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Hans Eysenck's interface between the brain and personality: Modern evidence on the cognitive neuroscience of personality

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ABSTRACT

In this review, incorporating functional and structural MRI and DTI, with evidence gathered over the last 15 years, we examine the neural underpinnings of extraversion and neuroticism, the two major personality dimensions in Eysenck's (1967) biological model of personality. We present clear evidence that, as proposed by Eysenck nearly half-a-century ago, these traits relate meaningfully to the functioning and structure of various cortical and limbic brain regions. Specifically, there is a robust relationship between neuroticism and the functioning of several emotion processing networks in the brain, particularly during exposure to negative stimuli. The brain regions showing this association include a number of cortical regions implicated in emotion regulation, depression and anxiety, in addition to many sub-cortical/limbic regions. Currently, there are few studies directly assessing the relationship between extraversion and the cortical arousal system in the context of varying stimulations but data available so far are remarkably consistent with Eysenck's model. Future neuroimaging studies guided by relevant personality and cognitive theories, and with sufficient power to allow application of sophisticated analysis methods (for example, machine learning) are now needed to improve our understanding of the biological basis of individual differences and its application in the promotion of well-being and mental health.

1. Introduction

Well before the advent of modern human brain imaging, Hans Eysenck, the visionary psychologist and the most influential personality researcher in recent history, proposed a theory (Eysenck, 1967) that went beyond description and measurement of personality and, for the first time, provided the neurophysiological causes of personality. It was unique in trying to explain extraversion and neuroticism, the two major personality dimensions in Eysenck's model (the third dimension, psychoticism, added formally later in 1975), in terms of individual differences in the functioning of aspects of the central nervous system (Eysenck, 1967). Here, we review neuroimaging evidence, gathered mainly over the last 15 years, examining the association between extraversion and/or neuroticism and brain activation/connectivity patterns elicited by a wide range of cognitive and affective tasks. We have included relevant functional magnetic resonance imaging (MRI), structural MRI and diffusion tensor imaging (DTI) studies generated in the context of Eysenck's three-factor factor model as well as Costa and McCrae's five-factor personality model (Neuroticism, Extraversion, Openness to Experience, Agreeableness & Conscientiousness). There is a reasonable correspondence between the two models for extraversion and neuroticism (Costa & McCrae, 1995). We have also considered findings relating to the remaining three factors of the five-factor model as well as those relating to psychoticism, the third dimension in Eysenck's revised model (Eysenck & Eysenck, 1975), were examined within the same study, for completeness.

2. fMRI evidence

2.1. Cognitive processing

Eysenck's theory proposed that the extraversion–introversion dimension (extraversion = positive affectivity, marked by pronounced engagement with the external world and characterized by high sociability, talkativeness, energy and assertiveness) is caused by variability in cortical arousal (Eysenck, 1967). Those who score low for extraversion (introverts) have lower response thresholds and are consequently more cortically aroused than those who score high for extraversion (extraverts). It further postulated an inverted U-shaped relation between cognitive performance and 'level of arousal', jointly determined by environmental arousal potential (defined in terms of a range of environmental manipulations and task parameters) and subject arousability as reflected in

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extraversion. These postulates jointly predict that, at low environmental arousal potential, extraverts' performance would be lower than that of introverts'. As environmental arousal increases, performance of extraverts should improve and they should catch up with introverts; and, at high levels of environmental arousal, extraverts should out-perform introverts with a decline in introverts' performance, until it becomes so arousing as to evoke transmarginal inhibition (TMI) (Eysenck, 1994; Gray, 1964). With evocation of TMI, introverts may experience lower arousal increments than extraverts. There is considerable support for these predictions from behavioral studies (Eysenck, 1981). Eysenck's model further postulated that level of arousal, resulting from a combination of environmental arousal and subject arousability, is mediated by activity in a 'cortical arousal system', modulated by reticulo-thalamic-cortical pathways (Eysenck, 1967, 1981). A circuit that seemingly corresponds to this cortical arousal system, including the dorsolateral prefrontal cortex (dlPFC) and anterior cingulate regions, has been identified in studies applying fMRI to a wide range of cognitive tasks (Duncan & Owen, 2000). Importantly, findings of an fMRI study (Kumari, ffytche, Williams, & Gray, 2004), the only one so far to test the predictions concerning extraversion and cortical activity at different cognitive loads (or stimulation levels), are remarkably consistent with Eysenck's model. Specifically, this study showed that the higher the extraversion score, the greater the change in fMRI signal in the dlPFC and anterior cingulate from rest (through 1- and 2-back) to the 3-back working memory load condition. Furthermore, also consistent with Eysenck's model, which treats neuroticism and psychoticism dimensions as independent of extraversion, the relationship between extraversion and dlPFC and anterior cingulate activity was not found for neuroticism or psychoticism in Kumari et al.'s (2004) study.

Concerning neuroticism, Eysenck proposed that the neuroticism-stability dimension (neuroticism = negative affectivity, marked by emotional instability and low tolerance for stress or aversive stimuli, and characterized by anxiety, fear, moodiness, worry, envy, frustration, jealousy, and loneliness) is explained by differences in the level of activity primarily in the limbic system (Eysenck, 1967). Perhaps not surprisingly, most existing fMRI studies have examined the effects of neuroticism in implicit or explicit affect processing, emotion regulation, fear/anxiety stress induction paradigms (reviewed and discussed in the next section) rather than with pure cognitive paradigms. A very recent study, which examined the effects of personality using the five-factor model, found that decreased and increased effective connectivity within the working memory network, activated by a 3-back working memory task, were associated with high neuroticism and high conscientiousness, respectively (Dima, Friston, Stephan, & Frangou, 2015). Although these findings show a significant effect of personality in neuroplasticity, their interpretation is rather difficult because neuroticism and conscientiousness had opposite effects. The effects of conscientiousness, however, appear consistent with possible extraversion effects, since conscientiousness correlates positively with extraversion when assessed using the Eysenckian scales (Costa & McCrae, 1995). Notably, extraversion itself, as in the five-factor model, did not have any influence in this study.

An important line of enquiry in relation to fMRI of neuroticism using cognitive (and other) paradigms is indicated by experimental evidence showing greater trial-to-trial variability in cognitive performance (particularly reaction time) of high neuroticism scorers, relative to low neuroticism scorers (Robinson & Tamir, 2005). This behavioral effect may reflect task-irrelevant cognitions such as worries and preoccupations in neurotic individuals. Moment-to-moment brain signal variability is also known to be present in neuroimaging studies and has important implications for fMRI activation and connectivity studies (Garrett et al., 2013). Interestingly, moment-to-moment brain signal variability correlates with less, rather than more, reaction time variability across various paradigms and samples (Garrett, Kovacevic, McIntosh, & Grady, 2011; McIntosh, Kovacevic, & Itier, 2008; Misic, Mills, Taylor, & McIntosh, 2010; Raja Beharelle, Kovacevic, McIntosh, & Levine, 2012). Despite a highly likely influence of neuroticism in this phenomenon, given its known association with reaction time variability, no published study has yet examined the effect of neuroticism in moment-to-moment/trial-to-trial variability in brain activations.

2.2. Affect

One of the great challenges faced by the human mind is the need to comprehend the content of other minds. Thus a rapidly increasing literature has sought to explore the psychological and neural mechanisms behind "the mental operations that underlie social interactions, including perceiving, interpreting, and generating responses to the intentions, dispositions, and behaviors of others" (Green et al., 2008), namely 'social cognition'. One of the most fundamental means we have of making these inferences is the emotion cues that other people display. However, individual differences associated with personality traits are a key influence on the way we perceive and respond to emotion cues (Britton, Ho, Taylor, & Liberzon, 2007). Indeed, our personality, whether we tend to be shy or outgoing, anxious or contented, has a major influence on our lives and the way we interact with the world around us (Hamann & Harenski, 2004). For example, highly neurotic individuals preferentially respond to negative emotion cues, and highly extravert individuals preferentially respond to positive emotion cues (Canli et al., 2001). Personality has these effects because it comprises an integrated pattern of thinking, feeling and behaving that varies between individuals but is relatively stable within individuals over time (Suslow et al., 2010). These chronic affective styles associated with personality tune the affective system to be more sensitive towards one class of cues than to another (Cunningham, Arbuckle, Jahn, Mowrer, & Abduljalil, 2010; Fruhholz, Prinz, & Herrmann, 2010). Beyond their everyday implications for understanding normal socio-cognitive behavior, neuroticism and extraversion are of great importance as trait dimensions, because of the implications for individual vulnerability for emotion-related psychopathologies such as anxiety and mood disorders (Brandes & Bienvenu, 2006; Foster & MacQueen, 2008; Gale et al., 2011; Keller, 2004; Klein, Kotov, & Bufferd, 2011; Wright, Kelsall, Sim, Clarke, & Creamer, 2013).

Adoption of cognitive neuroscience techniques undoubtedly facilitates a clearer understanding of how personality influences the way people react to emotion cues. It has even been said by some that neuroimaging might prove superior to behavioral or cognitive paradigms in characterising the effects of personality dimensions on reactivity to emotion cues (Harenski, Kim, & Hamann, 2009). The thinking here is that whereas behavioral and cognitive indices represent the combined effects of all brain activity components during a task, neuroimaging can isolate specific aspects of neural reactivity as being influenced by specific personality dimensions. Although some psychological determinants of individual variability in emotional reactivity have been determined at the behavioral level, research has only recently begun to explore the brain mechanisms that might enable this individual variability (Canli et al., 2001). This is because most prior neuroimaging studies have taken a group-based approach, in which the mechanism that determines emotional reactivity is studied in a group of healthy individuals not preselected for any specific criteria (Calder, Ewbank, & Passamonti, 2011; Hamann & Canli, 2004). Here the effect of individual differences on emotion perception at the neural level is frequently ignored or dismissed as statistical noise (Calder et al., 2011; Canli, 2004; Hamann & Canli, 2004). Yet these individual differences can exhibit remarkable stability within participants, suggesting that they are not random fluctuations, and that they relate to traits that are different between, but consistent within, individuals (Canli, 2004). With a correlational approach, individual differences in neural reactivity do not represent noise, rather they represent valuable signal that can reveal much about aspects of brain function of fundamental value to the study of social cognition (Canli & Amin, 2002; Hamann & Canli, 2004).

Since the trait of neuroticism involves enhanced processing of negative emotion cues (Canli et al., 2001), one way of establishing the