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Look who's judging—Feedback source modulates brain activation to performance feedback in social anxiety

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It is as yet unknown if behavioral and neural correlates of performance monitoring in socially anxious individuals are affected by whether feedback is provided by a person or a computer. This fMRI study investigated modulation of feedback processing by feedback source (person vs. computer) in participants with high (HSA) (N = 16) and low social anxiety (LSA) (N = 16). Subjects performed a choice task in which they were informed that they would receive positive or negative feedback from a person or the computer. Subjective ratings indicated increased arousal and anxiety in HSA versus LSA, most pronounced for social and negative feedback. FMRI analyses yielded hyperactivation in ventral medial prefrontal cortex (vmPFC)/anterior cingulate cortex (ACC) and insula for social relative to computer feedback, and in mPFC/ventral ACC for positive relative to negative feedback in HSA as compared to LSA. These activation patterns are consistent with increased interoception and self-referential processing in social anxiety, especially during processing of positive feedback. Increased ACC activation in HSA to positive feedback may link to unexpectedness of (social) praise as posited in social anxiety disorder (SAD) psychopathology. Activation in rostral ACC showed a reversed pattern, with decreased activation to positive feedback in HSA, possibly indicating altered action values depending on feedback source and valence. The present findings corroborate a crucial role of mPFC for performance monitoring in social anxiety.

1. Introduction

Exaggerated fear of social (performance) situations and particularly negative evaluation are core symptoms of social anxiety disorder (SAD; DSM-V, American Psychiatric Association, 2013). SAD patients experience such fear persistently, intensely and chronically, often leading to avoidance of social and performance situations, difficulties with everyday activities and work, and with forming and maintaining interpersonal relationships. Lifetime prevalence of SAD has been estimated at about 12.6 % for adults in the U.S. (Kessler et al., 2005), highlighting the need for research into etiology, neural underpinnings and treatment options for this disorder.

High levels of social anxiety can also be found in non-clinical populations, suggesting that SAD and non-pathological shyness as opposite ends of a continuum for social anxiety may depend on the same dysfunctional mechanisms (Stein et al., 2000). Contemporary theories of social anxiety in non-clinical populations and SAD focus on the role of cognitive processes, specifically negative information processing biases, for maintenance of the disorder (Clark and Wells, 1995; Leary and Kowalski, 1995; Rapee and Heimberg, 1997). Individuals with high levels of social anxiety are prone to destructive interpretation particularly of negative evaluative information, anticipating social rejection and other negative consequences (Clark and Wells, 1995; Turner et al., 1992). Biased information processing is also evident in altered responses to ambiguous social stimuli and systematic underestimation of occurrence rates for positive social events (for a review, see Heinrichs and Hofmann, 2001). Furthermore, socially anxious individuals are prone to dysfunctional self-perception and self-focused processing in situations of potential social threat (Clark and Wells, 1995).

An increasing number of neuroimaging studies have taken on identifying the neural underpinnings of SAD. These studies frequently report hyperactivation in anterior cingulate cortex (ACC), amygdala, insula, prefrontal cortex (PFC), and sensory regions during processing of different types of disorder-related stimuli in SAD (e.g. Amir et al., 2005; Cooney et al., 2006; Phan et al., 2006; Stein et al., 2002; Straube et al., 2004; Straube et al., 2006). Moreover, anticipation of public speech situations, a common tool in symptom provocation, is associated with deactivation of the ventral striatum, a region crucially involved in reward processing (Boehme et al., 2013). Overall, these findings suggest that SAD involves a distributed network of brain regions contributing to emotional and threat processing as well as performance monitoring. In accordance with this, a recent study reported altered feedback processing in a sample of high socially anxious (HSA) subjects (Heitmann et al., 2014). Activation in medial prefrontal cortex (mPFC) to performance feedback was increased in HSA as compared to low socially

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anxious individuals (LSA), likely reflecting increased self-focused attention in response to feedback in social anxiety. This notion is supported by earlier findings of increased mPFC activation in response to self-referential comments in HSA (Blair et al., 2008). This is well in line with the cognitive model of social anxiety (Clark and Wells, 1995) which proposes increased self-focused attention in social situations to trigger anxiety and dysfunctional processing.

Surprisingly, only few studies have as yet investigated modulating factors for performance monitoring in SAD patients or HSA individuals. Recent findings from an electroencephalography (EEG) study with event-related potentials suggest that presence of an observer is associated with increased neural responses to performance errors in HSA subjects (Barker et al., 2015). These results emphasize the importance of the (social) context in which an action takes place for performance monitoring. Additionally, neural responses and brain activation patterns to feedback may also be modulated by feedback source. Specifically, it is as yet unclear if performance feedback is differentially processed in HSA as compared to LSA subjects depending on whether feedback is provided by a person (i.e. social feedback) or by, for instance, a computer (non-social feedback). The present functional magnetic resonance imaging (fMRI) study was aimed to scrutinize this question. HSA and LSA subjects performed a computerized choice task in which they received positive or negative performance feedback that was provided by either a person or a computer. Subsequently, outside the scanner, participants rated feedback with regard to subjective valence, arousal, and perceived anxiety. HSA subjects were expected to experience both negative and positive feedback as more negative, more arousing, and more anxiety-inducing than LSA subjects, particularly when provided by a person (social feedback). Moreover, we expected neural responses to feedback to be modulated by both feedback valence and feedback source in HSA as compared to LSA subjects. Specifically, HSA relative to LSA subjects were hypothesized to show differential activation patterns for social as compared to non-social feedback within brain regions previously implicated in SAD and in feedback processing, i.e. mPFC, ACC, amygdala, insula, and striatum.

2. Material and methods

2.1. Subjects

Participants were selected from a large volunteer database at the Institute for Biological and Clinical Psychology at the University of Jena, Germany. This database comprised 639 persons who had previously completed an online version of the Liebowitz Social Anxiety Scale (LSAS; German version; Stangier and Heidenreich, 2004) as part of a large-scale screening for social anxiety. Of these persons, 32 (age range 18 to 26 years) were selected for participation in the present study based on strict criteria in order to yield two extreme groups of subjects (N = 16 for each) that differed maximally with regard to social anxiety scores. Specifically, 16 subjects (all female) with the highest LSAS scores (≥60) were assigned to the high socially anxious (HSA) group, and 16 subjects with the lowest LSAS scores (<25), matched to the HSA group for gender and age, were assigned to the low socially anxious (LSA). Note that HSA subjects did not receive full diagnostic evaluations and thus cannot be referred to as SAD *patients*, even though LSAS scores >60 indicate symptom levels that are commonly observed in clinical samples (Mennin et al., 2002; Rytwinski et al., 2009). In order to further ensure two extreme groups with regard to social anxiety, subjects were required to complete the German version of the Social Phobia and Anxiety Inventory [SPAI; Fydrich, 2002]. For HSA subjects, SPAI scores of ≥4 were required. For LSA subjects, SPAI scores of <3.5 were required. All participants were female to ensure homogeneity within and between the two groups, and none of the subjects were students of either art or psychology, due to the stimulus material used in the experimental task and the cover story (see below). All participants were right-handed adults (according to self-report) with no history of neurological or psychiatric diseases. Subjects had normal or corrected-to-normal vision and met the general requirements for participation in fMRI studies (e.g. no ferromagnetic implants, no claustrophobia). At time of testing, participants were asked to complete the German versions of the Beck Depression Inventory [BDI, Hautzinger et al., 1995] and the Fear of Negative Evaluation [SANB; Kemper et al., 2011] questionnaire.

Mean age and mean scores on the clinical questionnaires for HSA and LSA subjects are provided in Table 1. HSA as compared to LSA subjects showed significantly higher scores for all questionnaires sensitive to social anxiety and fear of evaluation. Furthermore, BDI scores were significantly increased in HSA as compared to LSA, reaching mild clinical significance.

The present study conforms to the Declaration of Helsinki and was approved by the ethics committee of the University of Jena, Germany. Written informed consent was obtained from all subjects prior to participation. Subjects received monetary compensation or course credit for participation.

2.2. Experimental task

The task was an elaborate computerized choice task specifically designed for high personal relevance and standardized performance-related feedback. Participants were informed that the study was aimed to investigate task performance and feedback processing in task that required high levels of abstract thinking. Subjects viewed pictures of artwork and selected the alleged artist's intent from four options provided on the screen, subsequently receiving positive or negative feedback about their choice. Importantly, prior to starting the task, subjects were informed that a member of the Psychology Department had specifically selected the pictures according to unambiguity of content and wealth of information about the artists and their work in order to allow for correct and incorrect choices. In reality, pictures had been selected for ambiguity and two plausible and two rather implausible choices were provided on each trial in order to allow feedback to be standardized while still appearing performance-related to the subjects. In addition, for several pictures, one extremely unlikely response option was provided and coupled with negative feedback in case subjects wanted to "test" the task.

A schematic illustration of the time course of stimulus presentation in the task is provided in Fig. 1. On each trial, a painting was presented alongside four plausible artist intent options for 6 seconds. Participants selected an option by pressing one of four response buttons, followed by a delay phase (2 to 6 s) in which a fixation cross was presented. Subsequently, subjects received positive or negative feedback about their choice or were asked to respond faster on future trials if response time had exceeded 6 s. Feedback was represented by a letter stimulus ("R" for correct, "F" for false) that was shown centrally for 2 s. Trials ended with presentation of a fixation cross for 6 to 10 s.

Crucially, participants completed two runs of the task. In one run, participants were informed that feedback was provided by the computer based on a program that accessed information about correct and incorrect responses for each picture. In the second run, participants were informed that feedback would be provided by a person (social

Table 1
Mean age and mean scores (± standard deviation) on clinical questionnaires for high (HSA) and low socially anxious subjects (LSA)

	HSA	LSA	*t* value	*p* value
Age (years)	20.88 ± 1.93	21.75 ± 2.05	−1.244	.223
LSAS	74.88 ± 10.18	9.02 ± 5.92	22.368	<.0001
SPAI	4.69 ± 0.48	2.39 ± 0.59	12.073	<.0001
SANB	59.63 ± 8.68	37.63 ± 7.96	7.474	<.0001
BDI	14.39 ± 9.30	2.95 ± 2.76	4.701	<.0001

LSAS, Liebowitz Social Anxiety Scale; SPAI, Social Phobia Anxiety Inventory; SANB, Fear of Negative Evaluation; BDI, Beck Depression Inventory.

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