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Sensation Seeking Predicts Brain Responses in the Old-New Task: Converging Multimodal Neuroimaging Evidence

Adam L. Lawson^{1,2}, Xun Liu^{3,4}, Jane Joseph^{3,5}, Victoria L. Vagnini², Thomas H. Kelly², and Yang Jiang²

¹Department of Psychology, Eastern Kentucky University, Richmond, KY

²Department of Behavioral Science, University of Kentucky, Lexington, KY

³Department of Anatomy and Neurobiology, University of Kentucky, Lexington, KY

⁴Institute of Psychology, Chinese Academy of Sciences, Beijing, China

⁵Department of Neurosciences, Medical University of South Carolina, Charleston, SC

Abstract

Novel images and message content enhance visual attention and memory for high sensation seekers, but the neural mechanisms associated with this effect are unclear. To investigate the individual differences in brain responses to new and old (studied) visual stimuli, we utilized Event-related Potentials (ERP) and functional Magnetic Resonance Imaging (fMRI) measures to examine brain reactivity among high and low sensation seekers during a classic old-new memory recognition task. Twenty low and 20 high sensation seekers completed separate, but parallel, ERP and fMRI sessions. For each session, participants initially studied drawings of common images, and then performed an old-new recognition task during scanning. High sensation seekers showed greater ERP responses to new objects at the frontal N2 ERP component, compared to low sensation seekers. The ERP Novelty-N2 responses were correlated with fMRI responses in the orbitofrontal gyrus. Sensation seeking status also modulated the FN400 ERP component indexing familiarity and conceptual learning, along with fMRI responses in the caudate nucleus, which correlated with FN400 activity. No group differences were found in the late ERP positive components indexing classic old-new amplitude effects. Our combined ERP & fMRI results suggest that sensation-seeking personality affects the early brain responses to visual processing, but not the later stage of memory recognition.

Keywords

novelty seeking personality; old-new effect; recognition memory; evoked potentials; brain imaging; ERP; fMRI

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Please send correspondence to: Yang Jiang, Associate Professor Department of Behavioral Science University of Kentucky College of Medicine, Lexington, KY, 40536 Phone: (859) 257-2122 Fax: (859) 323-5350 yjiang@uky.edu.

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¹The use of expanded time windows to capture a component's peak latency in comparison to mean amplitude was done to accommodate individual variability in peak latency.

Introduction

Sensation seeking is a biologically-based personality trait characterized by the tendency to seek varied, novel, complex and intense sensations and experiences, along with the willingness to take risks for the sake of such experiences (Derringer et al., 2010; Zuckerman, 1971; 1994). High sensation seekers are more likely to engage in risky behaviors, such as illegal drug use (for review see Bardo et al., 1996) and risky sexual activity (e.g., Bancroft et al., 2004; Kalichman et al., 1994; Sheer & Cline, 1995), and exhibit aggressive, nonconformative and unsocialized behaviors associated with juvenile delinquency and criminality (e.g., Arnett, 1996; Knust & Stewart, 2002; Lyman & Miller, 2004). These behaviors put high sensation seekers at increased risk for a variety of adverse health outcomes.

Given that high sensation seekers are at increased risk, targeted prevention interventions have been directed towards this group (for a review see Stephenson, 2003). The sensation value of materials used in prevention interventions is an important determinant of intervention efficacy for high sensation seekers (Donohew et al., 1991; Palmgreen & Donohew, 2010; Stephenson & Palmgreen, 2001). Sensation value is characterized by the extent to which materials are new, complex, rapidly changing and unexpected. The use of high sensation content has been shown to increase attention and recall and to enhance persuasion among high sensation seekers in laboratory studies (e.g., Everett & Palmgreen, 1995; Donohew et al., 1991; Palmgreen et al., 1995). Furthermore, public service announcements with high sensation value materials have been effective in reducing marijuana use (Palmgreen et al., 2001; Stephenson & Palmgreen, 2001) and risky sex (Zimmerman et al., 2007) in prevention campaigns. While the effectiveness of high sensation value prevention materials for high sensation seekers is well established, the cognitive and neural mechanisms underlying these effects are less well understood (Stephenson, 2003).

One key element of sensation value is contextual novelty, defined as familiar items that are new or unexpected within a given context (e.g. have not seen recently). The neural mechanisms of contextual novelty and memory recognition of learned items have been examined effectively in ERP and fMRI research using the old-new memory task (see Yonelinas, 2002 for a review). This task allows for the testing of brain responses during the presentation of studied or *old* items compared with not studied or *contextually novel* (i.e., new) items. Since old stimuli are recently viewed and studied while new stimuli are not, differences in behavioral and brain responses to old and new items can be associated with differences in familiarity and contextual novelty, respectively.

The aim of the present study was to examine behavioral and brain responses to studied and contextually novel common objects among high and low sensation seekers. The use of neuroimaging tools has been pivotal in detecting both distinct neural mechanisms associated with old-new effects and differences in the functional contributions of these mechanisms (Friedman & Johnson, 2000; Henson, 2005; Paller, 2001; Yonelinas, 2002). Distinguished by the ability to measure temporal changes in brain activity at the millisecond range, the classic old-new ERP effect is that studied (old) evoked larger positive going ERP responses than contextually novel (new) items, and the new items elicit more negative-going activation than old items about 200 – 800 ms post-stimulus onset.

Importantly, ERP studies have identified two partially distinct ERP markers that encompass old-new effects. Dual-process memory models describe these processes as *familiarity* and *recollection* (Mecklinger, 2000; Yonelinas, 2002). Occurring early in the ERP waveform (~200 – 500 ms), the more automatic familiarity mechanisms are encompassed by N2 (i.e.,

N200) and FN400 components and accompany a feeling of *knowing*, but do not reflect contextual details (i.e., source memory) that often accompany recognition. The fronto-central N2 (~200 – 350 ms) reflects a new or lack of familiarity by virtue of increased negative going amplitude for new than studied items that is sensitive to stimulus novelty and orienting processes (Folstein & Van Petten, 2008). The FN400 component (~300–500ms) or frontal old/new effect indexes familiarity by less negative-going amplitude for studied than new items, reflecting the global similarity between the test stimulus and all other previously viewed items (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007). Recent research has also implicated the FN400 with conceptual priming, although it is unclear to what extent familiarity mechanisms comprise conceptual priming (Paller, Voss, & Boehm, 2007; Voss, Schendan, & Paller, 2010). Occurring later in the ERP waveform (~500 – 800 ms), the Late Positive Component (LPC) reflects recollection processes comprising recognition memory, such as when and where an item was encountered (e.g., Curran & Cleary, 2003; Schloerscheidt & Rugg, 2004). The LPC has also been linked to processes associated with directed attention and working memory in the prefrontal cortex (Picton, 1992).

fMRI studies have provided important insights into familiarity mechanisms by identifying activation differences between old and new items. Activity in the hippocampus and associated limbic and medial temporal areas, including the entorhinal and perirhinal cortex, parahippocampal cortex, amygdala, and medial dorsal thalamus, are critical for forming and retrieving memories (Henson, 2005; Petrides, 2008). The caudate nucleus has also been implicated in recognition and is known to play an important role in habit learning which is relevant for recognizing previously studied items (Grahn, Parkinson & Owen, 2009; Kiehl, Laurens, Duty, Forster, & Liddle, 2001). Several regions have been implicated for correct rejections of unfamiliar or novel items including the prefrontal and cingulate cortices (Lisman & Grace, 2005; Ranganath & Rainer, 2003). The orbitofrontal cortex has also been involved in novelty detection, and is thought to regulate medial temporal lobe structures, including the amygdala and hippocampus, in relation to expectations of novelty and subsequent encoding into memory (Petrides, 2007).

Given that brain responses serve as reliable markers of old-new detection, we explored ERP and fMRI responses of brain activity among high and low sensation seekers completing an old-new task. The intention of the current study was two-fold. First, we examined whether ERP components and fMRI regions known to index familiarity and memory recognition processes to common objects differed as a function of sensation seeking status. Second, we examined whether ERP components and fMRI regions known to index contextual novelty differed as a function of sensation seeking status. To this end, individuals who scored in the top (high) or bottom (low) quartiles of the general population distribution of scores on a brief sensation seeking scale (Harrington et al., 2003) participated in the study. Participants initially studied a set of common images prior to brain imaging and then performed an old-new task during separate ERP and fMRI sessions. For all participants, we expected that brain activity and structures previously identified in old-new effects to be indexed by both ERP and fMRI measures. Based on our hypothesis that high and low sensation seekers process novelty in different ways, differential brain activation patterns for old and new items were expected in these two groups. Since recent research demonstrated that sensation seeking affects repetition priming (Jiang et al., 2009), FN400 ERP activation was expected to be one component of familiarity that would be different for high and low sensation seekers. We also expected that fMRI responses in cortical regions associated with familiarity would be different between high and low sensation seekers. For contextual novelty, we hypothesized that high sensation seekers would show greater activation than low sensation seekers for unfamiliar and novelty-related processes indexed by the N2 ERP component and differences in fMRI responses in prefrontal, cingulate and orbitofrontal regions. We further hypothesized that recollection memory processes indexed by the LPC ERP component

(classic old-new effect) and fMRI responses to contextually new objects in the medial temporal including hippocampus would be greater for high than low sensation seekers.

Method

Participants

Young adult nonsmoking volunteers, ages 18 to 25, were recruited from flyers placed on the campus of the University of Kentucky, class announcements, word of mouth, and advertisements in the campus and community newspapers. Potential volunteers were directed to a website where they provided introductory health information and completed the 8-item Brief Sensation Seeking Scale (BSSS, Hoyle et al., 2002). Those reporting good health and who were in the upper (score ≥ 32 for both males and females, $M_{BSSS} = 24.55$, $SD_{BSSS} = 4.58$) or lower (score ≤ 27 for males and ≤ 25 for females, $M_{BSSS} = 15.47$, $SD_{BSSS} = 5.71$) quartiles of college-student scores on the BSSS (based on data from Harrington et al., 2003) were contacted by telephone and invited to participate.

Potential volunteers attended an initial interview/medical screening session prior to the study. During the medical screening, individuals completed medical and psychological questionnaires. Exclusion criteria included: (1) any source of metal in the body, (2) claustrophobia, (3) any major medical conditions, including neurological (e.g. stroke, Alzheimer's disease, seizures) and psychiatric (e.g. depression, schizophrenia, panic disorder) disorders, (4) prior closed head injury or concussion, (5) current use of medications that affect the central nervous system, (6) diagnosis of a learning disability, and (7) left-handedness. Urine samples were collected and tested for drug use and pregnancy during the medical screening and prior to each session. No samples were positive for either pregnancy or drug use.

Twenty high ($M_{age} = 20.11$, $SD_{age} = 1.59$, range 18–24) and twenty ($M_{age} = 20.15$, $SD_{age} = 2.42$, range 18–25) low sensation seekers (10 male and 10 female per group) (5% Asian, 12.5% African American, 82.5% Caucasian) completed the study. An additional six participants were excluded from analysis for incomplete data (5 subjects) or in relation to exclusion criteria (1 subject – left handedness). Each participant completed one fMRI session and one EEG session on days separated by a minimum of 24 hours and no more than 7 days. Order of exposure to sessions was counterbalanced among high and low sensation seekers. Procedures used during the two sessions were identical unless stated otherwise. Participants received financial compensation, including payments for the medical screening (\$25), each completed session (\$40/session) and a bonus (\$40) for completing both scheduled sessions and abstaining from drug use for the duration of the study.

Old-New Task

Old-new images consisted of 280 two-dimensional pictures of common objects taken from Snodgrass and Vanderwart (1980), normed for familiarity and complexity. Each picture was presented in black with a white background and within an 8.3 by 5.8 cm area, with a 65 cm viewing distance, and at a visual angle of approximately seven degrees. Half of the old-new stimuli were used in each session. The 140 images used in each session were divided into two groups, with 70 'old' images being studied by participants immediately prior to the session and 70 'new' images presented for the first time during the task. Fixation crosses were presented as control stimuli (70 for ERP session, 140 for fMRI session). An additional 15 studied and 15 new images not employed in the task were used during old-new practice trials prior to each session.

During the old-new task, old, new and fixation trials were presented in random order within a single block of trials. For the fMRI session, all stimuli had a duration of 1000 ms and the

inter-trial interval (ITI) was 2500 ms with the remaining time filled by a blank screen. Stimulus presentation was jittered by 100, 300, or 500 ms to prevent anticipation of stimulus onset. Stimulus presentation for the EEG session was identical except the stimulus duration of each fixation cross was lengthened to 1500 ms to allow participants adequate time to blink when each time a fixation was encountered.

Procedure

Participants began the experiment with a study phase (approximately 25 minutes total for each session) in which they studied 100 pictures (70 used during the session, 15 used for practice, 15 unused) presented for five seconds each. They subsequently studied this list a second time in a different randomized order. They also studied these pictures in a booklet (12 pictures per page) for five minutes. Subjects were told to relate each image to personal experience and that they would be tested for recognition after the study period. Subjects were then given 30 practice test items (15 studied, 15 new) to familiarize them with the old-new task, followed by placement inside the MRI scanner or placement of a 64-channel EEG Quick-Cap (Neuromedical Supplies) on the participant's head. The old-new task was then performed during the collection of EEG or fMRI data (approximately 10 minutes for each session). Participants were instructed to recognize whether an image was previously studied or not by pressing a button with one hand for studied images and the other hand for new items. Assignment of hands to indicate studied versus new images was counterbalanced across groups. During both EEG and fMRI sessions, subjects were instructed to minimize head and body movements during the task. During the EEG session, subjects were additionally asked to minimize blinking during the task unless a fixation cross was displayed.

EEG Protocols

Electroencephalographic recordings were made from 62 scalp sites using Ag/AgCl electrodes embedded in an elastic cap at locations designed to provide even coverage across the scalp. Two additional channels were used for monitoring horizontal and vertical eye movements. Trials with incorrect responses and trials contaminated by electro-ocular artifacts were excluded from subsequent analyses. A left mastoid reference electrode was used online and the reference was changed offline to the average of left and right mastoid recordings. Impedance was less than 10K Ω . EEG signals were filtered with a band-pass of 0.05–40 Hz and sampled at a rate of 500 Hz. Each epoch lasted 1000 ms with an additional 100 ms recorded prior to stimulus onset to allow for baseline correction.

fMRI Protocol

Data Acquisition—A 3T Siemens Trio magnetic resonance imaging system equipped for echo-planar imaging (EPI) was used for data acquisition. The EPI images were acquired using the following parameters: TR = 2500 ms, TE = 30 ms, flip angle = 81°, 40 contiguous axial slices (matrix = 64×64, in-plane resolution = 3.5×3.5 mm², thickness = 3.5 mm, no gap). A high-resolution T1-weighted MP-RAGE anatomical set (192 sagittal slices of full head, matrix = 224×256, field-of-view = 224×256 mm², slice thickness = 1 mm, no gap) was collected for each participant.

Stimuli were presented using a high-resolution rear projection system with responses recorded via two fiber-optics response pads (Avotec, Stuart, Florida), each with one button. A computer running E-Prime (Version 1.1 SP3, Psychology Software Tools, Pittsburgh, PA) controlled stimulus presentation and recorded responses. In addition, the timing of the stimulus presentation was synchronized with trigger pulses from the system magnet.

Image Pre-processing—Prior to statistical analysis, the first four volumes of each run were discarded to allow the MR signal to reach steady state. The remaining images in each participant's time series were motion corrected using the MCFLIRT module of FSL (FMRIB's Software Library, v3.1) package (<http://www.fmrib.ox.ac.uk/fsl>). Images in the data series were then spatially smoothed with a 3D Gaussian kernel ($\text{FWHM} = 7 \times 7 \times 7 \text{ mm}^3$), and high-pass filtered. The FEAT (FMRIB's Expert Analysis Tool) module of the FSL package was used for these steps and later statistical analysis.

Statistical Analyses

Behavioral Analyses—Response times (RTs) were initially examined for outliers and any RT data shorter than 200 ms or longer than 1500 ms was deemed as being a participant error and excluded from subsequent analyses (less than 1% of data were excluded as outliers). For RT and response accuracy, a 2 sensation seeking group (low, high) $\times$ 2 old-new status (old, new) analysis of variance (ANOVA) with repeated measures on the latter variable was separately applied to each dependent measure and each data collection session (i.e., fMRI and EEG sessions).

ERP Analyses—For ERP data, a preliminary examination of electrode sites indicated that midline sites provided a good representation of group effects, and thus were used in significance testing. N2 latency was defined as the latency with the highest negative peak from 200 – 300 ms, FN400 latency reflected the highest negative peak from 300 – 500 ms, and LPC latency was defined as the latency with the highest positive peak from 300 – 800 ms. Visual inspection of grand ERPs for each group indicated that the time intervals 250 – 350, 350 – 500, 500 – 650, 650 – 800, and 800 – 900 ms best represented differential components and activation patterns.² In addition to these time windows, mean amplitude data based on the peak latency for the N2 and FN400 components were also determined for each participant by utilizing a time window that was 50 ms before and 50 after (100 ms window) the respective latency peaks. Approximately 20 percent of trials were excluded due to incorrect responses or electro-ocular artifacts. For each peak latency and mean amplitude interval, the corresponding ERP data were subjected to a 2 sensation seeking group (low, high) $\times$ 2 old-new status (old, new) $\times$ 8 midline electrode site (Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz) ANOVA with repeated measures on the latter two variables, and level of significance set to $\alpha = 0.05$. Greenhouse-Geisser corrections were reported with all effects having two or more degrees of freedom in the numerator. Pairwise comparisons using the Bonferroni test were conducted to examine main effects, and simple-effects models were used to examine interactions.

fMRI Analyses—Customized square waveforms for each participant were initially generated for the individual's specific counterbalanced order of experimental conditions. These waveforms were convolved with a double gamma hemodynamic response function (HRF). For each participant, we used FILM (FMRIB's Improved Linear Model) to estimate the hemodynamic parameters for the different explanatory variables (e.g., one for studied items – “old”, and another for non-studied items – “new”) and to generate statistical contrast maps of interest (e.g., a contrast between the “new” versus “old” items).

Data from each participant were analyzed separately prior to the higher-level group analysis. The individual-subject contrast maps were warped into common stereotaxic space before mixed-effects group analyses were performed. This involved registering the average EPI image to the MP-RAGE image from the same participant, and then to the ICBM152 T1

²The P1 (60 – 120 ms) component was not included in analyses due to excessive noise that potentially obscured this component for a number of participants.

template, using the FLIRT (FMRIB's Linear Image Registration Tool) module. For the mixed-effects group analyses, the FLAME (FMRIB's Local Analysis of Mixed Effects) module was used to obtain the group mean of brain activation.

To identify regions of brain activation, we defined the ROIs first by clusters of 30 or more contiguous voxels (Xiong et al., 1995). Parameter estimate (PE) values differed significantly from zero using $Z > 3.3$, $p < 0.001$ (two-tailed) for within-group effects. We used $Z > 2.58$, $p < 0.01$ (two-tailed) for cross-group effects. The lower Z score used for cross-group analyses reflected lower statistical power due to larger variances between groups. Using the Mintun peak algorithm (Mintun et al., 1989), we further located the local peaks (maximal activation) within each ROI.

ERP & fMRI Relationship Analyses

Multiple regression analyses were used to explore whether ERP components that varied significantly as a function of familiarity or novelty were related to fMRI signals that also varied significantly as a function of familiarity or novelty. The magnitude of the ERP signal was determined by subtracting the amplitude on old trials from new trials (new-old). Due to the large number of ERP components and electrode sites, a principal components analysis with varimax rotation (PCA) was initially conducted to reduce the large number of predictors to a more manageable group and reduce the potential for multi-collinearity. Multiple regression analyses were then used to examine relationships between the ERP factors and magnitude of fMRI response in each fMRI region listed in Tables 1 and 2. The rationale for including all ERP factors in the regression analysis for each fMRI region was that each ERP predictor indexed familiarity or novelty differences in the prior ANOVA analyses. Therefore, including each factor allowed for a more comprehensive and unbiased examination of ERP and fMRI relationships. Given that many ERP factors and fMRI regions also implicated group differences, group status was included as a predictor. The ERP factors revealed by the PCA and sensation seeking group status (dummy coded, high sensation seekers = 1, low sensation seekers = 0) served as predictors in a step-wise regression conducted separately for each significant fMRI brain region (results from Tables 1 and 2). All ERP factors were entered into a step-wise regression such that the strongest variable would be entered into step-one, the next strongest in step-two, and so on until all variables had been entered or the inclusion of the variable did not lead to a significant increase in the variability accounted for. Specifically, the ERP factor with the strongest relationship was entered first, and subsequent ERP variables examined would be in order of relationship strength, until they no longer resulted in a significant increase in the R^2 . The rationale for this analysis approach was to insure that all relationships examined in the regression analyses reflected significant findings from the separate ERP and fMRI analyses. In order to be consistent with the ERP coding of new minus old difference values, fMRI outcome variables reflecting recognition memory activation (i.e., old minus baseline, old minus new) were reversed coded (i.e., baseline minus old, new minus old).

Results

Behavioral Results

Behavioral data for three high sensation-seeking participants during the fMRI session were lost due to equipment failure. Response accuracy approached ceiling levels with 93.6 % (old = 93.9 %, new = 93.2 %) and 94.8 % (old = 94.8 %, new = 94.7 %) correct responses found during the ERP and fMRI sessions, respectively. Response times (RTs) for both sessions were also similar, with main effects of old-new status found during both the ERP, $F(1, 37) = 27.61$, $p < .0005$, and fMRI, $F(1, 34) = 26.52$, $p < .0005$, sessions. Participants consistently responded faster to old (ERP $M = 716$ ms, fMRI $M = 667$) than new (ERP $M = 752$ ms,

fMRI $M = 690$ ms) images. No sensation-seeking group effects were found with accuracy or RT during either session.

ERP Results

Data from one low sensation seeking participant was excluded from ERP analyses due to recording problems, leaving 19 low sensation seekers and 20 high sensation seekers for analyses. Figure 1 displays the grand ERP waveforms for low and high sensation seeking groups following old and new image presentations at all midline sites. Peak latency and mean amplitude data were examined for N2, FN400, and Late Positive (LPC) components.

N2 Results—N2 peak latency values (200 – 300 ms) did not distinguish between groups nor old-new status. N2 amplitude was centered over FCz ($M_{\text{latency}} = 265$, $SD_{\text{latency}} = 30.30$), and a main effect of old-new status, $F(1, 37) = 20.30$, $p < .0005$, indicated greater N2 activation for new than old images. Also, a significant 2-way interaction among group and electrode, $F(7, 259) = 4.92$, $p = .01$, was found. Simple effects revealed that high sensation seekers had a larger N2 than low sensation seekers, $F(1, 37) = 6.20$, $p = .017$, at frontal and central sites (Fpz – Cz). In addition, mean amplitude from the 250 – 350 ms window revealed a significant 3-way interaction among group, old-new status and electrode, $F(7, 259) = 2.92$, $p = .045$. Simple effects revealed an old-new by electrode interaction for low sensation seekers only. Low sensation seekers, $F(7, 126) = 3.19$, $p = .04$, had greater activation for new than old images at all sites except for Fpz. High sensation seekers, $F(7, 133) = 1.53$, $p = .23$, however, had consistently greater new than old activation across all sites. As Figure 2 illustrates, this effect reflects more frontally distributed novelty activation for high than low sensation seekers.

FN400 Results—FN400 peak latency values (300 – 500 ms) peaked at frontal sites (Fpz, Fz, FCz), revealing a 2-way group by old-new status interaction, $F(1, 37) = 5.19$, $p = .029$. Simple effects indicated that low sensation seekers, $F(1, 18) = 8.92$, $p = .008$, had shorter FN400 latencies for old than new images, while high sensation seekers, $F(1, 19) = 0.12$, $p = .914$, showed no old-new latency differences. For mean amplitude, the FN400 distribution was centered over site Fz ($M_{\text{latency}} = 421$, $SD_{\text{latency}} = 42.37$). No group effects were found, although an old-new main effect, $F(1, 37) = 62.70$, $p < .0005$, was found. Negative going activation was consistently greater for new than old images. Mean amplitude data from the 350 – 500 ms window were consistent with the FN400 results.

LPC Results—Peak latency values corresponding to the LPC component (350 – 800 ms) centered over CPz and Pz ($M_{\text{latency}} = 614$, $SD_{\text{latency}} = 44.44$). A main effect of old-new status, $F(1, 37) = 43.20$, $p < .0005$, was observed, with latencies being shorter for old than new images. A significant 2-way group by electrode site interaction, $F(7, 259) = 6.21$, $p < .0005$, was also found. Simple effects revealed that high sensation seekers had shorter LPC peak latencies at posterior than frontal sites, $F(7, 133) = 15.87$, $p < .0005$. Low sensation seekers, $F(7, 126) = 0.77$, $p = .514$, did not differ in LPC peak latency across midline electrodes.

LPC amplitude activation was separated into 500 – 650, 650 – 800, and 800 – 900 ms intervals (i.e., mean activation during these intervals). The LPC distribution was centered over site Pz. Two-way old-new by electrode site interactions were observed at 500–650, $F(7, 259) = 6.25$, $p < .0005$, and 650–800, $F(7, 259) = 2.79$, $p = .046$, intervals. Simple effects for the 500 – 650 interval interaction revealed that while new images had consistently less positive activation than old items, and this effect was more robust parietally (at Pz, $F(1, 38) = 32.85$, $p < .0005$) reflecting the typical LPC activation pattern. In contrast, simple effects

for the 650 – 800 interval interaction indicated that new images had more positive activation than old items across all sites except for Fpz (at Fpz, $F(1, 38) = 0.32$, $p = .58$).

During the 800 – 900 ms interval, a main effect of group, $F(1, 37) = 4.95$, $p = .032$, was found. As Figure 1 shows, high sensation seekers had more positive activation than low sensation seekers, indicative of a slower return to baseline for the high sensation seeking group.

fMRI Results

Task-Related Main Effects—Brain regions sensitive to the old-new status of images are shown in Table 1. Many visual processing areas such as the lingual gyrus, middle occipital gyrus, and fusiform gyrus had more activation for new than old images. New images also engendered more activation in the hippocampus along with the frontal areas such as the postcentral gyrus and superior frontal gyrus. Several areas showing increased activity for old relative to new images include the posterior cingulate cortex, superior orbitofrontal gyrus, and caudate nucleus.

Group Main Effects—Brain regions associated with group differences are shown in Table 2. For activation of new images in comparison to baseline, high sensation seekers had greater activation than low sensation seekers in the calcarine sulcus, superior parietal cortex, postcentral gyrus, middle orbitofrontal gyrus, and cerebella. For old images in comparison to baseline, the high sensation seeking group showed greater activation in the calcarine sulcus, cuneus, inferior temporal gyrus, inferior orbitofrontal gyrus, and vermis. No regions had significantly greater activation for low than high sensation seekers.

The cuneus and cerebella showed a 2-way group by old-new status interaction. Whereas both sensation seeking groups had greater activation for old than new images at these two regions, this activation difference was greater for high than low sensation seekers.

ERP and fMRI Integration

The PCA matrix derived from the ERP components revealed five principal components, shown in Table 3. Not surprising, the PCA components largely mapped onto the ERP components, with the exception of the LPC 500–650 component that broke into two posterior components. Also, anterior activation from both the LPC 500 – 650 and LPC 650 – 800 ms time windows were grouped together in a component. Five new factors were created based on the five PCA components by using the factor scores associated with each component.

The results of the step-wise regression analyses using these 5 ERP factors, along with sensation-seeking group status (dummy coded) as predictors, are presented in Table 4. The sensation seeking group factor loaded onto three fMRI regions (right superior orbitofrontal gyrus, right middle orbitofrontal gyrus, caudate nucleus). N2 activation was a predictor of orbitofrontal activity (Figure 3), and FN400 activity predicted caudate nucleus activation (Figure 4). The anterior electrodes of the LPC (500–800ms) component was a predictor of the medial orbitofrontal cortex. The posterior LPC component (500–650ms) was a predictor of the caudate nucleus and the posterior LPC (650–800ms) component was a predictor of the caudate nucleus and posterior cingulate cortex.

Discussion

The focus of the current study was to examine sensation seeking status and brain responses during an old-new memory recognition task. High and low sensation seeking groups showed

differential cortical processing of studied and new visual objects as revealed by differences in several ERP components and fMRI responses. The ERP N2 and FN400 group differences and their relationships to orbitofrontal and caudate nucleus regions, respectively, confirmed our hypotheses that high and low sensation seekers process novelty in different ways.

The N2 component was larger for new than old images over orbitofrontal sites. Furthermore, the distribution of the N2 signals varied between high and low sensation seekers with high sensation seekers showing a more anterior distribution, and low sensation seekers showing a more posterior distribution (Figure 2). N2 responses have been linked to novelty detection, particularly at frontal sites (Folstein & Van Petten, 2008). Previous research using visual stimuli has shown that N2 is sensitive to novelty and stimulus expectancy, with more novel and less anticipated items evoking greater N2 amplitudes at frontal sites (e.g., Altenmüller & Gerloff, 1999; Courchesne et al., 1975; Davidson et al., 2000; Gehring et al., 1992). Our results and previous findings confirm the hypothesis that high sensation seekers would show greater responses to mechanisms reflecting unfamiliarity and contextual novelty.

Interestingly, low compared to high sensation seekers exhibited increased N2 activation to novel stimuli at frontal sites in an ERP study reported by Zheng et al. (2010). Also, Pd3 (subtraction wave reflecting novelty processing) responses were enhanced and less habituated in high sensation seekers. Their study results support our findings that high and low sensation seekers differ in frontal N2 components, but our results differ in that we found heightened N2 activation for high sensation seekers as opposed to low sensation seekers. Methodological differences between our study and Zheng and colleagues likely account for these opposing effects. Their task was an odd-ball task of triangles and unusual visual stimuli. We used an old-new task of common objects. Hence, we examined contextual novelty that is frequent in everyday life as opposed to perceptual novelty. Second, their subjects were recruited from the Chinese population that may have different sensation seeking characteristics while we recruited college students in the United States. These methodological differences may account for the difference in the N2 result, but both studies collectively confirm that sensation seeking does impact old-new oriented processes occurring as early as 200 ms during the evaluation of visual stimuli.

While prior ERP literature typically implicates N2 activation in novelty, our findings of N2 activation being correlated with novelty processing in orbitofrontal regions reveal a more complex integration of processes. Group fMRI differences were apparent with high sensation seekers having higher activity than low sensation seekers in the middle orbitofrontal gyrus and inferior orbitofrontal gyrus (Table 2). Our regression results (Table 4) further revealed that right middle orbitofrontal gyrus (Table 2) was related to novelty seeking status and N2 responses (Figure 3). The relationship between N2 novelty and orbitofrontal activation may signify an important psychophysiological distinction between high and low sensation seekers detectable by combined fMRI and ERP measures. The role of the orbitofrontal cortex in emotion regulation, reward-related processing (Liu et al., 2007), and learning is well established (e.g., Bevens, 2001; Joseph et al. 2009; Rolls, 2000; Rule et al., 2002). The dissimilar fMRI associations among middle, inferior and superior regions of the orbitofrontal gyrus with sensation seeking status (Table 2) and to new and old images (Table 1) provides evidence that this region has multiple functions related to both new and studied processes contributing to learning (Butter, 1964; Paradiso et al., 1997). It has also been suggested that orbitofrontal activity for studied images may reflect input received from structures such as the perirhinal cortex, important for learning new and familiarity information (Henson, 2005). These differing patterns of orbitofrontal activation are likely related to multiple control and monitoring functions that characterize this area. The present results indicate that high and low sensation seekers showed differential activation in the orbitofrontal cortex in response to novelty as early as 200 msec, which

provide new evidence that functions of the orbitofrontal cortex can be modulated by personality.

A body of recent research (e.g., Curran & Hancock, 2007, Wolk et al., 2006) has implicated FN400 activation with familiarity mechanisms in that FN400 amplitude is less for studied than new items, although this ERP component has also been implicated with conceptual priming (e.g., Voss et al., 2010). The results of the present study confirm the involvement of the FN400 component in familiarity. In addition, this is the first study to report sensation seeking group differences in the FN400 component. While both high and low sensation seekers expressed a typical FN400 old-new effect for amplitude (less negative going amplitude for old than new items), group differences emerged with peak latency. Low sensation seekers had shorter FN400 latencies for old than new images whereas high sensation seekers showed no latency effect.

To date, no definitive cognitive process has been implicated with changes in FN400 latency, although it is presumed to be a function of amplitude changes consistent with familiarity and/or conceptual priming processes. The relationship between the FN400 component and caudate nucleus activation revealed by our regression results provide additional clues about these cortical mechanisms and their relationship to sensation seeking (Figure 4). The caudate nucleus is one of several structures that comprise the basal ganglia, and has particularly strong connections to the frontal cortex (White, 2009; Zald et al., 2004). The outflow of processing from the basal ganglia and especially the caudate nucleus is known to be involved in functions that are critical to repeated learning, familiarity and memory, especially for learning correct action schemas for a task (Grahn et al., 2009). Consistent with studies linking the FN400 to conceptual priming, the caudate nucleus is also implicated in priming based on the meaning of stimuli (e.g., Rissman et al., 2003). These results suggest a complex relationship between automatic familiarity mechanisms and mechanisms that distinguish high from low sensation seekers. Although speculative, the lack of latency old-new differences for high sensation seekers may reflect atypical involvement of the caudate in task related processes that involve conceptual priming. It is clear that future research examining the relationship between FN400 and caudate activation, and whether this relationship could reliably differentiate high from low sensation seekers is warranted.

In addition to differences in orbitofrontal and caudate nucleus activity, the fMRI results revealed significant interactions between task and sensation seeking status in the cuneus and cerebella. For both regions, high sensation seekers had more robust recognition memory effects (i.e., old greater than new) than low sensation seekers. Both of these regions are known to be involved in attention and memory retrieval (Desmond, 2001; Makino et al., 2004), and this study implicates these structures in the differentiation of memory processes among high and low sensation seekers. Given the need for drug prevention materials to capture audiences' attention and facilitate their remembering of anti-drug messages, the functional nature of these structures in differentiating high and low sensation seekers should be further explored.

fMRI results also revealed group differences with components and regions involved in early visual attention and perceptual processes. The between-group fMRI comparisons revealed that high sensation seekers had greater activation than low sensation seekers in the visual cortex (i.e., calcarine sulcus & cuneus), inferior temporal gyrus, and superior parietal cortex.

In addition to the new and familiarity effects revealed by the N2 and FN400 components, two group effects were also found with LPC activation. Our hypothesis predicted sensation seeking differences in LPC amplitude that reflects group differences in recollection memory processes. Our group effects, however, only reflected a shift in LPC activation for high as

opposed to low sensation seekers. High sensation seekers had delayed LPC peak latencies in comparison to low sensation seekers. A group difference in LPC amplitude (800 – 900 ms) was found, but this effect mirrors the peak latency shift as opposed a difference in LPC activation that would reflect recollection memory. Finding a similar ERP effect using repeated visual experience, Jiang and colleagues (2009) showed that frontal LPC latency during visual adaptation was correlated with self-reported boredom susceptibility. High compared to low sensation seekers showed a delayed frontal LPC response, reflecting decreased sensitivity to neural changes reflective of repetition priming. Delayed P3a activation (reflecting an orienting response) has also been linked to individuals who have a low tonic level of dopamine, a marker of high sensation seeking (Gabbay, Duncan, & McDonald, 2010). These past and current findings suggest that LPC delays in high sensation seekers may be the product of a slow orienting response reflected by increased boredom. While our group effects show a delayed LPC, the ERP and fMRI findings suggest that recollection processes in themselves are not substantially affected by sensation seeking. The regression results revealed that LPC activity is related to medial orbitofrontal, caudate nucleus, and posterior cingulate activation, all regions known to be important for recollection and episodic memory processes. These current and prior results suggest that recollection processes comprise only a minor role in differentiating high and low sensation seekers.

Increased activation for new relative to old items has been reported in regions of the middle occipital gyrus, ventral visual processing stream (e.g., lingual gyrus, fusiform gyrus), hippocampus (e.g., Jessen et al., 2002; Lisman & Grace, 2005), and the superior frontal gyrus (Dobbins & Wagner, 2005). Many neuroimaging studies have found that activity in the hippocampus and associated middle temporal areas provide a robust neurobiological marker for novelty detection, and include both stimulus novelty (Henson, 2005) and contextual novelty (Crottaz-Herbette et al., 2005; Hamada et al., 2004; Laurens et al., 2005; Strange & Dolan, 2001) effects. The fMRI results of this study are consistent with these previous findings, and the increased hippocampal activation for new images is consistent with its established role in novelty detection and old-new memory. The regression analyses also revealed that early LPC (500–650) activity at posterior sites is related to superior frontal gyrus activation for new images, and supports previous findings that prefrontal novelty activation may be related to slower orientation and response times to new items (Gabbay, Duncan, McDonald, 2010; Ranganath & Rainer, 2003). Participants' response times to new images occurred about 700 ms, also supports this interpretation.

High sensation seekers are more likely to engage in a variety of risky behaviors (Bardo et al., 1996; Kelly et al., 2006; Stoops et al., 2007; Zuckerman, 2005), and the sensation value of materials used in prevention interventions targeted at these at-risk individuals is an important determinant of intervention efficacy (Donohew et al., 1991; Palmgreen & Stephenson, 2002). Novelty is a key dimension of sensation value (Palmgreen & Donohew, 2010). In the current study, group differences were found for both early (i.e., N2, FN400) and late (i.e., LPC) ERP components, but only the early components (Frontal novelty-related N2, familiarity-related FN400) revealed group differences related to contextual novelty. In contrast, no sensation seeking differences that could be attributable to recollection memory (classic old-new ERP effect in LPC/P300 amplitude) were observed. These ERP results suggest that high and low sensation seekers likely differ in cortical processing related to early familiarity and novelty, but not for the latter memory recollection stage. These results provide insights into stimulus characteristics and features of prevention interventions that may be associated with enhanced efficacy among high sensation seekers. The current study suggests that sensation seeking status indexes differential brain processes in response to novelty and suggests that novelty may be one key feature associated with gaining attention and recognition memory among high sensation seekers. Future research will be needed to

determine whether these differences in high and low sensation seekers in the processing of old and new images can translate into differences in processing and/or retaining drug prevention messages.

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Highlights

- > We examined biological basis of sensation or novelty seeking personality using combined ERP & fMRI methods
- > The ERP Novelty-N2 responses were correlated with fMRI responses in orbitofrontal gyrus.
- > No group differences in the late ERP responses indexing classic old-new effects
- > Our results suggest that sensation-seeking personality affects the early brain responses to visual processing, but not the later stage of memory recognition.

Figure 1. Event-related potentials (ERP) of responses to old (solid line) and new (dashed line) images for each sensation seeking group. ERP components are labeled on FPz (N2, FN400) and Oz (Late Positive Component).

Figure 2.

Topographic maps of new minus old differences in ERP activation during the 250 – 350 interval (N2 component) for high and low sensation seekers. The center of activation is denoted by an asterisk.

Figure 3.

Significant bivariate correlations for N2 responses and related fMRI responses in the regression analysis. Values for both ERP and fMRI novelty index reflect new minus old differences. Filled (high sensation seekers) and hollow (low sensation seekers) diamonds are shown to illustrate the effect of group found with the right middle orbitofrontal gyrus.

Figure 4. The significant bivariate correlation between FN400 and fMRI of the caudate nucleus. Filled (high sensation seekers) and hollow (low sensation seekers) diamonds are shown to illustrate the effect of group. The ERP and fMRI familiarity index reflect old minus new differences.

Table 1

Brain Regions Showing an Effect of Old-New Status

Cluster Size	x	y	z	Max Z	Label
Novelty Activation (New > Old, $z > 3.30$, $k > 30$)					
41	38	-10	-32	3.73	Fusiform Gyrus
463	30	-44	-16	4.37	Fusiform Gyrus
390	-30	-38	-20	4.81	Fusiform Gyrus
133	22	-12	-14	4.19	Hippocampus
49	20	-80	-14	3.86	Lingual Gyrus
202	40	-84	18	3.87	Middle Occipital Gyrus
178	-42	-88	14	3.99	Middle Occipital Gyrus
130	58	-6	34	4.17	Postcentral Gyrus
44	-16	0	52	4.04	Superior Frontal Gyrus
Old-New Activation (Old > New, $z > 3.30$, $k > 30$)					
43	4	48	-6	3.57	Medial Orbitofrontal Cortex
56	26	60	0	3.88	Superior Orbitofrontal Gyrus
31	10	10	0	3.85	Caudate Nucleus
55	-8	8	2	4.2	Caudate Nucleus
6870	0	-34	26	6.78	Posterior Cingulate Cortex

Table 2

Brain Regions Showing an Effect of Sensation Seeking (high SS > low SS).

Cluster Size	x	y	z	Max Z	Label
New Objects Versus Baseline ($z > 2.58$, $k > 30$)					
55	-18	-60	-40	3.80	Cerebellum
53	30	46	-12	3.56	R. Middle Orbitofrontal Gyrus
126	24	-68	14	3.39	Calcarine Sulcus
30	-26	-66	12	3.67	Calcarine Sulcus
155	46	-8	32	3.64	Postcentral Gyrus
68	28	-80	52	3.39	Superior Parietal Cortex
Old Objects Versus Baseline ($z > 2.58$, $k > 30$)					
92	2	-52	-14	3.28	Vermis
65	-46	-56	-12	3.07	Inferior Temporal Gyrus
35	-24	18	-12	2.98	Inferior Orbitofrontal Gyrus
35	24	-66	14	3.06	Calcarine Sulcus
35	0	-70	28	2.76	Cuneus
Old Versus New Objects ($z > 2.58$, $k > 30$)					
104	8	-84	-20	3.19	Cerebella
97	-6	-66	24	3.60	Cuneus

Table 3

Principal Component Analysis of ERP Amplitude for Each Component and Electrode.

	N2	FN400	LP Cearly-posterior	LP Clate-posterior	LPC-ant
N2 Fpz	0.245	0.309	-0.248	0.421	-0.070
N2 Fz	0.702	0.362	-0.184	0.205	-0.274
N2 FCz	0.867	0.265	-0.096	0.175	-0.113
N2 Cz	0.904	0.259	0.055	0.157	0.008
N2 CPz	0.952	0.146	0.147	0.040	0.077
N2 Pz	0.899	0.001	0.299	0.011	0.075
N2 POz	0.868	-0.278	0.263	-0.049	0.047
N2 Oz	0.709	-0.340	0.356	-0.226	0.075
FN400 Fpz	-0.212	0.686	-0.117	0.077	0.491
FN400 Fz	-0.071	0.901	0.024	-0.003	0.292
FN400 FCz	0.038	0.881	0.157	0.074	0.335
FN400 Cz	0.128	0.861	0.291	0.067	0.215
FN400 CPz	0.287	0.823	0.323	-0.018	0.064
FN400 Pz	0.288	0.720	0.473	-0.110	-0.072
LPC 500to650 Fpz	-0.114	0.252	0.035	0.071	0.828
LPC 500to650 Fz	0.006	0.305	0.332	0.132	0.798
LPC 500to650 FCz	0.156	0.297	0.465	0.163	0.727
LPC 500to650 Cz	0.231	0.285	0.647	0.171	0.560
LPC 500to650 CPz	0.223	0.274	0.747	0.275	0.405
LPC 500to650 Pz	0.134	0.233	0.849	0.253	0.195
LPC 500to650 POz	0.176	0.043	0.875	0.195	-0.001
LPC 500to650 Oz	0.002	0.121	0.854	0.010	-0.148
LPC 650to800 Fz	-0.098	0.101	-0.268	0.322	0.661
LPC 650to800 FCz	-0.069	0.040	-0.217	0.557	0.692
LPC 650to800 Cz	0.129	-0.014	-0.099	0.636	0.669
LPC 650to800 CPz	0.186	-0.039	0.069	0.769	0.501
LPC 650to800 Pz	0.088	-0.009	0.096	0.875	0.351
LPC 650to800 POz	0.040	0.065	0.189	0.896	0.245
LPC 650to800 Oz	0.063	-0.097	0.145	0.919	0.119

Table 4

Step-wise Regression Results.

Model	β	<i>t</i> -statistic	Probability (<i>p</i>) (** = .01 significant group effect * = marginal group effect)
Superior Orbitofrontal Gyrus			
<i>N2</i>	.502	3.60	.001
<i>Group</i>	-.245	-1.75	.088*
Medial Orbitofrontal Cortex			
<i>LPC500 – 800 (anterior)</i>	.274	1.74	.091
R. Middle Orbitofrontal Gyrus			
<i>Group</i>	.373	2.88	.007**
<i>N2 component</i>	.423	3.24	.003
<i>LPC (650 – 800) posterior</i>	-.336	-2.57	.015
Superior Frontal Gyrus			
<i>LPC(500 – 650) (posterior)</i>	.343	2.22	.032
Caudate Nucleus (10,10,0)			
<i>FN400</i>	.342	2.21	.034
<i>Group</i>	-.267	-1.73	.093*
Caudate Nucleus (-8,8,2)			
<i>LPC650 – 800 (posterior)</i>	.369	2.41	.021
Posterior Cingulate Cortex			
<i>LPC650 – 800 (posterior)</i>	.427	2.87	.007