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Psychosocial versus physiological stress — Meta-analyses on deactivations and activations of the neural correlates of stress reactions

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ABSTRACT

Stress is present in everyday life in various forms and situations. Two stressors frequently investigated are physiological and psychosocial stress. Besides similar subjective and hormonal responses, it has been suggested that they also share common neural substrates. The current study used activation-likelihood-estimation meta-analysis to test this assumption by integrating results of previous neuroimaging studies on stress processing. Reported results are cluster-level FWE corrected.

The inferior frontal gyrus (IFG) and the anterior insula (AI) were the only regions that demonstrated overlapping activation for both stressors. Analysis of physiological stress showed consistent activation of cognitive and affective components of pain processing such as the insula, striatum, or the middle cingulate cortex. Contrarily, analysis across psychosocial stress revealed consistent activation of the right superior temporal gyrus and deactivation of the striatum. Notably, parts of the striatum appeared to be functionally specified: the dorsal striatum was activated in physiological stress, whereas the ventral striatum was deactivated in psychosocial stress. Additional functional connectivity and decoding analyses further characterized this functional heterogeneity and revealed higher associations of the dorsal striatum with motor regions and of the ventral striatum with reward processing.

Based on our meta-analytic approach, activation of the IFG and the AI seems to indicate a global neural stress reaction. While physiological stress activates a motoric fight-or-flight reaction, during psychosocial stress attention is shifted towards emotion regulation and goal-directed behavior, and reward processing is reduced. Our results show the significance of differentiating physiological and psychosocial stress in neural engagement. Furthermore, the assessment of deactivations in addition to activations in stress research is highly recommended.

Introduction

In everyday life we are confronted with social, cognitive or physiological stressors in various situations. Stress is a response to demands placed upon the body independent of the stressors' nature. Various stressor types that are associated with potential threat can induce stress (Selye, 1998; reprinted from 1936). The bodily stress reaction activates the hypothalamic–pituitary–adrenal gland (HPA) axis and subsequently the release of cortisol (Kirschbaum et al., 1993). The psychological homeostatic process is also altered by stress (Burchfield, 1979; Koob, 2009). Thus, the stress response is linked to a state of arousal and hypermobilization of the body's normal activation and emotion system (Hennessy and Levine, 1979; Koob, 2009). According to this view, two distinct types of stressors are physiological stress and psychosocial stress.

Physiological stress is indicated by an unpleasant sensoric, emotional and subjective experience that is associated with potential damage of body tissue and bodily threat (Peyron et al., 2000; Price, 2000; Tracey, 2005). Different bodily conditions may fulfill these criteria, e.g. pain, hunger, oxidative stress, etc. (see e.g., Colaianna et al., 2013). In the current study we will focus on pain processing as physiological stressor, for two main reasons. First, investigating pain as a physiological form of stress has a long lasting history (Lupien et al., 2007; Selye, 1998; Vachon-Presseau et al., 2013b). Second, pain processing is easily

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manipulated and therefore most frequently investigated in neuroimaging environments. Handling pain integrates sensory as well as affective processing (Price, 2000) and it has an arousing effect, increasing cortisol release and negative affect (Rainville, 2002; Vachon-Presseau et al., 2013a; Zubieta and Stohler, 2009). In neuroimaging environments, acute pain is induced by paradigms such as electric shocks or ice cold water which are known to increase cortisol and noradrenalin release.

Psychosocial stress is induced by situations of social threat including social evaluation, social exclusion and achievement situations claiming goal-directed performance (Dickerson and Kemeny, 2004; Pruessner et al., 2010). The need to be affiliated with others and to maintain the social-self are core psychological needs (Dickerson and Kemeny, 2004; Panksepp, 2003; Tossani, 2013). If the gratification of these needs is threatened, for example by a negative judgment of performance by others, then social threat and therefore stress is induced (Dickerson and Kemeny, 2004). Social evaluation as well as cognitive achievement with unpredictable outcome induce heightened cortisol responses, which are accompanied by increases in electrodermal activity, subjective stress reports and negative affect (Dedovic et al., 2009a; Dickerson and Kemeny, 2004; Eisenberger and Lieberman, 2004). Individuals having higher sensitivity towards social evaluation also express elevated cortisol response to acute stressors such as achievement tasks or social exclusion (Kirschbaum et al., 1995; Pruessner et al., 1999, 2008; Seidel et al., 2013; Somerville et al., 2010; Stroud et al., 2002).

Generally, neuroimaging studies refer to neural activations; however, studies investigating psychosocial stress also frequently report neural deactivations (Dagher et al., 2009; Dedovic et al., 2009a; Gradin et al., 2012; Pruessner et al., 2008). The interrelation between activated and deactivated neural areas is not well understood (Arsalidou et al., 2013b). Particularly, deactivations in limbic and cortical regions associated with emotion processing are reported (e.g., Critchley et al., 2000a; Moor et al., 2012; Onoda et al., 2009). However, some studies also report activations in these regions (e.g., Cacioppo et al., 2013; Eisenberger et al., 2003; Sebastian et al., 2011). Thus, inconsistent results regarding activation and deactivation have been reported, particularly in brain regions such as the hippocampus/amygdala, the anterior cingulate cortex (ACC) and prefrontal areas.

In contrast to psychosocial stress, the neural correlates of physiological stress are better characterized. Various meta-analyses of the neural correlates of pain processing identified a network of activated brain areas including primary and secondary motor and somatic regions, insula, dorsal ACC, thalamus, periaqueductal gray and prefrontal cortex (e.g., Apkarian et al., 2005; Friebel et al., 2011; Strigo et al., 2003). These regions process sensory-discriminative information as well as affective-cognitive pain properties (Tracey, 2005). Similar to psychosocial stress, specific deactivations during pain processing in emotion regulation areas such as the amygdala, nucleus accumbens and frontal regions, as well as in motor and sensoric-related areas have been reported (e.g., Aziz et al., 1997; Becerra et al., 2001; Derbyshire et al., 1997).

Taken together, pain as a physiological stressor and achievement situations and social exclusion as psychosocial stressors cause similar subjective, emotional and peripheral stress responses (e.g., Eisenberger et al., 2003; MacDonald and Leary, 2005; Mee et al., 2006; Meerwijk et al., 2013). Both psychosocial and physiological stress are associated with situations that threaten survival (Karremans et al., 2011), and both stressors alter the mesolimbic dopamine transmission in the striatum and the prefrontal cortex (Adler et al., 2000; Pruessner et al., 2008; Saal et al., 2003; Scott et al., 2006). Additionally, it has been argued that similar neural regions, such as the limbic-prefrontal circuit, are activated in processing psychosocial as well as physiological stress (Zubieta and Stohler, 2009). However, until now, this assumption has not been tested quantitatively. The primary interest of the current study lies in assessing the neural correlates of human stress responses to different stressors. In addition to neural activations, we wanted to further determine deactivations from both psychosocial and physiological stress. Therefore, the current meta-analysis set out to test whether psychosocial and physiological stress share overlapping and also distinct neural deactivations and/or activations. To do so, we used an activation-likelihood-estimation (ALE) meta-analysis approach (Eickhoff et al., 2012).

Based on previous results, we expected to find overlaps in deactivations between psychosocial and physiological stress in the amygdala, prefrontal regions and distinct somatosensory areas. Contrarily, brain regions associated with peripheral arousal, emotion processing and avoidance (e.g. prefrontal regions, insula, ACC) were suspected to be activated during both psychosocial and physiological stress.

Material and methods

Selection criteria for used data

Literature research was conducted using PubMed (www.pubmed.com) searching for combinations of the keywords: “fMRI”, “PET”, “neuroimaging”, “stress”, “achievement/cognitive stress”, “psychosocial stress”, “social exclusion”, “social stress”, “social rejection”, “ostracism”, “social pain”, “physiological stress”, “pain”, or “pain regulation”. Additional studies were identified by review articles, other meta-analyses and by tracing references from retrieved studies. Furthermore, in the case that a study did not sufficiently report the results, the corresponding authors were contacted and asked to provide more information on their data. In the following the term “experiment” refers to any single contrast analysis, and the term “study” refers to a scientific publication, usually reporting more “experiments” (Laird et al., 2011).

Only data of healthy adults (aged 18 and older) with no prior report of neurological, psychiatric or pain-related disorders were considered for the current meta-analysis, while results of patient or group effects (e.g., gender differences) were excluded. Furthermore, only neuroimaging studies which utilized either functional magnetic resonance imaging (fMRI) or positron emission tomography (PET) on a whole-brain level and reported the coordinates of brain region activation or deactivation in standard anatomical reference space (Talairach/Tournoux; Montreal Neurological Institute [MNI]) were included. We excluded articles that conducted solely region-of-interest (ROI) analyses or did not report all significant peak-voxels at a specific threshold as well as receptor-PET studies. At last, we excluded studies in which any stress type served as an independent factor affecting further cognitive domains (e.g., fear conditioning, decision making), any pharmacological/placebo studies and correlation or resting-state analyses.

For psychosocial stress we included social exclusion and rejection studies as well as studies investigating cognitive achievement under time pressure or concurrent social evaluation. For physiological stress we included paradigms manipulating pain experience (e.g., extreme heat or cold, electrical stimulation, etc.). As we focused on both activation and deactivation of brain regions during a stressful event compared to a control or baseline condition, activation peaks were defined as brain regions more strongly activated during stress than during control or baseline (stress > control/baseline) and deactivation peaks as less activated during stress compared to control or baseline (control/baseline > stress). As of January 29th, 2014, this resulted in inclusion of 43 experiments for psychosocial (26 activation/17 deactivation; $n = 1130$) and 82 experiments for physiological (69 activation/13 deactivation; $n = 967$) stress (Table 1).

Activation-likelihood (ALE) estimation

All meta-analyses were performed according to the standard analysis method used in previous studies (cf. Bzdok et al., 2012; Langner and Eickhoff, 2013; Rottschy et al., 2012). In particular, analyses were based on the revised ALE algorithm for coordinate-based meta-analysis of neuroimaging results (Eickhoff et al., 2012). This algorithm aims at identifying topographic clusters of activation/deactivation that show significantly higher convergence across experiments than expected under random spatial distributions. Importantly, the reported foci are