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Gray matter correlates of creative potential: A latent variable voxel-based morphometry study

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ABSTRACT

There is increasing research interest in the structural and functional brain correlates underlying creative potential. Recent investigations found that interindividual differences in creative potential relate to volumetric differences in brain regions belonging to the default mode network, such as the precuneus. Yet, the complex interplay between creative potential, intelligence, and personality traits and their respective neural bases is still under debate. We investigated regional gray matter volume (rGMV) differences that can be associated with creative potential in a heterogeneous sample of $N = 135$ individuals using voxel-based morphometry (VBM). By means of latent variable modeling and consideration of recent psychometric advancements in creativity research, we sought to disentangle the effects of ideational originality and fluency as two independent indicators of creative potential. Intelligence and openness to experience were considered as common covariates of creative potential. The results confirmed and extended previous research: rGMV in the precuneus was associated with ideational originality, but not with ideational fluency. In addition, we found ideational originality to be correlated with rGMV in the caudate nucleus. The results indicate that the ability to produce original ideas is tied to default-mode as well as dopaminergic structures. These structural brain correlates of ideational originality were apparent throughout the whole range of intellectual ability and thus not moderated by intelligence. In contrast, structural correlates of ideational fluency, a quantitative marker of creative potential, were observed only in lower intelligent individuals in the cuneus/lingual gyrus.

Introduction

Creativity has become a topic of increasing interest to cognitive and neuroscientific psychology (Dietrich and Kanso, 2010). In a world changing more rapidly than ever before, the ability to come up with creative new ideas is of extraordinary importance to cultural development and the progress of human civilization. While creativity has long been considered a dark and nebulous phenomenon that is reserved to eminent geniuses and cannot be subject to population-based studies, an emerging line of research triggered by Guilford's (1950) influential ideas has begun to demystify both the creative process and the creative person. Creative idea generation is now viewed as a common cognitive process that is of relevance to many areas of everyday life (e.g. Silvia et al., 2014) and creative potential is known to reflect a normally distributed trait just as any other mental ability (Eysenck, 1995). Yet, the neuroscientific investigation of creativity is still in its infancy and much work needs to be done in order to gain a deeper understanding of the creative brain (Abraham, 2013; Arden et al., 2010; Dietrich and Kanso, 2010; Fink and Benedek, 2014a,b; Sawyer, 2011).

Creative potential as a cognitive marker of real-life creativity

Creative potential is usually defined as the ability to produce something *novel* and *useful*, also known as the "standard definition of creativity" (Runco and Jaeger, 2012, p. 92; see also Barron, 1955; Stein, 1953). This ability can be assessed by means of divergent thinking tests, which have proved to be reliable and valid indicators of a person's creative potential (e.g., Benedek et al., 2014b; Benedek et al., 2013; Runco and Acar, 2012; Silvia et al., 2008). A common divergent thinking task is the alternate uses task that asks participants to find many uncommon and creative uses for objects of daily use (e.g., a can). Individuals differ with respect to their abilities to produce a high *quantity* (ideational fluency) and a high *quality* (ideational originality) of ideas in these tasks. Both, quantitative and qualitative indicators were found to have predictive validity with respect to real-life creative accomplishments across different domains including music, arts, or science (Jauk et al., 2014). Creative potential is known to be associated with openness to experience (Batey and Furnham, 2006; Feist, 1998, 2010; Nusbaum and Silvia, 2011a) and intelligence (Batey and

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Furnham, 2006; Kim, 2005; Nusbaum and Silvia, 2011b). Moreover, the creativity–intelligence relationship was found to be moderated by the intelligence level, which is referred to as *threshold effect* (Guilford, 1967). Intelligence may be relevant for creative potential up to an above-average IQ but loses its impact thereafter (Jauk et al., 2013; Karwowski and Gralewski, 2013). Thus, intelligence can be conceived a cognitive prerequisite of creative potential. In other words, above-average intelligence forms a necessary, but not sufficient condition for high creative potential. Openness, in contrast, may influence creativity even at fairly high levels of IQ (Jauk et al., 2013).

Functional brain mechanisms underlying creative idea generation

EEG studies of divergent thinking processes generally show that EEG alpha power is indicative of creative idea generation (Fink and Benedek, 2014a). Increased alpha power is assumed to reflect a state of internally focused attention that facilitates processes of semantic search and imagination involved in the generation of new ideas (Benedek et al., 2011; Benedek et al., 2014d). Functional MRI studies of divergent thinking revealed, among others, activation in the left inferior and superior frontal gyri and inferior parietal regions such as the angular gyrus (Abraham et al., 2012; Benedek et al., 2014c; Fink et al., 2009; for a recent meta-analysis, see Gonen-Yaacovi et al., 2013). These results point to a central role of (prefrontal) executive as well as (parietal) memory-related processes that are known to be crucial for the fluent production of novel ideas from behavioral research (Beaty et al., 2014b; Benedek et al., 2012; Nusbaum and Silvia, 2011b; Silvia et al., 2013). Studies using research paradigms other than divergent thinking, however, could not yet reveal consistent results, which is most likely due to the variety of employed tasks and measures (Arden et al., 2010; Dietrich and Kanso, 2010; Fink and Benedek, 2014a; Sawyer, 2011).

Brain structural correlates of creative potential

Although there exists converging evidence on the functional mechanisms underlying creative idea generation, it remains an intriguing question whether individual differences in creative potential relate to differences in brain *structure*. In one of the first studies, Jung et al. (2010) found negative correlations between creative potential (originality) and cortical thickness in several, mostly right-hemispheric regions including posterior areas such as the cuneus and the inferior parietal cortex; only one positive association was observed in the right posterior cingulate cortex. Takeuchi et al. (2010) used voxel-based morphometry (VBM) to identify volumetric differences related to creative potential. They found positive correlations between regional gray matter volume (rGMV) and creative potential scores in the right dorsolateral prefrontal cortex, bilateral striate, a cluster including midbrain structures, and regions in the precuneus; no negative relationships were reported in this study. Both, Jung et al. (2010) and Takeuchi et al. (2010) used participant's sex, age, and general intelligence as covariates in their regression models to control for possible influences of these variables. However, the results of the different structural parameters (cortical thickness and rGMV) cannot be directly compared to each other. A recent study reported significant correlations between verbal creative potential and rGMV in the bilateral inferior frontal gyri (Zhu et al., 2013). The effects were also controlled for sex, age, general intelligence, and additionally total gray matter volume. Fink et al. (2014a) investigated regional gray matter density correlates of different indicators of verbal creative potential, namely ideational fluency and ideational originality as well as a combined fluency/flexibility score (i.e., number of responses and number of different categories these responses belong to). They found that ideational originality correlated positively with density in the right cuneus while the fluency/flexibility score showed correlations in the right precuneus and cuneus. No significant effects were observed for the pure fluency score. Similar to Zhu et al. (2013), participant's age, sex, general intelligence, and total intracranial volume were considered as covariates. Similarly, Kühn et al. (2014) found structural correlates of ideational originality in the precuneus (albeit in the left hemisphere), the ventromedial prefrontal cortex, and also the left insula and the right temporo-parietal junction. Another study examining visual creative potential reported associations with right-parietal rGMV (Gansler et al., 2011).

As Jung et al. (2013) conclude in their recent review, one of the most striking findings across morphometric studies of creative potential is that many of the regions repeatedly reported belong to the default mode network (DMN; Gusnard and Raichle, 2001; Raichle and Snyder, 2007). Three out of four studies investigating verbal creative potential by means of VBM reported positive associations between indicators of creativity and brain structre in the precuneus. The precuneus was also found to be *functionally* involved in divergent thinking (Benedek et al., 2014c; Fink et al., 2010, 2012) and metaphor generation (Benedek et al., 2014a). Specifically, it was observed that the precuneus, which – as part of the DMN – is usually deactivated during cognitive tasks, shows weaker deactivation in high- as compared to low-schizotypic individuals during creative cognition (Fink et al., 2014b). In a similar vein, highly creative individuals show reduced deactivation in the precuneus during a working memory task (Takeuchi et al., 2011). These findings conform to the notion that the precuneus is involved in internally guided attention (Cavanna and Trimble, 2006); a process closely associated with creativity (Fink and Benedek, 2014a).

While intelligence was considered a covariate of no interest in most of the studies reported above, one study explicitly addressed the role of intelligence as a moderator of the brain–creativity-relationship: Jung et al. (2009) conducted a magnetic resonance spectroscopy study and found that IQ level moderates the relationship between creative potential and the concentration of *N*-acetyl-aspartate (NAA), a marker of neuronal integrity. The authors interpret their findings in terms of increased left-hemispheric functioning in higher intelligent people, which might facilitate access to left-hemispheric semantic networks. To date, however, no study examined whether intelligence may also moderate the relationship between creative potential and brain *structure* in terms of rGMV.

The present research

This study investigates rGMV correlates of creative potential by means of voxel-based morphometry. Creative potential can be assessed by different indicators. We used scores of ideational fluency and originality in order to account for both quantitative as well as qualitative indicators of creative potential. Moreover, these measures were shown to have discriminant validity given an adequate scoring that avoids the confounding influence of fluency (Benedek et al., 2013; Jauk et al., 2014; Silvia et al., 2008).

While VBM is considered a highly reliable method (Jung et al., 2013), the tests commonly used to assess creative potential sometimes show low reliability (Arden et al., 2010; Dietrich and Kanso, 2010). Therefore, we use structural equation modeling (SEM) to obtain latent factors of ideational fluency and originality based on an extended set of six divergent thinking tasks. SEM allows accounting for measurement error in observed variables in order to obtain “true” scores of the underlying psychological constructs. Latent scores help to overcome common pitfalls in psychometric research (cf. Silvia, 2008) and can be used as powerful predictors in neuroimaging studies (cf. Colom et al., 2013). Finally, we included intelligence and openness to experience as covariates since they are known to be correlated with creative potential. Considering the influence of these relevant covariates allows determining gray matter effects that are specific to creative potential.

Given the often inconsistent findings regarding the neuroscience of creativity (Arden et al., 2010; Dietrich and Kanso, 2010) and of neuroscientific findings in general (Uttal, 2012), an attempt of replication and extension of previous findings using state-of-the-art methods is considered a powerful and necessary means toward establishing dependable empirical evidence. Taking into account evidence from