic projections onto the nucleus accumbens, or ventral striatum (Düzel et al., 2009).

Dopaminergic projections in these areas code for anticipation of reward, and receipt of unexpected rewards and novel stimuli (Bromberg-Martin & Hikosaka, 2009). There are also several connections to the cortex and areas responsible for cognitive control and motivation (Krebs et al., 2009; Wittmann et al., 2008; Bunzeck & Thiel, 2016). This could be seen for example in connections originating from the orbitofrontal cortex (OFC) and dorsolateral prefrontal cortex (dlPFC) on the VTA, or in interactions with stimuli valuation through the ventral medial prefrontal cortex (vmPFC) (Bush et al. 2002). These dopaminergic projections also themselves extend to many other cortical areas, such as the basal ganglia and anterior cingulate, as shown by neuroimaging studies in humans and in invasive neural stimulation studies using animals (Haber & Behrens, 2014; Li et al., 2017; Chandler & Gass, 2013). Most modulation appears to occur at the core VTA dopaminergic projections to the nucleus accumbens (Alcaro et al., 2007; Düzel et al., 2009). Interventions and studies targeting this system and type two dopamine receptors (D2) in particular seem effective at assisting with addiction and reward system dysfunction (Han et al. 2011, Norbury, 2016, Hamidovic et al. 2009; Sweis et al. 2018).

Sensation seeking is related to the dopaminergic reward system (Norbury & Husain, 2015; Düzel et al., 2009; Düzel et al., 2010; Krebs et al., 2009). In particular, sensation seeking studies have primarily localized its biological mechanism to the striatal and ventral tegmental area system (mesolimbic pathway) and its connections to the prefrontal cortex (Norbury, 2016; Bardo et al., 1996; Bechara, 2005; Büchel et al., 2017; Gershman & Tzovaras, 2018; Chen et al., 2013). It also has been implicated, specifically in relation to emotional and sexual stimuli, with the amygdala and the anterior cingulate cortex (Cyders, 2009; Cardinal et al., 2002). The dopaminergic reward system has been found to increase in activity in anticipation of reward as measured by increased dopamine binding at D2 receptors (Bromberg-Martin & Hikosaka, 2009; Norbury, 2016). These cells also fire after presentation of novel stimuli, another factor that affects experience seeking (Bunzeck & Thiel, 2016; Wittmann et al., 2008; Zheng et al., 2010). This dopamine signal has a number of effects throughout the brain, including promoting memory encoding and long-term potentiation in the hippocampus (Davidow et al., 2016; Duncan et al., 2018; Duszkiewiczs et al., 2019; O'Doherty et al., 2017; Wittmann et al., 2007).

Multimodal Assessment

In scale development and personality literature, multimodal assessment refers to the ability for multiple different measurements of the same variable to be studied using different methods or scales, and the inter-reliability between these methods (Bornovalova et al., 2008). In the case of sensation seeking, the only existing measurement is through self-report scales. Recent studies have made clear the case that there is a greater need for integration of a biopsychosocial design in order to fully understand behavior (Moeller et al., 2013; Daw et al., 2006). This sort of integration would entail studies combining physiological measures of biological processes and genetic influences with psychopathologies, behaviors, and self-report responses in order to apply results out of the laboratory (Moeller et al., 2013). The best way to combat limitations in psychology is to be open to multimodal assessments. What's more, the larger number of multimodal data we accumulate, the better we are able to hypothesize and use prior findings for future studies using Bayesian statistics and machine learning algorithms (Gillan et. al, 2017; Calhoun & Sui, 2015).

Self-report surveys have been the standard measurement for sensation seeking personality type, but as mentioned previously, self-report surveys are susceptible to various forms of bias. For example, Stanton and colleagues (1996) found that adolescents had difficulty recalling information over large stretches of time. Another study by Elgar and colleagues (2005) found that self-reported height and weight, which should theoretically be very easy for a participant to intentionally record correctly, were biased by the participants and was thus underreported. The potential for these biases as well as response bias in altering the completion of these reports is a fault inherent in self-reporting (Mortel et al., 2008). This is not to say that self-report measures are invalid, it is only another example of how no one method is perfect, thus requiring multimodal approaches in psychology and science at large.

Potential modalities which are well equipped to measure sensation seeking other than self-report would be behavioral studies and neuroimaging. Behavioral models are common in psychology and have been used in several different constructs and personality traits including those similar or related to sensation seeking (Roberti, 2004). However, less progress has been made with sensation seeking itself. The existence of a behavioral task for sensation seeking would be an important tool in measuring predictability of engaging in health risk behavior. Such a task could potentially be developed based on previously validated tasks, such as attentional dot probe measures of bias (Macleod et al., 1986).

Behavioral assessments of sensation seeking

One recent attempt has been made at creating a behavioral measure of sensation seeking. Norbury (2016) created a design in which the computational valuation an individual gives an economic task could predict sensation seeking score. The experiment was an explore-exploit decision making task in which participants would try to maximize points gained in the task. However, some of the trials would include a mild electric shock along with the reward, with the shock being more often included with higher point values. They found that high sensation seekers consistently rated the electric shock eliciting values as more positive than those low in sensation seeking. This design is a significant advancement in behavioral measures of sensation seeking, however it does have limitations. Mild electric shock is still painful and certainly could be considered to be invasive to most participants. As well, this study measured sensation seeking using the SSS-V, rather than other measures such as the SSPT which can separate subtypes of experience-seeking and risk-seeking. Further behavioral advancements should be possible as other studies have found measurable differences in these similar behavioral constructs, such as novelty seeking and gambling tasks as seen in alcoholics or addiction models (Noël et. al, 2011; Dong et al., 2017; Lucantonio et al., 2015).

Attentional bias as measured through dot-probe tasks could also be a tool used in studies concerning sensation seeking. A dot-probe task measures attentional bias towards types of images based on performance in a reaction time task and was originally developed by MacLeod and colleagues (1986). Participants are shown pairs of stimuli for a very short amount of time, which are followed by a small cue (the dot-probe) behind one of the stimuli, after which the participant is required to report the location of the dot via a speeded button press. The logic is that if the participants are motivated towards and attending a particular stimulus, then they will be able to more accurately and/or rapidly report the dot-probe location when it appears in the same location of the attended stimulus. Macleod (1986) initially found that clinically anxious individuals, but not those who were also clinically depressed, showed bias towards threat inducing words. Current cigarette smokers have been found to display greater bias towards smoking cues than former smokers through an attentional bias dot-probe task (Ehrman et al., 2002). Given the similarities discussed previously between sensation seeking and addiction related neural correlates, this suggests that such a task may be able to differentiate sensation seeking personality trait levels as well.

Neuroimaging techniques

Neuroimaging has strong potential for finding biomarkers that could be used to identify high sensation seeking individuals. Clementz (2016) combined imaging with behavioral tasks, psychological screenings, saccadic control through eye tracking, genetic panels, and other potential biomarkers to classify different types of psychoses with greater discrimination than clinical diagnosis alone. This approach has been used in Alzheimer's disease as well (Esmaeilzadeh et al., 2018). There is also a potential to utilize multimodal imaging methodologies along with other biomarkers in psychiatry through symmetric data (Calhoun & Sui, 2016; Gillan & Whelan, 2017; Lawson et al., 2012). The potential benefits of this approach are likely to grow given development of advanced statistical techniques such as Bayesian Modeling, Dynamic Causal Modeling, and Structural Equation Modeling (Cooper et al., 2019).

Functional Near Infrared Spectroscopy (fNIRS)

A common neuroimaging approach is measuring the Blood Oxidation Level Dependent (BOLD) response in functional Magnetic Resonance Imaging (fMRI) and in functional Near Infrared Spectroscopy (fNIRS) (Turner, 1998; Kocsis, 2006; Cope & Delpy, 1988; Ferrari & Quaresima, 2012). Oxygenated and deoxygenated blood have various different properties due to the change of their molecular orientation, and these differences allow the relative change in concentration to be measured. The movement of oxygenated and deoxygenated blood can then be identified in order to measure relative activity patterns of the brain non-invasively (Cope & Delpy, 1988). It should be noted however that this change in oxygenation takes some amount of time, usually around 6-8 seconds. The exact timing for analysis in imaging software can be determined through a hemodynamic response function (Lindquist et al., 2009). Though both use the BOLD response in order to assess neural activity, fMRI and fNIRS have several advantages and disadvantages. fMRI uses the different magnetic properties of hemoglobin (oxygenated hemoglobin being diamagnetic, while deoxygenated being paramagnetic) to visualize the concentration of each through manipulating the magnet induced spin and relaxation of hydrogen atoms found within hemoglobin. By taking multiple images at different times through an MRI scan, these changes can be followed throughout the duration of the scan. This provides good spatial resolution across the entire brain, but as it is dependent on requiring more powerful magnetics to reduce the gap between consecutive magnetic pulses (TR), fMRI has relatively poor temporal resolution (Turner, 1994). Motion artifacts are common as well, as it is required that the participants must remain still for the duration of the entire scan.

fNIRS, however, utilizes different spectrographic properties of hemoglobin in order to follow the change in oxygenation (Kamran, 2016; Kim et al. 2017). Near infrared light (roughly 700-1100nm in wavelength) is capable of piercing the outer skin, bone, and tissue around the skull and into the cortex up to a few centimeters in depth. Both oxygenated and deoxygenated hemoglobin absorb light maximally at different wavelengths, allowing for the concentration to be measured using the isometric point between oxygenated and deoxygenated hemoglobin. This can be done very quickly, reducing overall time of fNIRS compared to fMRI (though still retaining the 6-8 second delay of hemodynamic functioning), but with the consequence of not being able to penetrate deeply enough to target deep brain structures such as the basal ganglia. However, for areas on the cortical surface, signal will show both high spatial and higher temporal resolution than fMRI (Kocsis, 2006; Lloyd-Fox et al., 2010). It should still be noted that the temporal resolution of fNIRS is still poor due to the nature of the BOLD signal. Because sensors are directly attached to the head via a skull cap and don't require the head to remain completely still as in fMRI, fNIRS is ideal for use in studies requiring movement, difficult populations, and children in developmental studies as well (Gogtay et al., 2004). This presents fNIRS as a cheaper alternative to fMRI when used appropriately, and in some cases is a better fit for the study design.

Neuroimaging Studies of Sensation Seeking

In prior neuroimaging studies, a few regions of interest have been shown activity sensitive to sensation seeking. The orbitofrontal cortex (OFC) and ventral medial prefrontal cortex (vmPFC) have been shown to respond to rewarding stimuli as seen in decision making studies (Camara et al., 2009; Hommer et al., 2011; Rolls et al., 2000; Kahnt et al., 2014). In a study by Rolls, Burton, and Mora (1980), squirrel and rhesus monkeys had electrodes implanted in the orbitofrontal cortex and other reward-based areas allowing the monkeys to self-stimulate these areas by pressing on a brass bar. The monkeys would self-stimulate the OFC when hungry and stop when they were satiated, implying that activation of this area is based on how the animal would need or value the food (Rolls, Burton, & Mora, 1980). For sensation seeking behavior in particular, a study by Lawson and colleagues (2012) took recordings with EEG and fMRI while completing an old-new task in which the participants needed to recall previously studied (old) stimuli. High sensation seekers responded with increased activity localized in the orbitofrontal cortex in response to new images than low sensation seekers. This indicates that the OFC is displaying a difference in valuation of stimuli in the OFC, and clearly responds differently to high sensation seekers (Lawson et al., 2012). This agrees with existing theories concerning economic decision making such as approach-avoidance and explore-exploit to be dependent on separate regions taking into account reward valuation (Steinberg, 2008; Sanfey et al., 2003).

fMRI has been used extensively in examining closely related constructs to sensation seeking, such as risk avoidance and novelty (Kahnt, 2018; Luijten et al., 2017). In a study by Li and colleagues (2017), personality traits were correlated with salience related connectivity changes during a salience expectancy task using rated pictures from the International Affective Picture System. Novelty seekers were found to have greater disconnection between the anterior insula and middle cingulate cortex when expecting pictures considered “high salience” according to normative data for the IAPS (Li et al., 2017). Further, studies using NIRS specifically, while not directly measuring sensation seeking but looking at closely related constructs, found significant differences in neural activity relative to measures in harm avoidance, novelty seeking (Nakao et al., 2013), or reward in regard to prior substance abuse (Hammers & Suhr, 2010). For example, the Nakao study used resting state slow oscillations in the dorsal and ventral medial areas of the PFC to differentiate between different levels of novelty seeking and harm avoidance (Nakao et al., 2013).

Sensation seeking has been implicated in multiple health-risk behaviors, but the neural mechanism and precise behavioral differences compared to typical health population functioning are not well understood. The independent components relevant to sensation seeking have been difficult to parse out and lack agreement between subtypes and scales (Roberti, 2004). Assessing the differences between high and low sensation seeking would aid in both understanding behavioral differences as well as neurocognitive mechanisms. For this thesis, I aimed to create a novel task which would discriminate between high and low experience-seeking and risk-seeking by using an attentional bias dot probe task which displayed bias towards sensation-seeking images. Different behavior in those high in sensation seeking could be measured by bias towards sensation seeking stimuli in the task. Accuracy, reaction time, and likelihood to select and image regardless of congruency were then compared to scores on the Sensation Seeking Personality Type (SSPT) scale (Conner, 2020) in order to correlate scale measurement with task performance and apparent bias. By performing more accurately and quickly on sensation seeking congruent trials, an attentional bias towards sensation-seeking images can be inferred. Further, the task was run on a second sample of participants from the same source while using fNIRS, to compare localized activity differences in frontal areas of the cortex. I hypothesize that individuals high in sensation-seeking personality type will have a noticeable attentional bias towards sensation-seeking imagery, demonstrated by increased accuracy, reduced reaction time, and greater preference of selecting sensation-seeking imagery in congruent sensation-seeking trials. Further, I predict that those high in sensation-seeking personality type, both risk and experience-seeking, will have a significantly different BOLD response to sensation-seeking congruent trials compared to control congruent trials within the lateral PFC and OFC regions of interest.

METHODS

Participants and Procedures

This study involved analyses of two samples of a college population. 246 undergraduate students (140 female, 56.9%; mean age = 19.5) recruited from introductory psychology courses and compensated with class credit completed the SSPT-18 (18 item sensation seeking personality type scale), the sensation seeking dot-probe (SSDP), and a battery of other measures not relevant to the current study. 30 different undergraduate students recruited from the same source completed the SSPT-18 and then performed the dot probe task during NIRS recording using a NIRScout Extended (NIRx Medical Technologies, Los Angeles, CA) system. These 30 participants either scored high or low on a self-report measure of sensation seeking. Due to problems in the quality of recorded NIRS data, 5 participants had to be removed from this sample, for a final participant count of n = 25.

Measures and Procedure

<u>Behavioral sample (n = 246)</u>

<u>Sensation Seeking Personality Type Scale – 18 (SSPT; Conner & Henson, 2011):</u>

Participants responded to items on the SSPT indicating agreement with a given sentence using a 5 item Likert-type scale, the minima and maxima being “Strongly disagree/agree” respectively. This is the 18 item version with two subscales, risk seeking (ex. “I enjoy participating in unsafe activities,”) and experience seeking (ex. “I think it is important to try as many new things as I can,”) for which higher scores indicate greater risk seeking and experience seeking, respectively.

Sensation Seeking Dot Probe Task (SSDP; Wilton Logic 2013):

The SSDP is an attentional dot-probe bias task, a task which attempts to measure behavior through an individual's reaction to different stimuli in the trial. The design of this task was based on other attentional dot-probe tasks as seen in the MacLeod (1986) and Ehrman (2002) studies. Two images are being attended to by the participant, with a small dot-probe hiding behind each image. During the trial, the images disappear, potentially revealing the dot-probe behind one of the images. The participant is then required to select which image the dot-probe was behind or if there was no dot-probe. It is expected attentional bias can be measured as participants will perform better on trials congruent with the attended stimuli, usually through reaction time and trial accuracy. Trials would consist of low bias trials, in which both stimuli were of the same type, or high bias, in which there would be one experimental stimuli type and one control stimuli. In the Macleod (1986) study, this was a difference between a threat inducing word and a control word, looking between clinically anxious and clinically depressed participants. The Ehrman study (2002) used cigarette smoking cues versus control images to differentiate behavior in current smokers and non-smokers.

Classic attentional bias dot-probe tasks typically focus on two measurements in order to determine bias: accuracy (or performance based on congruency) and reaction time (MacLeod 1986, Ehrman et al., 2002). Accuracy is calculated by examining the tendency for participants to select the stimuli hiding the dot-probe correctly differently based on trials using the hypothesized bias stimuli and control stimuli. For example, in Ehrman's 2002 study, images of smoking cues and neutral control images were presented to tobacco smokers. Trials consisted of either low bias trials in which both images were of the same type and high bias trials in which a smoking cue and control image were present. The high bias trials were categorized as congruent if the dot-probe was behind the smoking cue and incongruent if behind the control image. Smoking cue bias was measured with accuracy, based on the participant's overall ratio of correct hits in congruent smoking trials compared to correct hits in incongruent trials. The SSDP was modeled similarly, in which the experimental stimuli were sensation seeking imagery.

In the original example of an attentional bias dot probe task, reaction latency was used to gauge the bias towards words associated with threat in either clinically anxious or depressed individuals. They used this measure of latency and reaction time to assess the inherent bias towards experimental stimuli, in that case, clinically anxious individuals to words based on threat. This resulted in a shorter reaction time during congruent threat trials and longer reaction time in the incongruent threat trials. They also looked at accuracy measured in the same way as the Ehrman study, finding a greater number of correct hits for clinically anxious individuals to the threat stimuli than control stimuli (MacLeod et al. 1986; Ehrman 2002).

In the SSDP, our experimental stimuli consisted of three types of presented images, action sport (Sports), sensation seeking other than action sports (OtherSS), or neutral people-based controls (Control). Sports images consist of people engaged in a physically demanding, exciting, or extreme sport. OtherSS images feature emotionally arousing stimuli that are not an action sport. Control images consist of people in non-exciting or relaxed environments. Trials could be low bias for any stimuli type, in which there would be two of the same type of stimuli, or high bias, where a Sports or OtherSS stimuli were paired with a Control image. Some trials were neutral and contained no dot-probe, for which the participant was meant to select that it was not behind either picture. The dependent variables used were individual measurements of percentage of correct responses in trials for each stimuli type (Sports, OtherSS, Controls) in congruent or incongruent trials. Individual reaction time dependent variables were measured based on the stimuli type, congruency, and whether it was a correct or incorrect response. In addition, we measured the likelihood of each participant to select each stimuli type based on their apparent tendency to select that stimuli type regardless of the congruency of the trial.

Accuracy would depend on the participants ability to correctly select which stimuli held the dot-probe based on whether it was low or high bias and the trial's congruency. A congruent trial would feature the dot-probe behind the relevant stimuli, for example a congruent Sports trial would have the dot probe behind the Sports image. Reaction time would be measured by the latency between the dot-probe appearing and the participant selecting a response. This could be separately measured based on congruent or incongruent trials, as well as trials in which the participant correctly or incorrectly selected the image with the dot-probe. Two images are displayed at once on the left and right sides of fixation on a screen following a fixation cross. The two images remain for 450ms, and then disappear, potentially revealing a small dot behind one of the pictures for 50ms. The participant is asked to respond as quickly and accurately as possible using directional buttons which picture had the dot probe behind it, the left or the right, or if there was no dot at all with a central "None" button.

There were 64 trials total following a brief training session, with a balanced mixture of 52 bias trials, half of which the dot-probe was congruent with sensation seeking bias (behind a sensation seeking image, half of these Sports and half OtherSS, combined as AllSS) and half where it was incongruent (behind a Control image). Half of the congruent and incongruent trials were "low bias", where both images were of the same type, and half were "high bias" in which there was one sensation seeking and one control image. This resulted in 13 Sports congruent trials, 13 OtherSS congruent trials, and 26 Control congruent trials. High bias trials would always contain a control image, so the resulting pairings would either be OtherSS vs Control or Sports vs Control. There were also 12 trials in which there was no dot present, coded as a neutral (None) trial. Accuracy and reaction time for each trial were recorded to measure performance in the task and attentional bias towards particular stimuli. Additionally, a bias score for each type of sensation seeking stimuli (One for Sports and one for OtherSS) was calculated as the likelihood of a participant selecting the particular stimuli when presented alongside a Control image during the SSDP. An important consideration to note is that the bias score was just the tendency to select a stimuli type and trial congruency was completely irrelevant in its calculation, which was only determined by the ratio of selected stimuli in each category. A series of linear regressions were used to assess a relation between SSPT subtype scores (risk and experience seeking) as measured by the previous Sensation Seeking Personality Type measure and the various dependent measurements of accuracy, reaction time, and bias.

Table 1: Structure of the Sensation Seeking Dot Probe Task (SSDP)

<table>
<tr><th colspan="4">Arrangement of the task by trial type</th></tr>
<tr><th>All trials</th><th>Bias v. neutral</th><th>Congruency to Sensation Seeking</th><th>SS stimuli type</th></tr>
<tr><td rowspan="5">64 trials total</td><td rowspan="4">52 Bias Trials</td><td rowspan="2">26 Sensation Seeking Congruent Trials (Control Incongruent Trials) (AllSS)</td><td>13 Sports Congruent Trials</td></tr>
<tr><td>13 OtherSS Congruent Trials</td></tr>
<tr><td rowspan="2">26 Sensation Seeking Incongruent Trials (Control Congruent Trials)</td><td>13 Sports Incongruent Trials</td></tr>
<tr><td>13 OtherSS Incongruent Trials</td></tr>
<tr><td colspan="3">12 Neutral Trials (No Dot-probe)</td></tr>
</table>

fNIRS sample (n = 25)

Near Infrared Spectroscopy:

Data was acquired using a NIRScout Extended (NIRx Medical Technologies, Los Angeles, CA) system using 32 detectors and 48 dual-wavelength sources (760 and 850nm). A 128-position EasyCap (EasyCap, Germany) using the EEG 10-5 International Electrode system was used for optode placement. A whole brain optode distribution pattern was used for the scan. Source-detector spacing was between 25-30mm and 64 total positions were used (32 detectors and 32 sources). All detector-source pairs with an acceptable signal to noise ratio were used to synthesize channels, while unacceptable “bad” detectors had their signal interpolated from neighbors. This yielded 1024 channels with approximately 20% yielding sufficient signal to noise ratio, for around 204 channels. We then determined which participant data was acceptable by removing any participants who had less than 2/3 “good” signals compared to the total within the channels used in the ROI, specifically channels formed from those optodes closest to the anterior of the brain. This resulted in our final participant count of 25. Each optode location was digitized for transformation to MNI space using a Polhemus Patriot digitizer (Colchester, VT). All signals were resampled at 1hz. Light sources were time-multiplexed to avoid spatial confusion over the source of light for each detector.

All neuroimaging results were analyzed using SPM fNIRS (Tak et al., 2016), a MATLAB (MATLAB ver. R2018b, 2018) toolbox that works together with SPM 12 (Penny et al., 2006) neuroimaging statistical analysis software that is specifically designed for analysis of fNIRS data. SPM 12 natively cannot interpret fNIRS data, thus requiring the use of SPM fNIRS. Thus, the initial results were first prepared in SPM fNIRS, then used as first level analyses in SPM as SPM files, and then using an SPM fNIRS script for second level analysis directly on the contrasts created from first level analyses. First level analyses were performed for each of the 25 participants individually. A single t-test contrast was formed comparing activation during congruent Sports and OtherSS trials combined with congruent Control trials (AllSS > Control). Two second level (Group) analyses were performed comparing the AllSS> Control contrasts for the those high versus low in risk seeking (11 and 14 respectively), and high versus low in experience seeking (10 and 15 respectively). Via this two-step process, two 2x2 ANOVAs were conducted with a within-subjects measure of SS (AllSS versus Control) and a between-subjects measure of sensation seeking (high vs. low risk seeking, and high vs low experience seeking. These ANOVAs were fit separately to each of the fNIRS channels within the two regions of interest (Lateral PFC and OFC).

Procedural difference from behavioral sample:

Participants in the NIRS sample initially took the SSPT-18 in the exact same format as described above for the behavioral sample. They then completed the same SSDP task as with the behavioral sample, with the only difference being a small black spot presented at the same time as the fixation cross in the corner of the screen and the inclusion of the NIRS scanning. The spot in the corner was used to initiate the NIRS scan concurrently with the fixation cross.

RESULTS

Behavioral results

Across all subjects the mean risk seeking score was 28.06, (median = 28, range 10-43) and the mean experience seeking score was 20.38 (median = 20, range 9-25) on the SSPT. All behavioral results were analyzed by linear regression in R (R Core Team, 2019) using the OLSRR package (Hebbali, 2020). Analyses on behavioral data compared the general linear regression of either risk seeking subscale or experience seeking subscale scores of the SSPT on the dependent variables. Dependent variables included accuracy on the dot-probe task, as well as reaction time in regard to the congruency of the trial. There were no significant findings from these analyses in this study. Participant performance on the SSDP did not significantly differ based on risk seeking or experience seeking score.

The linear regression model of risk seeking score on bias for Sports stimuli over Control stimuli found that there was a significant difference, with higher risk seeking scores leading to a greater likelihood of Sports images selected (Figure 1A; $r = 0.503$, $p < 0.001$, SE 0.141, adj. $r^2 = .250$). This effect is seen regardless of the congruence of the trial, meaning participants would have had both greater correct hits and greater false positive selections for sensation seeking images. In addition, increased risk seeking resulted in a faster reaction time in selecting a Sports image (Figure 1B; $r = -0.205$, $p < 0.001$, SE = 6.146, , adj. $r^2 = .038$) without considering trial congruence. Higher risk seeking predicted a significant difference with OtherSS stimuli, with tendency to select the OtherSS image when paired with Control images regardless of the congruence of the trial (Figure 2A; $r = .267$, $p < .001$, SE = 0.13, adj. $r^2 = .068$). The effect however did not translate to a faster reaction time on selecting the OtherSS images, as with the Sports stimuli.

A separate set of linear regression models examined the relation between experience seeking with bias measures. Experience seeking was significantly related to the likelihood of selecting Sports stimuli in a trial over Control stimuli, with higher experience seeking scores associated with a greater tendency to select Sports images (Figure 1C: $r = 0.286$, $p < 0.001$, SE = 0.386, , adj. $r^2 = .078$). In addition, like with risk seeking, increased experience seeking scores were associated with faster reaction times selecting Sports images (Figure 1D; $r = -0.185$, $p < .003$, SE = 15.205, , adj. $r^2 = .030$). Also similar to the risk seeking results, there was a significant difference in bias towards selecting the OtherSS images as opposed to Control images for those with higher experience seeking scores (Figure 2B; $r = 0.227$, $p < .001$, SE = 0.324, , adj. $r^2 = .048$). Again, this bias is calculated regardless of the congruence of the trial or accuracy and was not accompanied by significantly faster reaction times selecting OtherSS stimuli. It should also be noted that these are all quite low adjusted r^2 values, indicating a poor fit for the model.

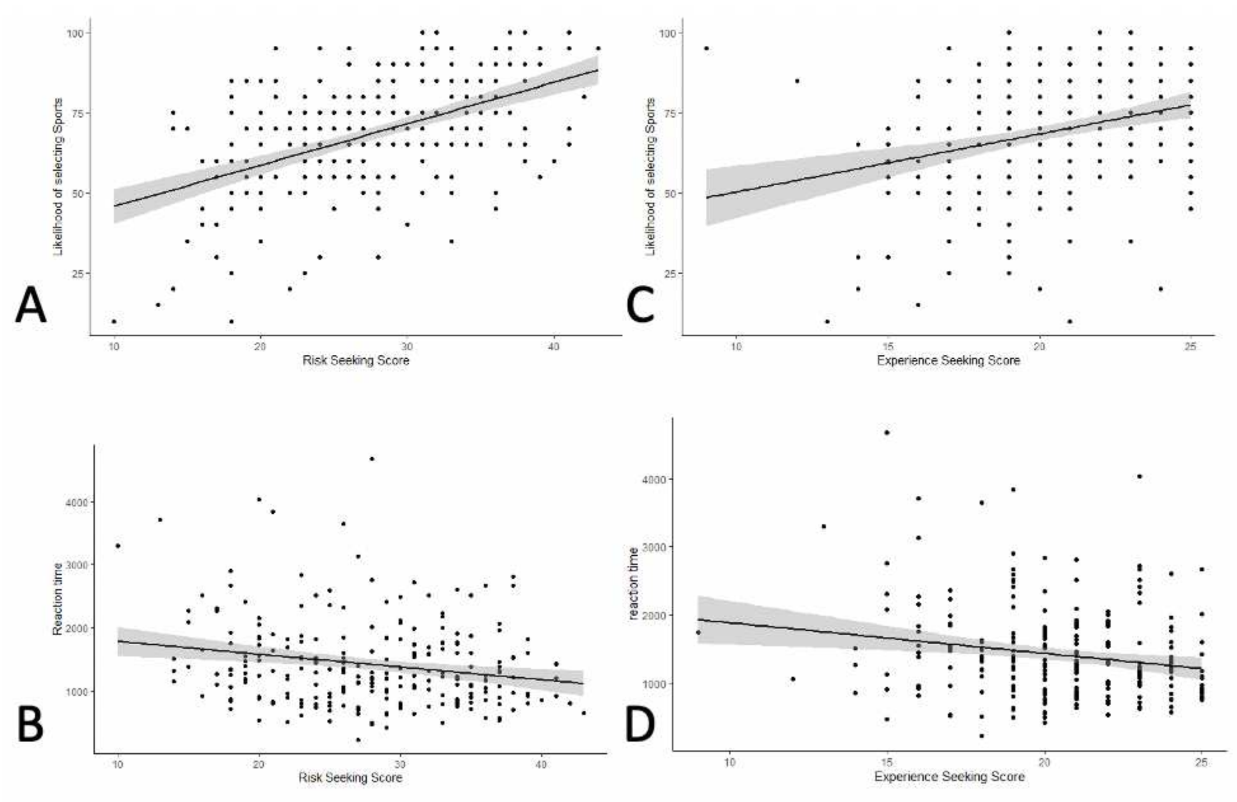

Figure 1 – Effects of risk and experience seeking score on tendency to select Sports stimuli Linear regressions of the likelihood of selecting Sports stimuli compared to control stimuli based on risk seeking and experience seeking. A) Likelihood of selecting Sports stimuli opposed to control stimuli, as a function of risk seeking score. B) Reaction time in selecting Sports stimuli opposed to control stimuli as a function of risk seeking score. C) Likelihood of selecting Sports stimuli opposed to control stimuli, as a function of experience seeking score D) Reaction time in selecting Sports stimuli opposed to control stimuli as a function of experience seeking score

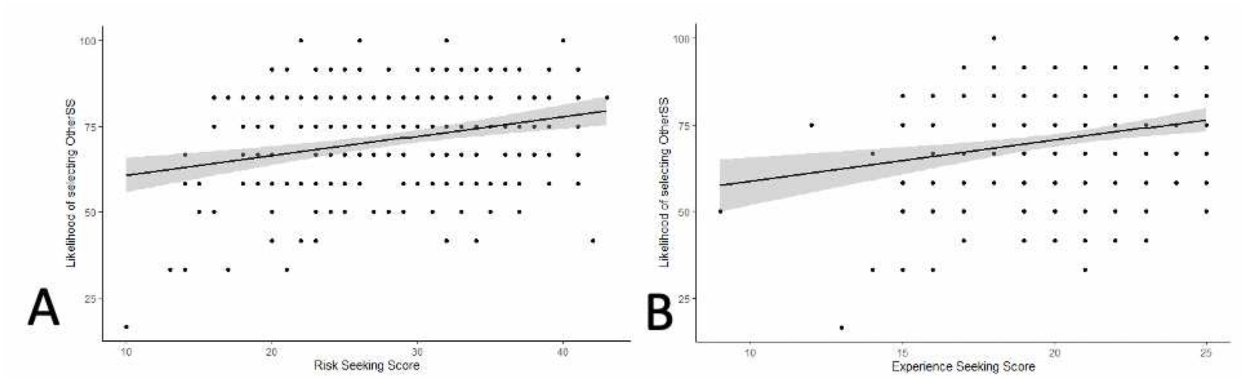

Figure 2 – Effects of risk and experience seeking score on tendency to select OtherSS stimuli Linear regressions of the likelihood of selecting OtherSS stimuli compared to control stimuli based on risk seeking and experience seeking scores. A) Likelihood of selecting OtherSS stimuli opposed to control stimuli as a function of risk seeking score. B) Likelihood of selecting OtherSS stimuli opposed to control stimuli as a function of experience seeking score.

Functional Near Infrared Spectroscopy Between-Subjects Results

When examining the risk seeking groups, in the lateral PFC ROI there were significant differences in activation between high and low Risk Seekers for the AllSS> Control contrast, as illustrated in Figure 3. These activated areas were centered at channel 4 (MNI: -59, 14.67, 4.67; $t = -3.19$, $p < .001$), 7 (MNI: -44.3, 25, -22.67; $t = -2.20$, $p < 0.04$), 14 (MNI: 66.33, 4.33, 27; $t = -2.41$, $p < 0.02$), 15 (MNI: 61.33, 15.33, 5.67; $t = -2.17$, $p < 0.04$), and 20 (MNI: 70, -16.67, 16.67$t = -2.07$, $p < 0.05$). In the set OFC ROI, shown in Figure 4, there was a significantly different response at channel 10 (MNI: -70, -19.67, -17.33; $t = -2.20$, $p < .04$). All significantly activated areas between groups had a degree of freedom of $n = 23$. P values were not corrected to account for the number of tests.

When examining the experience seeking groups, high experience seekers showed significantly different activity in the AllSS > Control contrast than low experience seekers in the Lateral PFC ROI at channel 8 (MNI: -68, -16.67, -15.67; $t = -2.32$, $p < .03$) as seen in Figure 5. In the OFC, there were no significant between-group differences at any of the channels for the AllSS > Control contrast, as shown in Figure 6. All significantly activated areas between groups had a degree of freedom of $n = 23$. P values were not corrected to account for the number of tests.

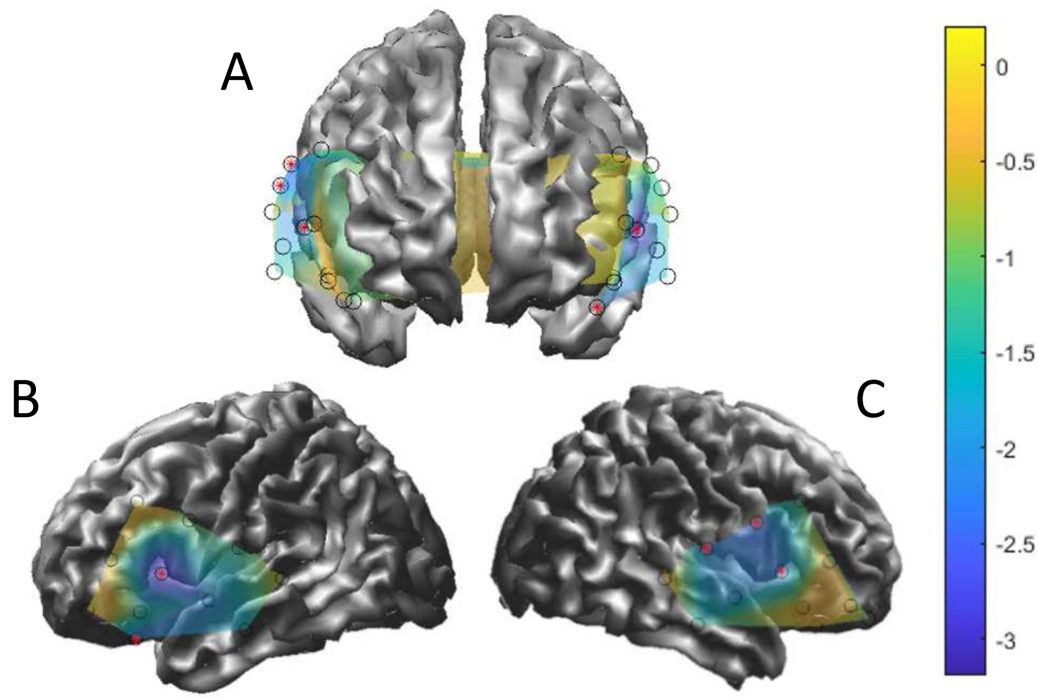

Figure 3 – Effect of high versus low risk seeking score in the lateral prefrontal cortex
BOLD activation in our established lateral PFC ROI during congruent sensation seeking trials versus congruent control trials compared across groups of those high in risk seeking to those low in risk seeking. Channels at which the differences reached statistical significance are marked with a red asterisk. A) An anterior coronal view of the defined lateral PFC region. B) Left lateral view. C) Right lateral view

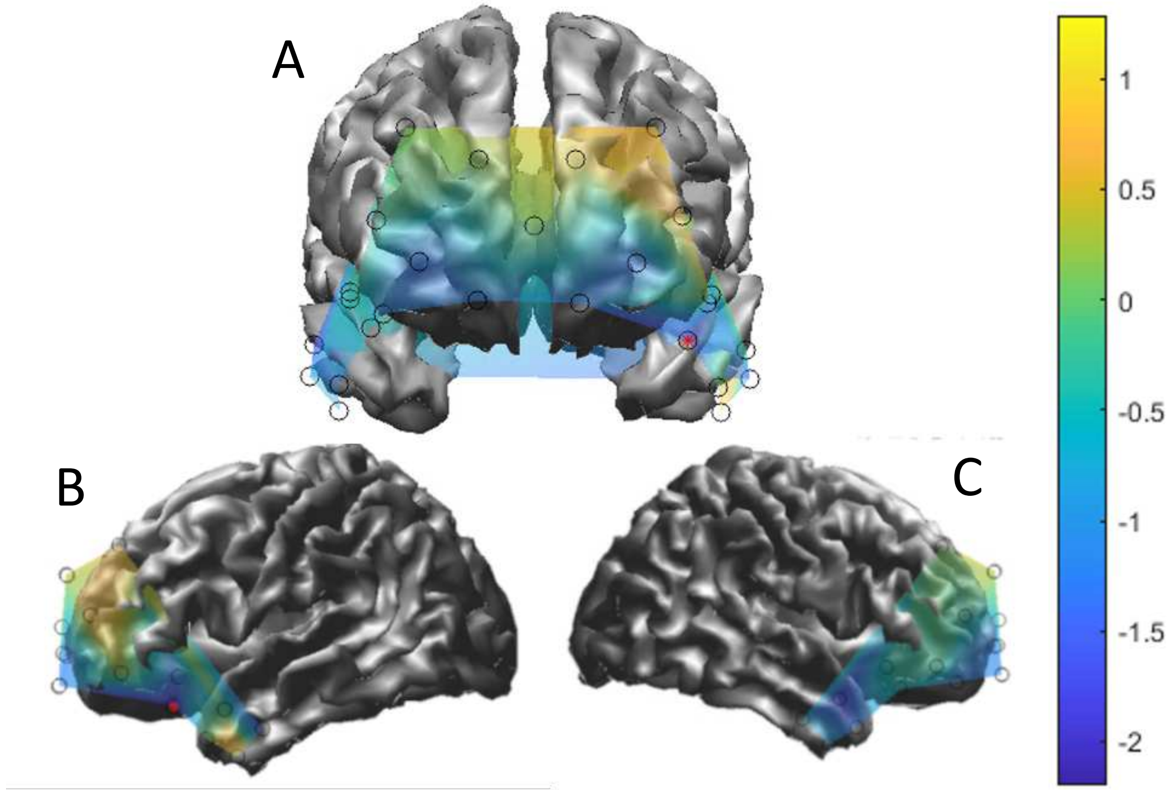

Figure 4 – Effect of high versus low risk seeking score in the OFC
BOLD activation in our established OFC ROI during congruent sensation seeking trials versus congruent control trials compared across groups of those high in risk seeking to those low in risk seeking. Channels at which the differences reached statistical significance are marked with a red asterisk. A) An anterior coronal view of the defined lateral PFC region. B) Left lateral view. C) Right lateral view

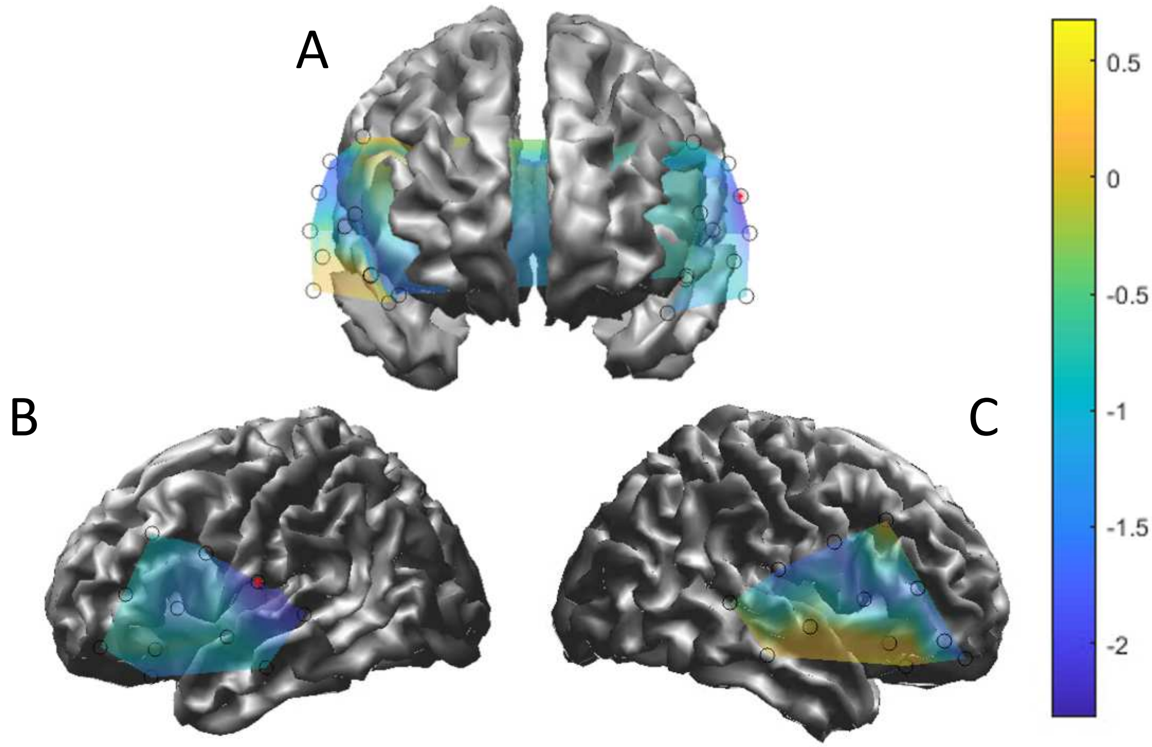

Figure 5 – Effect of high versus low experience seeking score in the lateral prefrontal cortex BOLD activation in our established lateral PFC ROI during congruent sensation seeking trials versus congruent control trials compared across groups of those high in experience seeking to those low in experience seeking. Channels at which the differences reached statistical significance are marked with a red asterisk. A) An anterior coronal view of the defined lateral PFC region. B) Left lateral view. C) Right lateral view

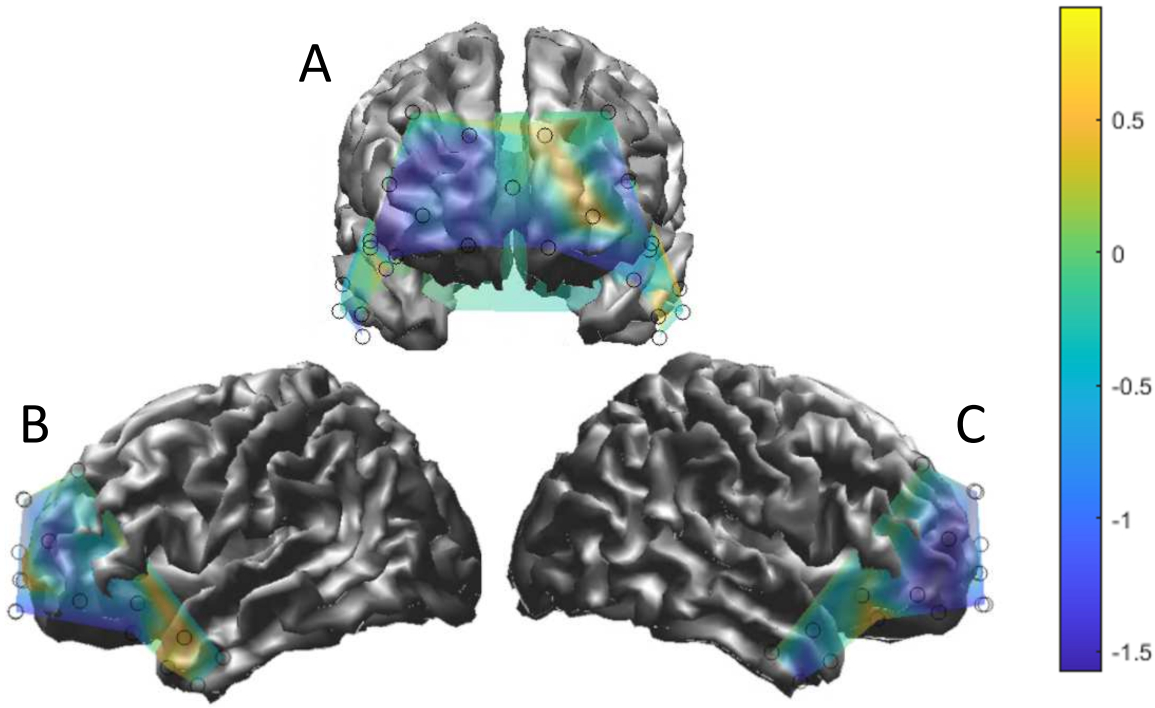

Figure 6 – Effect of high versus low experience seeking score in the OFC
BOLD activation in our established OFC ROI during congruent sensation seeking trials versus congruent control trials compared across groups of those high in experience seeking to those low in experience seeking. Channels at which the differences reached statistical significance are marked with a red asterisk. A) An anterior coronal view of the defined lateral PFC region. B) Left lateral view. C) Right lateral view

DISCUSSION

Behavioral

This study aimed to create a behavioral task capable of assessing sensation seeking personality type. While the task did not perform in a manner consistent with other attentional bias dot-probe tasks, aspects of the study have provided further understanding of how to measure sensation seeking. Those high in sensation seeking showed some behavioral differences from those low in sensation seeking, having an increased likelihood of selecting the sensation seeking stimuli over a control image, regardless of congruency. Previous attentional bias tasks have used accuracy and reaction time based on congruency to measure bias through task performance, assessing higher accuracy and shorter reaction time on congruent stimuli trials for the attended stimuli by group (MacLeod 1986, Ehrman et al., 2002). These measurements did not show significant differences related to sensation seeking in this study's attentional bias dot-probe task, the SSDP. Rather, an apparent bias towards sensation seeking imagery manifested in the sensation seekers choosing Sports and OtherSS stimuli over control imagery more often, in a manner unrelated to the congruency of each trial.

A series of linear regressions were run to assess changes the various accuracy and reaction time variables as a function of risk and experience seeking scores, but no significant results were found. This leaves the SSDP unable to identify group bias in sensation seekers through the usual means in attentional bias dot-probe tasks. The lack of these differences in performance implies that the SSDP was not able to differentiate high and low sensation seekers.

However, for the SSDP we also made a calculation for a direct bias variable. Rather than being based on accuracy and reaction time in congruent and incongruent trials by stimuli type in the task, this was only based on the number of times the participant selected a sensation seeking image, either Sports or OtherSS, over Control images featuring people doing non-sensation seeking activities during high bias trials. This calculation did show significant differences between high and low sensation seekers. Both high risk and high experience seekers were found to have a higher likelihood of selecting either types of sensation seeking images when paired with a people control image during a high bias trial. In addition, for the Sports stimuli specifically, a slightly faster reaction time occurred during these trials as well when selecting the Sports image. Thus, in regard to identifying behavioral differences between high and low sensation seekers, the SSDP did succeed by finding bias towards sensation seeking images in those high in sensation seeking.

fNIRS

In the second part of this study I was interested in neural activation differences between high and low risk and experience seekers in the lateral PFC and the defined OFC region. I hypothesized that there would be differential activity in the lateral PFC and the OFC between those high and low in risk seeking in response to sensation seeking images compared to control images. Likewise, the same expectation for differential activity in those areas was to occur for those high in experience seeking compared to those with low experience seeking scores. The results showed mixed findings for neural activation differences but seem to confirm that there were some differences between each paired group. Specific loci of greater BOLD response in the Lateral PFC were found in both high risk and high experience seekers compared to low risk and low experience seekers respectively. High risk seekers also appeared to have some slight change in activation in the defined OFC ROI which was not found in experience seekers. The presence of these differences in response to sensation seeking stimuli implies an identifiable difference in neural activity between high and low sensation seekers.

The lateral PFC for risk seekers showed the greatest number of differentially activated channels in locations corresponding to primarily the anterior temporal lobe and ventral PFC, including Broca's area and locations known for being responsible for semantic memory and tasks. While the distributed pattern may correspond to the general cognitive control present in the lateral PFC, it should be noted that some of these areas have also been found to contain mirror neurons and are involved with observation (Hamzei et al., 2003). In such a case it is possible that risk seekers may be essentially projecting themselves or reacting to the observation more personally than low risk seekers. High experience seekers activity was centered around the anterior temporal lobe at the edge of the actual ROI near the ventral PFC. It is possible that this is functioning in a similar way, with these locations being critical for semantic memory.

For the set of OFC ROIs, high risk seekers had greater activity than low risk seekers in an area quite close in proximity to the same areas along the anterior temporal lobe and lateral PFC. It could be responding in a similar way as the activity with high experience seekers as the channels are very close.

The slight difference in location from the OFC could be due to difficulty in analyzing the OFC using BOLD techniques. This could potentially explain the lack of activation difference between high and low experience seekers in the OFC as well, causing the activated voxels to be just outside of the ROI. The OFC ROI was targeted to broadly include all ventral and medial parts of the frontal lobe due to their relation to sensation seeking stimuli in past studies (Camara et al., 2009; Hommer et al., 2011; Rolls et al., 2000; Rolls et al., 2014, Lawson et al., 2012). The close activated channels in risk seekers in the OFC and experience seekers in the OFC is between anterior temporal lobe, typically more responsible for memory and conceptual processing, and the vmPFC which is also related to memory and valuation (Ralph, 2017; Gilboa & Marlatte, 2017). fNIRS has previously had difficulty in analyzing the OFC and medial PFC, as they are further from the scalp than other more surface areas like the lateral PFC (Derosière et al., 2013; Kopton & Kenning, 2014). A possibility in the analysis of the OFC ROI is that due to the limitations of fNIRS, and difficulty of the OFC to be analyzed with fMRI, the BOLD response may have been more focused on the Frontopolar region (Stanger, 2006). This location is primarily concerned with executive control, typically in regard to overall goal-tracking in working memory and task switching (Badre & Nee, 2018). Given the SSDP had only one set of instructions for the task, selecting which image held the dot-probe, it would make sense for this area to not have a change in activity, as there is no change in task.

Potential Implications and Limitations

While the SSDP did not identify differences between high and low experience and risk seekers in the typical way that attentional bias dot-probe tasks do, it does seem to highlight the differences between high and low sensation seekers in general. Seeing as the only difference was found regardless of task congruency, this could potentially mean that the SSDP was too difficult for participants to reliably perform well on, or that the effects of this attentional bias do not transfer to task performance as with typical dot-probe designs. This could be due to a key difference in the previous dot-probe task literature. In both the Macleod (1986) and Ehrman (2002) studies discussed earlier, the dot-probe would not flash on the screen for 50ms as with the SSDP. Rather, the dot-probe would remain one the screen until the participant responded to the task, indefinitely for the Macleod task and for 2 seconds in Ehrman's study, after which the trial would end (Macleod, 1986; Ehrman et al., 2002). The SSDP attempted to have a much shorter interval in order to better ascertain slight attentional bias, but it is possible that this made the task too difficult or did not allow for the bias to be reflected in task accuracy or reaction time. Another consideration is that there few trials of each type in the SSDP, with only 13 high bias trials for each of the sensation seeking stimuli. This low number of trials may not have allowed for differences to be seen between those few trials but was apparent with the full 64 trials used when calculating the bias variables. Regardless, the bias towards sensation seeking stimuli in sensation seekers is not in doubt and would be useful to consider in designing future studies and task designs.

In addition to the similar behavioral functions of risk and experience seekers, it seems that both groups respond in the same way to both Sports stimuli and OtherSS stimuli. Both performed similarly for sensation seekers on the SSDP, with the exception of Sports stimuli also resulting in a slightly faster selection time. This does not seem to be convincing evidence that there are particular differences in the types of sensation seeking stimuli and can most likely be collapsed in future work.

Several possible conclusions can be drawn given the neuroimaging results. Risk seeking and experience seeking performed similarly in terms of BOLD activation differences between high and low groups near the anterior temporal lobe and ventral PFC, while only risk seekers had additional activation more towards the dlPFC in areas with connection to understanding observed actions. If we consider that the anterior temporal lobe - vmPFC activation found in both the lateral PFC ROI for risk seekers and the OFC in experience seekers could actually be of the same origin, it is possible that this area of activation persists across all sensation seekers while the additional increased lateral PFC areas are exclusive to risk seekers. This could be due to both subtypes finding value in the stimuli, but that risk seekers also engage in cognitive mirroring, perhaps due to the experience seekers enjoying the images as they are but the risk seekers imagining the experience as well. However, it is also possible that the anterior temporal lobe – vmPFC activity in each ROI are completely separate. In this case it would completely separate risk seeking and experience seeking in terms of neural activity while still exhibiting differential activity between high and low members of each group. This however would not explain why the two subscales have completely different activity changes from low sensation seekers.

A limitation that may also explain this finding could be from inherent difficulty in fNIRS (and fMRI) in analysis of the OFC. in fMRI, there are significant difficulties in assessing the OFC due to the nearby sinuses and general position in regard to the cortex and skull (Stanger, 2006). This problem, being due to the nature of the BOLD response, thus translates to fNIRS as well. This compounded with the inherent limitation in fNIRS to penetrate the scalp may have resulted in susceptibility artifacts for those ROI analyses. It may be necessary to use fMRI and specific methods to address this difficulty, such as parallel imaging, in order to find conclusive evidence for this region.

Another limitation to consider is that in all statistical analyses between the high and low groups, no values survive significance after a multiple comparisons check. Using a false discovery rate method through a between groups analysis script in SPM fNIRS, these results are nonsignificant in each area. While multiple comparison tests are common in fMRI due to the incredibly high number of tests performed at every potential voxel, in fNIRS there are significantly less, as statistical checks were only performed at a much smaller number of channels. In addition, by restricting the analyses to the two ROIs and only reporting the central channel voxels as results, this concern is reduced. Another consideration is that both groups are small and not equally represented due to the removal of some data. A total sample size of 25 is under the typical threshold considered for power in fNIRS. Reducing the sample to two, uneven groups for between groups analyses only compounds this issue. Future fNIRS studies should have a greater number of participants in order to ensure stronger statistical analyses and reliable results.

Given the behavioral results, my hypothesis that creating a behavioral task to assess sensation seeking personality type through attentional bias is possible appears to be supported. However, it did not affect accuracy or reaction time across congruency, or any part of the dot-probe itself. This warrants the creation of a better task design to better understand these qualities. Future considerations I have taken are using emergent engagement in sensation seeking behavior through video games or interactive virtual reality tasks. This would provide the opportunity to present sensation seeking stimuli and control stimuli but have participants engage in the tasks in alternative measurable ways not dependent a dot-probe paradigm. I may also attempt to identify issues with the SSDP and see if it would be possible to enhance its function to better address these topics.

The SSDP may not have performed in the manner which was expected as with other attentional bias dot-probe tasks, but it has demonstrated some evidence which helps us better understand sensation seeking and its subtypes. The neuroimaging results also presented with notable differences between high and low sensation seekers, implying functional neurological differences between those high in the personality type and those who are not. Though more work will be needed to create a reliable task and to better understand neurological differences in sensation seekers, this is a promising start for future studies that will need to address these discrepancies in order to have a clearer understanding of sensation seeking personality type.

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