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Affective traits link to reliable neural markers of incentive anticipation

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ABSTRACT

While theorists have speculated that different affective traits are linked to reliable brain activity during anticipation of gains and losses, few have directly tested this prediction. We examined these associations in a community sample of healthy human adults (n = 52) as they played a Monetary Incentive Delay task while undergoing functional magnetic resonance imaging (FMRI). Factor analysis of personality measures revealed that subjects independently varied in trait Positive Arousal and trait Negative Arousal. In a subsample (n = 14) retested over 2.5 years later, left nucleus accumbens (NAcc) activity during anticipation of large gains (+$5.00) and right anterior insula activity during anticipation of large losses (−$5.00) showed significant test–retest reliability (intraclass correlations > 0.50, p's < 0.01). In the full sample (n = 52), trait Positive Arousal correlated with individual differences in left NAcc activity during anticipation of large gains, while trait Negative Arousal correlated with individual differences in right anterior insula activity during anticipation of large losses. Associations of affective traits with neural activity were not attributable to the influence of other potential confounds (including sex, age, wealth, and motion). Together, these results demonstrate selective links between distinct affective traits and reliably-elicited activity in neural circuits associated with anticipation of gain versus loss. The findings thus reveal neural markers for affective dimensions of healthy personality, and potentially for related psychiatric symptoms.

Introduction

Early experimental psychologists suspected that the foundations of temperament lay deep within the brain (Eysenck, 1947; Gray, 1970; Pavlov, 1927; Wundt, 1897), but lacked the tools to test their theories. This persisting gap between theory and measurement prompted Gordon Allport to prophesy: "…traits are cortical, subcortical, or postural dispositions having the capacity to gate or guide specific phasic reactions. It is only the phasic aspect that is visible; the tonic is carried somehow in the still mysterious realm of neurodynamic structure" (Allport, 1966).

The development of psychometric measures allowed researchers to infer both the reliability (i.e., temporal stability) and validity (i.e., relevance to behavior) of latent affective traits (Eysenck, 1947). Factor analysis of these measures typically yields two independent dimensions associated with recurrent and intense affective states of "Positive Arousal" (i.e., positive and aroused affective experiences such as "excitement," which are associated with traits like extraversion) and "Negative Arousal" (i.e., negative and aroused affective experiences such as "anxiety," which are associated with traits like neuroticism; Russell, 1980; Watson et al., 1999). These affective states may arise during anticipation of significant but uncertain outcomes (Knutson and Greer, 2008) in order to promote adaptive approach towards opportunities and avoidance of threats (Watson et al., 1999).

Neuroimaging techniques with the capacity to resolve second-to-second changes in deep brain activity (including functional magnetic resonance imaging, or FMRI) have rekindled interest in the deep neural substrates of affective traits (e.g., Canli, 2006). Linking affective traits to neural activity requires not only reliable psychometric measures, but also reliable neuroimaging data. Studies examining the test–retest reliability of FMRI data, however, have produced mixed results (Bennett and Miller, 2010) — particularly with respect to reward-related activity (Fliessbach et al., 2010; Plichta et al., 2012).

Although some studies have explored links between reliably-assessed affective traits and brain activity, none have first established the stability of their neural measures. FMRI tasks such as the "Monetary Incentive Delay" (MID) task typically elicit robust neural activity during anticipation of monetary gains and losses in individuals. Meta-analyses of FMRI studies using these types of incentive tasks indicate that anticipation of increasing monetary gains increases nucleus accumbens (NAcc) and anterior insula activity whereas anticipation of increasing monetary losses primarily increases anterior insula activity (Diekhof et al., 2012; Knutson and Greer, 2008; Liu et al., 2011). Further, NAcc

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activity correlates with self-reported positive aroused affective states in response to large gain cues, while anterior insula activity correlates with self-reported negative or general aroused affective states in response to large loss cues (e.g., Knutson et al., 2005; Samanez-Larkin et al., 2007).

These neuroimaging findings have inspired an Anticipatory Affect Model (Knutson and Greer, 2008), which posits that while anticipation of gains elicits positive aroused affect as well as activity in relevant neural circuits (such as the NAcc), anticipation of losses instead elicits negative aroused affect as well as activity in distinct neural circuits (such as the anterior insula). By extension, we sought to determine whether affective traits would also potentiate neural activity in circuits associated with affective states. Specifically, in the context of a MID task during FMRI acquisition, we predicted that: (1) trait Positive Arousal would be associated with stable individual differences in NAcc activity during anticipation of large gains; (2) trait Negative Arousal would be associated with stable individual differences in anterior insula activity during anticipation of large losses; and (3) these associations would not depend on other individual difference confounds (e.g., sex, age, wealth).

Methods

Subjects

Subjects were initially recruited via a survey research firm to be ethnically and socioeconomically representative of San Francisco Bay Area residents. A community sample of 52 healthy right-handed native English-speaking adults (29 female; right-handed, mean age = 50 ± 16.5 SD; age range 21–75) participated in the first phase of data collection (Table 1). Subjects had no self-reported history of neurological or psychiatric disorders, and were not currently taking psychiatric or cardiac medications. Written informed consent was obtained from all subjects, under a protocol approved by the Institutional Review Board of the Stanford University School of Medicine. Beyond the 52 subjects included in the analysis, two additional subjects were excluded from further consideration due to excessive head motion (i.e., greater than 2 mm from one whole-brain acquisition to the next, both within and across runs), and a third was excluded for not completing the psychometric measures. In addition to $20.00 per hour payment for participating, additional payments were determined by the cumulative outcome of subjects' performance on the Monetary Incentive Delay (MID) task (M = $21.00 ± SD $7.00). Subjects who completed the MID task comprised a subset of those recruited for a larger study of financial decision making across the lifespan involving other tasks and measures (Samanez-Larkin et al., 2010).

A representative subset of 14 subjects from the full sample (8 female; right-handed, mean age = 41 ± 12.17 years; age range 24–70) returned for a second experimental session over 2.5 years after the first scan (mean retest interval = 922 ± 49 days). Written informed consent was again obtained from these subjects. As before, in addition to $20.00 per hour payment for participation, additional payment was determined by the cumulative outcome of the MID (M = $23.00 ± SD $5.00). Beyond the 14 subjects included in this analysis, one additional subject was excluded due to changes in medication status during the retest interval. Possibly due to the long delay, retested subjects were slightly younger than the rest of their cohort, but performed similarly (albeit slightly faster) on the experimental task during the retest session, and critically, did not differ with respect to affective traits (Table 1).

Table 1
Subject demographics and behavior.

	Test 1 (total)	Test 1 (only)	Test 1 + Test 2	Welch's *t*
Number (female)	53 (29)	38 (21)	14 (8)	0.11
Age (years)	50 ± 16.5	52 ± 16.0	41 ± 12.2	2.69*
Hit rate (%)				
+$5.00	63.97 ± 0.06	64.91 ± 0.05	67.62 ± 0.04	−1.85
+$0.50	63.72 ± 0.07	65.44 ± 0.07	63.81 ± 0.09	0.63
+$0.00	62.82 ± 0.06	63.33 ± 0.07	63.81 ± 0.10	−0.18
−$0.00	62.56 ± 0.07	62.81 ± 0.08	62.86 ± 0.11	−0.03
−$0.50	65.26 ± 0.07	65.09 ± 0.07	65.24 ± 0.04	−0.07
−$5.00	63.97 ± 0.11	64.04 ± 0.12	63.33 ± 0.04	0.30
Hit reaction time (ms)				
+$5.00	193.47 ± 21.03	195.68 ± 22.91	181.91 ± 13.97	2.61*
+$0.50	196.28 ± 21.45	198.48 ± 23.39	183.03 ± 20.19	2.34*
+$0.00	206.76 ± 24.69	209.36 ± 26.68	191.91 ± 26.01	2.13*
−$0.00	208.74 ± 27.32	213.04 ± 27.50	195.36 ± 21.78	2.41*
−$0.50	198.47 ± 25.14	200.45 ± 27.66	184.05 ± 16.18	2.63*
−$5.00	193.14 ± 21.02	195.19 ± 23.67	182.65 ± 15.71	2.20*
Traits (factor scores)				
Positive Arousal		−0.08 ± 0.98	0.22 ± 1.04	−0.95
Negative Arousal		−0.05 ± 0.97	0.13 ± 1.10	−0.53

* $p < 0.05$, uncorrected.

Affective trait measures

Subjects completed self-report measures of affective traits during the first experimental session, including the Neuroticism Extraversion Openness Five Factor Inventory (NEO-FFI; 60 items; McCrae and Costa, 2004), the Behavioral Inhibition/Behavioral Activation Scale (BIS/BAS; 20 items; (Carver and White, 1994)), and the Affect Valuation Index (AVI; 56 items; (Tsai et al., 2006)). Exploratory statistical analyses confirmed that no subject's responses deviated more than three standard deviations from the average group response. Standard subscales were derived from each measure. “Extraversion” and “neuroticism” scores from the NEO-FFI, “actual high-arousal positive” and “actual high-arousal negative” scores from the AVI, and “behavioral inhibition,” “behavioral activation-reward,” “behavioral activation-drive,” and “behavioral activation-fun” scores from the BIS/BAS scales were submitted to a principal component analysis with an orthogonal varimax rotation. A confirmatory factor analysis was conducted on the combined subscale scores of all measures to verify that their correlation structure yielded two independent affective factors. To ensure independence while minimizing corrections for multiple hypothesis tests in subsequent analyses, factor loadings on derived “Positive Arousal” and “Negative Arousal” dimensions were then used to index affective traits for each individual.

Monetary Incentive Delay task

During each testing session, subjects participated in a slightly modified version of the Monetary Incentive Delay (MID) task (i.e., with a 2 (valence) × 3 (magnitude) factorial structure) while being scanned with FMRI (Fig. 1). To accommodate older subjects, this version of the MID task included literal rather than symbolic cues and verbal as well as numerical notification of the outcome on each trial (i.e., the words “hit!” or “miss!”; Samanez-Larkin et al., 2007). Subjects received spoken and written instructions and then completed a brief practice session before beginning the experimental session in the scanner. During each task trial, subjects first viewed one of six types of cues indicating a combination of incentive valence (gain, loss) and magnitude (±$5.00, ±$0.50, ±$0.00; 2000 ms). This was followed by a fixation cross (2000–2500 ms; “anticipation” phase), after which a target was rapidly presented on the screen (~150–500 ms). If the subject pressed the button before target offset, they either gained or avoided losing the cued amount of money. Feedback indicating the trial outcome was then presented (2000 ms; “outcome” phase). Trials were separated by a variable intertrial interval (2000–6000 ms). 15 repetitions of each of the 6 trial types were presented in fully randomized order for each individual, summing to a total of 90 trials. Hit rate was targeted at 66% for each subject by an algorithm that adaptively changed target durations based on past performance within each condition. Individual functional volume acquisitions were time-locked to presentation of cues and outcomes using a temporal drift correction algorithm. Behaviorally, hit