Neural correlates of the “good life”: Eudaimonic well-being is associated with insular cortex volume

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Abstract

Eudaimonic well-being reflects traits concerned with personal growth, self-acceptance, purpose in life, and autonomy (among others), and is a substantial predictor of life events, including health. While interest in the etiology of eudaimonic well-being has blossomed in recent years, little is known of the underlying neural substrates of this construct. To address this gap in our knowledge, here we examined whether regional gray matter volume was associated with eudaimonic-wellbeing. Structural MR images from 70 young, healthy adults who also completed Ryff’s 42-item measure of the six core facets of eudaimonia were analysed with voxel-based morphometry techniques. We found that eudaimonic well-being was positively associated with right insular cortex gray matter volume. This association was also reflected in three of the sub-scales of eudaimonia: personal growth, positive relations, and purpose in life. Positive relations also showed a significant association with left insula volume. No other significant associations were observed, although personal growth was marginally associated with left insula, and purpose in life exhibited a marginally significant negative association with middle temporal gyrus gray matter volume. These findings are the first to our knowledge linking eudaimonic well-being with regional brain structure.

**Keywords:** gray matter volume; insula; psychological well-being; eudaimonia; personal growth; purpose in life; positive relations
Introduction

Recent years have seen a blossoming interest in the origins of human well-being and happiness (Seligman & Csikszentmihalyi, 2000). Within the broader positive psychology literature, a distinction is commonly made between subjective (or hedonic) well-being, and eudaimonic (or psychological) well-being (Ryan & Deci, 2001). Subjective well-being reflects positive emotional functioning (Diener, 1984). Eudaimonic well-being, in contrast, is more closely linked to human potentials: aspects of life relating to flourishing and character development (Ryff, 1989; Waterman, 1993). Although substantial interest has been directed at delineating the consequences of eudaimonia (Ryff, 1989), to date, limited work has examined this construct within a neuroscientific framework (Kringelbach & Berridge, 2009). This is unfortunate as this approach offers the possibility of important insights into the underlying biological bases of this trait. Here we sought to address this gap in the literature by examining whether regional gray matter volume was associated with eudaimonia in a large sample of young, healthy adults.

Eudaimonic Well-Being: A Brief Outline

Aristotle (1925/1998) distinguished between the experience of pleasure (i.e. hedonia) and the notion of a “virtuous activity of [the] soul” (p. 18), or eudaimonia. In this model, eudaimonia was thought of as the conscious and life-long active exercise of intellect and character virtues. Contemporary models of eudaimonia have developed these Aristotelian foundations, incorporating insights from research on human development detailed in the work of scholars such as Erikson, Allport, and Maslow (Ryff, 1989). This research led to the most widely used measure of eudaimonia: The 6-factor Ryff Scales of Psychological Well-being. These correlated
scales assess autonomy, personal growth, self-acceptance, purpose in life, environmental mastery, and positive relations with others, forming a superordinate eudaimonia factor (Ryff & Singer, 2006). This 6-factor model captures the qualities of belonging and benefiting others, flourishing, thriving and exercising excellence, although notably it omits some intellect qualities, character traits and values that Aristotle (1925/1998) would have emphasized, including wisdom, bravery, generosity, and justice. Several studies have supported the psychometric bases of this 6-factor model (cf. Ryff & Singer, 2006; but also see Springer & Hauser, 2006).

Eudaimonic well-being is increasingly recognized as an important domain of individual differences (Ryff, 1989; Ryff, 1995). For instance, both eudaimonic well-being and its facets are heritable (Archontaki, Lewis, & Bates, 2012), and low eudaimonia acts a risk factor for depression (Wood & Joseph, 2010). Low eudaimonic well-being has also been linked to poor physical health and with biomarkers linked to health (Ryff, Singer, & Dienberg Love, 2004; Ryff et al., 2006): In a large sample of elderly US women, eudaimonic well-being was predictive of lower levels of cardiovascular risk, pro-inflammatory cytokines, and daily salivary cortisol levels, and with longer duration REM sleep (Ryff, Singer, & Dienberg Love, 2004). Of interest, these associations are largely independent to those observed for subjective well-being suggesting a distinct pattern of biomarkers reflects eudaimonia.

**Neural Correlates of Eudaimonia**

Although much attention has been directed towards the origins of human well-being (both subjective and eudaimonic: Seligman & Csikszentmihalyi, 2000), little work to date has directly addressed the neural bases of eudaimonia. The first and only study directly examining neural correlates of eudaimonic well-being found evidence for an association with the frontal
cortex activity: greater left than right superior frontal cortex activation (measured using electroencephalography) is associated with eudaimonic (and hedonic) well-being (Urry et al., 2004). No study (to our best knowledge) has utilized MRI techniques to characterize structural or functional correlates of eudaimonia; however, several studies have identified structural correlates (gray matter volume) of depressive symptoms (in turn, negatively associated with eudaimonic well-being: Wood & Josephs, 2010), including insular cortex (Bechdolf et al., 2012; Hwang et al., 2010; Sprengelmeyer et al., 2011), amygdala (Sheline, Gado, & Price, 1998; von Gunten, Fox, Cipolotti, & Ron, 2000; but see Frodl et al., 2002), and hippocampus (Campbell, Marriott, Nahmias, & MacQueen, 2004). There is some basis, then, for speculating that these regions may reflect variation in eudaimonic well-being.

In addition to these empirical findings, Kringelbach and Berridge (2009) have suggested that neural regions associated with the “default network” (Buckner, Andrews-Hanna, & Schacter, 2008; Gusnard, Raichle, & Raichle, 2001) – specifically, the anterior cingulate cortex, orbitofrontal cortex, and medial prefrontal cortex – may be related to eudaimonic well-being, on account of links from the default network to representations of self (Lou et al., 1999) and internal modes of cognition (Buckner et al., 2008): these cognitive processes are closely analogous to the characteristics ascribed to eudaimonia. Finally, Archontaki et al. (2012) recently noted that the mechanism underlying eudaimonia must be capable of exerting control across all facets of eudaimonia, implying a top-down control mechanism over multiple systems processing emotional, reward-incentive, and motivational information related to eudaimonic well-being. Although several cortical regions are active during self-control activity, right ventrolateral prefrontal cortex activation (rVLPFC) is present regardless of domain (Cohen & Lieberman,
2010), leading Archontaki et al. (2012) to hypothesize links from this region to eudaimonic well-being.

The Current Study

As noted above, little work to date has examined the neural bases of eudaimonic well-being. To address this gap in the literature, here we examined whether regional gray matter volume was associated with the general factor of eudaimonia, as well as the six eudaimonia subscales. Such neuroanatomical studies, as noted above have yielded novel links between gray matter volume and a broad range of psychological traits – including traits with clear relevance for eudaimonic wellbeing such as depressive symptoms (Bechdolf et al., 2012; Hwang et al., 2010; Sprengelmeyer et al., 2011) and mindfulness (Hölzel et al., 2008) – and so presented as a plausible approach for delineating the neural architecture of eudaimonic well-being. We analyzed structural MRI volumes collected from a sample of healthy, young adults (n = 70) using voxel-based morphometry (VBM) methods to assess whether differences in regional brain structure correlated with individual differences in eudaimonic well-being. In line with limited prior work in this literature, and several brain regions linked to traits of relevance to eudaimonic well-being, we elected to conduct whole-brain analyses so as to provide a more conservative test of neuroanatomical associations with eudaimonia (see Methods for full details).
Methods

Participants

Seventy healthy participants (42 females; mean age = 24.6 ± 3.76 years) were recruited from the local community of University College London. The study was approved by the local ethical committee and written informed consent was obtained from all participants.

Eudaimonic Well-Being Measures

Eudaimonic well-being was assessed using the 42-item Ryff Scales of Psychological Well-being (Ryff et al., 2007). The six scales (and an example item for each scales) are as follows: Autonomy: “I tend to be influenced by people with strong opinions”; Environmental mastery: “I am quite good at managing the many responsibilities of my daily life”; Personal growth: “I think it is important to have new experiences that challenge how you think about yourself and the world”; Positive relations with others: “People would describe me as a giving person, willing to share my time with others”; Purpose in life: “Some people wander aimlessly through life, but I am not one of them”; and Self-acceptance: “In many ways I feel disappointed about my achievements in life” (reverse-scored). All responses were made on 7-point scales (from 1: strongly agree, to 7: strongly disagree). Scale scores were computed as the sum of relevant items, reversing items where appropriate. Most of the sub-scales exhibited adequate reliability ($\alpha$s = .64 (autonomy), .67 (mastery), .52 (personal growth), .76 (positive relations), .76 (purpose in life), .89 (self-acceptance)). A latent factor of “eudaimonia” was derived as the first principle component extracted from the 6 sub-scales: This latent factor explained 58.34% of total variance and showed moderate-to-high positive loadings on each of the sub-scales (all > .55).
MRI Data Acquisition

MR images were acquired on a 1.5-T Siemens Sonata MRI scanner (Siemens Medical, Erlangen, Germany). High-resolution anatomical images were acquired using a T1-weighted 3-D Modified Driven Equilibrium Fourier Transform (MDEFT) sequence (TR = 12.24 ms; TE = 3.56 ms; field of view = 256 x 256 mm; voxel size = 1 x 1 x 1 mm).

Voxel-based Morphometry (VBM)

The MR images were first segmented for gray matter (GM) and white matter (WM) using the segmentation tools in SPM8 (http://www.fil.ion.ucl.ac.uk/spm). Subsequently, we performed Diffeomorphic Anatomical Registration Through Exponentiated Lie Algebra (DARTEL) in SPM8 for inter-subject registration of the GM images. To ensure that local gray matter volumes were conserved after spatial transformation, the image intensity of each voxel was modulated by the Jacobian determinants of the deformation fields. Registered images were then smoothed with a Gaussian kernel (FWHM = 8 mm) and transformed to MNI stereotactic space using affine and non-linear spatial normalisation implemented in SPM8 for multiple regression analysis.

The gender and age of the participants as well as whole-brain gray matter volume were included as covariates in the design matrix, thus regressing out effects correlated with these variables. As noted above, because little prior work facilitated targeted hypotheses we remained largely agnostic with regards to specific regions, instead focusing our analyses on the whole brain. We therefore analysed the data using a mask volume that comprised the entire brain with the exception of the cerebellum, which was thus excluded from analysis. The mask volume was constructed from a probabilistic MNI structural atlas (Mazziotta et al., 2001). Within this mask volume, clusters were initially identified as contiguous groups of voxels that exceeded an
uncorrected threshold of voxel-wise $p < 0.001$. We employed a threshold of $p(\text{corr}) < 0.05$ corrected for multiple comparisons across the entire mask volume at a cluster level using non-stationary correction (Hayasaka, Phan, Liberzon, Worsley, & Nichols, 2004) to identify regions in which gray matter volume correlated significantly with eudaimonia scores.

**Results**

Eudaimonia was positively and significantly correlated with the gray matter volume of right insular cortex ($p(\text{corr}) = 0.03, r = .47, t(65) = 4.33$; see Table 1 and Figure 1). No clusters exhibited significant (corrected) negative correlations with eudaimonia.

Within the subscales of the eudaimonia measures, the following associations were found. Purpose in life, positive relations, and personal growth scores all showed positive correlations with right insular cortex volumes ($p(\text{corr}) = 0.02, r = .46, t(65) = 4.23$; $p(\text{corr}) = 0.04, r = .51, t(65) = 4.76$; and $p(\text{corr}) = 0.05, r = .48, t(65) = 4.38$, respectively).

In addition to these links with right insula volume, positive relations and personal growth scores were also positively correlated with left insular cortex volume ($p(\text{corr}) = 0.04, r = .50, t(65) = 4.63$; and $p(\text{corr}) = 0.07, r = .45, t(65) = 4.09$, respectively). Finally, purpose in life showed a marginal negative correlation with middle temporal gyrus ($p(\text{corr}) = 0.08, r = -.44$, respectively).
t(65) = 4.00). No other associations between eudaimonia subscales and regional gray matter volume exceeded the corrected threshold used here.

**Discussion**

The current study found evidence for a positive association between gray matter volume in the right insular cortex and eudaimonic well-being in a large sample of young, healthy adults. These links with right insular cortex volume were also reflected in positive associations with several facets of eudaimonic well-being; namely, personal growth, positive relations, and purpose in life. Positive relations and personal growth also exhibited positive associations with left insular cortex at nominal and marginally significant levels, respectively.

Although insular cortex has not been explicitly linked to differences in eudaimonic well-being in previous theorising, the current results are broadly consistent with prior research showing a negative association between insula volume and depression (Bechdolf et al., 2012; Hwang et al., 2010; Sprengelmeyer et al., 2011): The finding that low levels of eudaimonia are associated with increased risk of depressive symptoms (Wood & Josephs, 2010) suggests that eudaimonia and depression may share important biological links. In addition, eudaimonia is fundamentally linked to notions of agency (Waterman, 1993), and recent work has identified insular cortex as a source of agentic control (Lee & Reeve, 2012). The insula has also been linked to facilitation of self-awareness (Craig, 2009), as well as to the regulation of bodily states and modulation of decision-making based on interoceptive information about these bodily states (Singer, Critchley, & Preuschhoff, 2009). Additional linkages to the guidance of behavior have also been postulated, based on activation of insular cortex during the segregation of internal and external stimuli for their relevance and subsequent incorporation in the active guidance of
behavior (Menon & Uddin, 2010). Finally, mindfulness meditation, a trait with prima facie links to eudaimonia, has been associated with right insular cortex gray matter volume (Hölzel et al., 2008).

This set of higher-order functions attributed to the insula are not mutually exclusive. Indeed, jointly, they closely reflect the multi-faceted psychological description of eudaimonia as reflected in high levels of self-awareness, self-reflection, and cognitive and emotional control in the service of dynamic goal selection and goal pursuit, and self governance and reflection (Ryff, 1995). In sum, then, insula cortex may facilitate eudaimonic well-being by generating a set of capacities which jointly act to integrate interoceptive states with external circumstances, and successfully manage this emotional milieu. Nonetheless, it should be recalled that the insula is implicated in many functions (cf. Craig, 2009; Menon & Uddin, 2010; Singer et al., 2009) and thus further work is required to confirm the mechanism by which insular cortex and eudaimonia are linked.

Specific limitations and recommendations for future work require mention. Firstly, the current study did not control for subjective (hedonic) well-being, which is moderately associated with eudaimonic well-being (Ryff & Keyes, 1995): As such, we cannot conclude that insula cortex is a unique correlate of eudaimonia, over and above neural bases of subjective well-being, and future work should address this shortcoming. Secondly, although the current results provide insight into the neural bases of eudaimonic well-being, the data cannot speak to causal directions; that is, the present data are unable to establish whether greater insular cortex facilitates eudaimonia, or if greater eudaimonic well-being causes increased insula gray matter volume. Longitudinal studies addressing development and change in cortical structure (Hedman, van Haren, Schnack, Kahn, & Hulshoff Pol, 2011) will be helpful to address this question. Some
work to date has addressed this issue, examining the influence of mindfulness meditation on structural changes in insula and hippocampus (Hölzel et al., 2011); however, this work failed to find changes following such interventions in insular cortex (although such changes were observed in hippocampus).

In summary, we provide evidence that gray matter volume in the right insular cortex, a brain region with links to, depression, as well as to interoception and control over bodily states (among other behaviours), is positively associated with eudaimonic well-being. These findings provide initial evidence of individual differences in brain structure showing links to an important psychosocial trait with links in turn to mental and physical health.
Acknowledgements

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References


Table 1. Summary of gray matter volume associations with eudaimonia and eudaimonia sub-scales.

<table>
<thead>
<tr>
<th>Moral Foundation</th>
<th>Area</th>
<th>H</th>
<th>MNI coordinates of peak voxel</th>
<th>Correlation (Pearson’s r)</th>
<th>t(65)</th>
<th>Cluster size (voxels)</th>
<th>p(corr)</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eudaimonia</td>
<td>Insula</td>
<td>R</td>
<td>39</td>
<td>5</td>
<td>-14</td>
<td>.47</td>
<td>4.33</td>
</tr>
<tr>
<td>Personal growth</td>
<td>Insula</td>
<td>R</td>
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<td>15</td>
<td>-11</td>
<td>.48</td>
<td>4.38</td>
</tr>
<tr>
<td></td>
<td>Insula</td>
<td>L</td>
<td>-33</td>
<td>6</td>
<td>-2</td>
<td>.45</td>
<td>4.09</td>
</tr>
<tr>
<td>Positive relations</td>
<td>Insula</td>
<td>R</td>
<td>-39</td>
<td>-1</td>
<td>-8</td>
<td>.51</td>
<td>4.76</td>
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<tr>
<td></td>
<td>Insula</td>
<td>L</td>
<td>39</td>
<td>3</td>
<td>-14</td>
<td>.50</td>
<td>4.63</td>
</tr>
<tr>
<td>Purpose in life</td>
<td>MTG</td>
<td>R</td>
<td>63</td>
<td>3</td>
<td>-23</td>
<td>-.44</td>
<td>4.00</td>
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<tr>
<td></td>
<td>Insula</td>
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Note: p(corr) denotes the p values corrected for multiple comparison at the cluster level across the volume of interest (see Methods for details). Significant results are denoted by * (p ≤ 0.05, corrected); n.s. indicates non-significant results; MTG = middle temporal gyrus; H = hemisphere; L = left; R = right.
Figure 1. Regions where gray matter volume was associated with eudaimonia are overlaid on a T1-weighted standard MNI template; t values are overlaid for regions that showed significant positive correlation in the VBM analyses (see the main text and Table 1). The color bar illustrates the corresponding t values.