Single-Neuron Correlates of Emotion Regulation in Humans

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Neuronal activity was monitored with implanted electrodes, using patients undergoing neurosurgery. Participants viewed videos with relatively high emotional content and were instructed to naturally view the content or regulate their emotions. We find that emotions regulation is reflected by systematic patterns in single neuron activity.

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Experiencing and Evaluating in the Brain: fMRI and Single-Neuron Studies
Chair: Moran Cerf, New York University, USA

Paper #1: 1. Identifying Emotions on the Basis of Neural Activation
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Paper #2: 2. Risk and Attribute Framing: They’re Different
Hilke Plassmann, INSEAD, France
Beth Pavlicek, École des Neurosciences de Paris, France
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Paper #3: 3. How incidental affect alters subsequent judgments: insights from a human fMRI study
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SESSION OVERVIEW

When experiencing daily interactions we often think of the momentary evaluation of an experience and its following evaluations as one. However, we now have mounting evidence to the contrary from psychology and neuroscience studies. Eating the chocolate or remembering its taste an hour later are distinguishably different experiences. We trust our memories and evaluation of past events and attach high confidence to them. Our evaluation of past experiences is often shaped by their encoding in our brains and the momentary emotional state we are at upon recalling them. Remembering, therefore, is just another form of evaluation – prone to many failures.

In this session we will address the notion of experience versus its following recount through evaluation, and focus on its effects on consumer decisions. In a sequence of four talks, we will address multiple facets of the problem and suggest methods to assess the difference between experience and reappraisal, as well as evidence for its direct effects on choice and decision-making.

To address these notions, Karim Kassam will initiate the session by showing a novel imaging study that proposes evidence for identifiable emotions signatures that generalize across individuals. That is, a method by which we can isolate a certain emotion by reading brain activity when a subject is experiencing a certain feeling. The emotions tested vary and include complex emotions such as pride, embarrassment and shame. Presumably, these emotions, which are not necessarily accessible to the subjects themselves or to a direct survey can then be read using this method in order to infer consumer evaluation of current experience and of past experiences.

Following this emotional evaluation introduction, William Hedgcock will show the results of a series of studies, which focus on a type of emotional difference between the experience and its evaluation. Dr. Hedgcock’s work focuses on a type of decisions prone to what s known as the framing effect, where decision makers respond differently to problems that are described in positive or negative terms despite the fact that the outcomes are objectively identical. In terms of evaluation of past choices, the framing effect provides evidence to the fact that our evaluations are not only likely to be mistaken but can easily be manipulated by the choice of question asked during the evaluation process. Additionally, Dr. Hedgcock will introduce the notion of emotion suppression as a tool that is often used by subjects to regulate their choices based on emotions.

The third project, presented by Hilke Plassmann, will look at the manifestation of the problem in effective consumer choices. In Dr. Plassmann’s work, subjects are asked to evaluate a preference based on their past experience – in the particular case, the taste of wine - and are showing biased choice based on monetary rewards received earlier. This direct manipulation of the choice acts as another evidence for the difference between the pure objective taste, which we deem the experience, and the following modified evaluation.

While the previous three presentations addressed the choice and the evaluation mainly using imaging techniques and behavioral responses, the fourth presentation will target the question using an alternative method, which is proven more precise yet less spatially distributed and quite invasive: directly recording of the activity of single neurons in the brains of humans undergoing neurosurgery. Moran Cerf’s presentation will demonstrate the ability to identify signature correlates of emotions similar to the work shown in the first presentation, only at the level of individual neurons. Dr. Cerf demonstrates the ability to identify single-neuron correlates of the experience and the regulation of a given emotion while patients are either empathizing with emotional content expressed, or while the patients are regulation the emotions and trying to change their evaluation of it. Regulation of the emotion will be demonstrated both using internal manipulation by the patients, or external biases of decision making as shown in the third work.

The four talks will address the ability to exhibit emotion and experiences in the lab, and scientists the ability to measure these emotions using various methods ranging from surveys, to imaging and invasive recordings of single neurons in the brains. The talks will show evidences for the differences between the direct experiences and the following evaluation of it over time, with evidence for the ability to bias decisions under certain conditions of reward or framing. Finally, the four presenters will show alternative methods used to regulate or enhance such biases and will address their potential usage in consumer psychology.

Audience and level of completeness
The potential ACR audience for this session is quite broad. This session will be of interest to researchers in the following areas: attitudes and intentions, affective and emotional processing, and decision making. In addition, it will be of interest to practitioners who use survey research methodologies, and researchers interested in exposure to imaging techniques and the novel single-neuron recording in humans.

All four presentations will present the results of completed studies.

Discussion
Moran Cerf will be the leading a discussion at the end of the session. Dr. Cerf is has been involved in both neuroscience and mar-
keting research, and has published papers in both fields as well as decision-making studies. Method-wise, his work has involved both imaging works and single-neuron recordings, which are the main methods discussed in the session. He therefore has a unique perspective for discussing these papers and leading a discussion about an appropriate research agenda for continued work in this area.

Plan for the Session
Each work will be presented for 15 minutes, followed by 5 minutes of question and answer. We will leave 15 minutes at the end for a general audience discussion.

Identifying Emotions on the Basis of Neural Activation

EXTENDED ABSTRACT

Development of reliable measures of specific emotion has proven difficult. Self-report, still the gold standard, is vulnerable to deception and demand effects. Physiological measures such as heart rate and skin conductance show some ability to discriminate between broad categories of emotion but have limited ability to make finer classifications. Facial expressions have also been used to categorize a subset of emotions, but emotions can occur in the absence of facial expressions and facial expressions can occur in the absence of emotion. Neural circuits that mediate certain emotion-related behaviors (e.g. freezing) have been identified, but researchers have yet to achieve reliable identification of emotions on the basis of neural activation. In short, existing methods of emotion measurement suffer from a variety of limitations.

Neuroimaging data has held the promise of providing more powerful methods for identifying emotions, but the promise of fMRI has yet to be realized. The search for neural correlates of emotion may have been hampered by the use of statistical methods not well suited to the task of identifying spatially-distributed activation signatures from very large data sets. Indeed, recent meta-analyses of fMRI studies using univariate analyses failed to find any region that was specifically and consistently activated by a single emotion.

Rather than search for neural structures associated with specific emotions, we applied recently developed multi-voxel pattern analysis techniques to identify distributed patterns of activity associated with specific emotions. These techniques relax linearity assumptions and acknowledge the fact that neural responses to emotional stimulation occur in many brain areas simultaneously. These algorithms frequently result in increased predictive power, and recent research suggests that they hold promise for classifying emotion using neurological and physiological data.

We applied a Gaussian Naïve Bayes pooled variance classifier to neurological data to classify a broad variety of emotional experiences. Participants were method actors experienced with entering and exiting emotional states on cue. Prior to the neuroimaging session, each wrote scenarios that had made them feel or would make them feel emotional states denoted by 18 words grouped into nine emotion categories: anger (angry, enraged), disgust (disgusted, revolted), envy (envious, jealous), fear (afraid, frightened), happiness (happy, joyous), lust (lustful, horny), pride (proud, admirable), sadness (sad, gloomy), and shame (ashamed, embarrassed). Participants also wrote a calm scenario that was used as a baseline. In the scanner, participants were given nine seconds to imagine the scenario and enter the appropriate emotional state, followed by eleven seconds to exit that state, rate their emotional intensity, and prepare for the next trial. Once this portion of the session was complete, participants viewed 12 disgusting images and 12 calm/neutral images in random order.

We first examined the ability of our classifier to identify a participant’s emotion on a particular trial on the basis of his/her neural activation during the other trials. In the cross-validation procedure used to assess emotion identification accuracy, the classifier was trained on four of the six presentations of a word and tested on the average of the two presentations held out. We report the mean rank accuracy of the classification performance, that is, the percentile rank of the correct emotion category in the classifier’s posterior-probability-ordered list of emotions, averaged across the 15 ways of choosing two of six presentations. If the classification were operating at chance level, one would expect a mean normalized rank accuracy of 0.50, indicating that the correct emotion appeared on average in the fifth position in the classifier’s output of a ranked list of all nine emotions. The rank accuracies for this within-subject analysis ranged from 0.72 to 0.90, with an average of 0.84, well above the chance classification rate of 0.5 (a mean accuracy greater than .51 would be significant at the p = .05 level). Thus, a participant’s neural activation patterns on one subset of trials could be used to reliably identify their emotions on a separate subset of held-out trials, indicating that participants exhibited consistent patterns of neural activation for all emotion categories.

Next we examined whether a participant’s specific emotions could be identified on the basis of other participants’ activation patterns. For these tests, the emotions experienced by each participant were identified using a classifier trained on the activation data from the other nine participants. Despite the challenges presented by individual variability in functional organization and methodological difficulties in normalizing morphological differences, the classifier achieved a mean rank accuracy of 0.70, well above chance levels (accuracy of 0.56 significant at the p = .01 level). Our classifier predicted the emotions experienced using activation patterns of other participants at significantly better than chance levels for eight of ten participants, suggesting that the neural correlates of emotional experience share significant commonality across individuals.

Finally, we investigated whether patterns of activation observed in self-induced emotion trials could predict the emotional content of a stimulus of an entirely different modality. We trained a classifier using participants’ neural activation during word-cued self-induced emotions, and tested whether it could identify the emotional content of a visual image. Successful classification would indicate that the activations observed correspond to emotional experience in general, rather than remembered or imagined emotional experiences specifically. This classification identified responses to disgust pictures with a rank accuracy of 0.91, well above chance rates (accuracy of 0.74 significant at the p = .01 level). Thus, even though the classifier had not encountered neural activation in response to pictures, it was able to accurately identify the emotional content of pictures. The results demonstrate a consistency in the neural representation of emotional response to qualitatively different stimuli.

In sum, we show that specific emotional states can be identified on the basis of their neural signatures, and that these signatures are reliably activated across episodes, across individuals, and across different types of emotional experiences. The results inform our understanding of emotional processes, highlight the predictive value of specific emotions, and suggest the potential to infer a person’s emotional reaction to an arbitrary stimulus — a flag, a brand name, or a political candidate, for example — on the basis of neural activation.
Risk and Attribute Framing: They’re Different

EXTENDED ABSTRACT

Framing effects occur when decision makers respond differently to problems that are described in positive or negative terms despite the fact that the outcomes are objectively identical. Framing effects are most often treated as homogenous phenomenon, though some research suggests there may be several distinctive types of frames (Levin, Schneider, and Gaeth, 1998). Two of the most common framing types that have been identified are risk and attribute framing. Risk frames involve a choice between a risky and a riskless option, and individuals typically have a higher preference for risky options when the problems are described in negative terms. In contrast, attribute frames involve evaluations where options are either risky or riskless and attribute descriptions, such as quality, are manipulated. Individuals typically give higher evaluations for options when the attributes are described in positive terms (e.g., % chance of being successful) and lower evaluations when the attributes are framed in negative terms (e.g., % chance of being unsuccessful).

Critically, these different framing effects may be caused by independent processes (Levin, Gaeth, Schreiber, 2002; Van Schie & Van der Pligt, 1995). In fact, within subject measurements of risk and attribute framing have not been significantly correlated (Levin et al., 2002). Additionally, risk framing and attribute framing correlate with different personality traits. Risk framing preference reversals correlate with high neuroticism, low openness, high conscientiousness, and low agreeableness (Levin et al., 2002). In contrast, individual differences in attribute framing correlate with low conscientiousness and high agreeableness (Levin et al., 2002). Note that though these two personality traits are correlated with risk framing as well, the correlations are in opposite directions.

There is some evidence that risk framing is associated with emotional processes (De Martino, Kumaran, Seymour, Dolan, 2006); though the evidence is mixed (Talmi, Hurlemann, Patin, Dolan, 2010). De Martino et al. (2006) found a correlation between “rational” decision making and activity in the ventromedial prefrontal cortex (VMPC). They further found that the anterior cingulate cortex (ACC) and the amygdala were involved in framing. In contrast, Talmi and colleagues (2010) did not find any differences between patients with amygdala damage and controls.

We conducted a series of behavioral and functional magnetic resonance imaging studies to investigate processing differences in risk and attribute framing using a within subject valence manipulation. The studies reported here examined (1) which personality traits were correlated with risk and attribute framing, (2) how risk and attribute framing effects were affected by emotion suppression instructions, and (3) the neural correlates of risk and attribute framing. We predicted:

Risk and attribute framing would have different personality trait correlates.

Attribute framing would be affected by emotion suppression instructions while risk framing would not be affected by emotion suppression instructions.

Risk and attribute framing would show distinct patterns of neural activation. Specifically, we predicted attribute framing effects would be more strongly associated with activity in regions of the brain such as the amygdala and VMPFC (regions associated with emotional processing) than risk framing.

Here we provide a series of studies demonstrating that independent processes likely govern attribute and risk framing.

Risk and Attribute Framing Correlate Study

Participants responded to risk and attribute framing questions as well as filling out the Big 5, and questions designed to measure their levels of risk and loss aversion. Attribute framing effects were not correlated to risk aversion, loss aversion, or any of the Big 5 personality traits (all ps > .15). On the other hand, risk framing effects were correlated with loss aversion (p < .05), neuroticism (p < .05), and numeracy (p < .05). This provides some preliminary evidence that risk and attribute framing may be caused by independent mechanisms.

Emotion Suppression Study

Participants responded to risk and attribute framing questions. Some of the participants received standard instructions to choose options they preferred the most while others received additional instructions to adopt a detached and unemotional attitude when choosing their preferred alternative. Participants in the control condition had the standard set of results. Negative risk framing increased risk seeking (p < 0.01) while negative attribute framing increased quality seeking (p < 0.05). However, results were different when participants received emotion suppression instructions. In this case, risk framing still lead to risk seeking (p < 0.01) but attribute framing did not lead to quality seeking (p = 0.41). Thus, emotion suppression did not affect risky framing but it did affect attribute framing.

fMRI Framing Study

Participants responded to risk and attribute framing questions while we measured brain activation with functional magnetic resonance imaging (fMRI). As expected, negative risk frames resulted in risk seeking (p < 0.01) while negative attribute framing resulted in quality seeking (p < 0.05). Preliminary analyses indicated the attribute framing effect was associated with activity in the amygdala and prefrontal cortex, whereas the risk framing effect was associated with activity in the parietal lobe. Moreover, there is very little overlap in activity between attribute framing and risk framing.

We provide considerable evidence that risk and attribute framing effects have different causes. We find risk framing is correlated with loss aversion, neuroticism and numeracy while attribute framing is not correlated to any of these measures. Further, we find emotion suppression affects attribute framing but not risk framing. Finally, we show risk and attribute framing have different neural correlates. Our results suggest researchers shouldn’t assume risk and attribute framing are driven by the same processes.

How Incidental Affect Alters Subsequent Judgments: Insights from a Human fMRI Study

EXTENDED ABSTRACT

People do not have stable, coherent and readily accessible preferences that can be reliably measured through self-report. Instead, judgments are constructed on the spot and recent, contextual factors exert a disproportionate influence on judgments (Payne, Bettman, and Johnson, 1992; Slovic, 1995). These contextual influences include feelings that are unrelated to the judgment (such as moods, emotions, and expectation of receiving a reward, Schwarz & Clore 1996). Why is the brain susceptible to these types of rewards that engender such changes in revealed preferences? To address this question, we discuss the impact of incidental affect on the neural representation of experienced value, an essential computation in the process of value-based decision-making.

We scanned human subjects’ brains (N=19, 6f, aged 21-46 years) using fMRI while engaging in a task that first involved the receipt of a monetary reward ($0, $50, $200) for real using a one-armed bandit task and subsequently the receipt of a food reward (two
different liked wines). During the tasting task, subjects were instructed to evaluate how much they liked the taste of each wine.

Behavioral analysis showed that the incidental rewards (i.e. amounts won from the slot machine) significantly biased participant’s judgments of how much they enjoyed the wines (F(1, 18) = 7.46, p<.01). No effect on reaction times was found.

We ran a set of different univariate fMRI analysis. First, we looked for brain areas correlating with the size of monetary reward and found that the size of incidental rewards triggered activity changes in different brain areas previously found to be involved in reward processing (i.e. vStr, dStr, amygdala, insula, inferior OFC). Second, we investigated brain areas that correlate with the size of reported experienced value (EV) and found that EV was encoded in brain areas that also have been previously found to encode EV (i.e. vmPFC, the inferior lateral OFC, anterior insula). Third, we analyzed the neural correlates of how the judgement of the consumption experience is biased by the size of the incidental reward. Interestingly, we found that incidental rewards affect EV through a negative correlation in two of the EV areas mentioned above, the insula and the inferior lateral OFC. Our own data and also previous studies could show that activity in these brain areas correlate negatively with taste pleasantness.

Our results show that incidental rewards have an effect of reported OV. Interestingly, our fmRI results reveal that incidental affect bias taste processing on an earlier stage as compared to more cognitive cues (i.e. the price of the wine, semantic label of an odor, Plassmann et al. 2008). Finally, it seems that incidental affect “make subjects dislike the wines less” instead of liking them more as compared to other papers that have looked at a cognitive modulation of OV.

**Single Neuron Correlates of Emotion Regulation In Humans**

**EXTENDED ABSTRACT**

Adult humans have the ability to regulate their emotions, an ability that emerges late in development and breaks down in some psychiatric diseases. A leading neurological model of emotional representations in the brain hypothesizes that the amygdala modulates prefrontal cortex activity by top-down influences. The basis of emotion regulation, however, has never been investigated in humans at the single neuron level. This research provides the first extensive study of what happens to the activity of individual neurons in the human brain as people experience and regulate their emotions while viewing emotional moving images.

In order to test participants’ ability to control and regulate their emotions we used a novel technique: recording the activity of single neurons directly from the brains of humans, while they were exhibiting emotions or regulating them.

Participants were 8 epilepsy patients undergoing brain surgery for possible clinical resection of the seizure foci, who agreed to participate in research studies during their hospital stay. During a clinical procedure, up to 128 electrodes were implanted in the exposed brain of each patient. These electrodes allow for the continuous recording of single neuron activity. This ability to record the brain’s activity in its highest resolution allows us to examine how thoughts and emotions are expressed using the brain’s own language of electrical spiking in individual neurons (Cerf et al., 2010; Kreiman et al., 2000; Gelbard et al., 2008) rather than imaging activity related to oxygenation in areas each containing many thousands of neurons, as in the method used in fMRI research, which is of significantly lower temporal and spatial resolution (Mukamel et al., 2005).

Participants viewed a number of short video clips, including excerpts from films, public-service ads, and political ads, intended to prompt emotional reactions. We also included neutral control clips designed not to induce emotional reactions. Participants were instructed first to view all of the clips and to let their feelings flow naturally. Following the viewing of the clips participants rated each clip on scales measuring emotion, engagement, and arousal. Next, participants were instructed to again view both the emotional and the control clips, but this time were instructed to regulate their emotions. That is, participants were instructed to suppress their positive or negative emotions such that the feelings they felt during the first viewing would not manifest during the second viewing. Patients also reported whether they had been able to successfully regulate their emotions.

In order to determine the timing of the onset and offset of emotional content in the clips, we first independently rated the clips continuously for their emotional content (positive/negative). Participants watched the clips in real-time and were instructed to rate them using a moving dial continuously. We used their ratings to estimate the moments of the onset and duration of emotional content while testing the neurological patients.

In trials where participants subjectively reported successfully regulating their emotions, we compared the spiking activity of single neurons in their brains in the two conditions. Cells in the amygdala – part of the brain which is commonly implicated with emotions, primarily negative ones such as fear and disgust – showed increased activity when participants viewed film clips during the first exposure. That is, when participants viewed the film clips naturally. However, during the second viewing, when the participants reported successful regulating of their emotions, we observed a gradual decrease in the amygdala firing over time, controlled by activity in the Orbito-Frontal Cortex (OFC), which is commonly said to be the seat of top-down executive control of emotions. These results show direct neuronal evidence for humans’ ability to regulate emotions.

Effectively, we found that neurons in the amygdala were modulated not only by emotional content in the stimuli, but also by the patients’ volitional regulating of emotions. Participants’ initial response to the stimuli occurred within an early temporal epoch, followed by a later epoch where responses were modulated by the regulation instruction, suggesting an early and mostly bottom-up response within the amygdala followed by a later response that is driven by top-down influences.

Using the activity of OFC neurons alone, we could predict a) how the content of the films affected participants (i.e., whether they would report feeling specific discrete emotions while watching the content), and b) whether they let these emotions naturally manifest, or whether they suppressed them. Decoding performance was above 90% during the first 3s of exposure to the emotional clips. Negative emotions were decoded within 1s from the onset of the emotional moment in the clip and were reflected by a change of STD above or below (dependent on the neurons excitatory or inhibitory properties) the baseline firing rate. Baseline was established during passive viewing of the screen without content.

These results should be of interest to consumer psychologists who study emotions, as they provide direct evidence of emotions in single-neuron activity in the human brain, and show the mechanisms underlying emotion regulation at the single-neuron level. The results also demonstrate the direct effect of the viewing of different types of emotional content on the human brain. They suggest that it is possible to use single-neuron activity to monitor the effect of different kinds of emotional content on consumers – whether they are reacting emotionally to the content, whether they are reacting positively or
negatively to the content, what specific emotions they are feeling, and whether they are able to control their emotional reactions.

The novel method of direct recording of neuronal activity from human brains will be of great interest to consumer psychologists, and we believe this conference is a perfect forum for exposing consumer psychologists, for this first time, to this new and unique method of measurement. We believe that this method could be used to examine a wide range of topics of interest to consumer psychologists, including how memories are formed in real-time, and how people form associations between one piece of information and another – such as a brand and its associations. Ultimately, this method can be used to examine how people form judgments and make choices in real-time, while directly examining the brain’s own coding mechanism.