Personality traits are associated with cortical development across adolescence: A longitudinal structural MRI study

Lia Ferschmann[1], Anders M. Fjell[1], Margarete E. Vollrath[2, 3], Håkon Grydeland[1], Kristine B. Walhovd[1], and Christian K. Tamnes[3]

[1]Center for Lifespan Changes in Brain and Cognition, Department of Psychology, University of Oslo, Norway

[2]Department of Psychosomatics and Health Behaviour, Norwegian Institute of Public Health, Oslo, Norway

[3]Department of Psychology, University of Oslo, Norway

Correspondence concerning this article should be addressed to Lia Ferschmann, Department of Psychology, University of Oslo, PB 1094 Blindern, 0317 Oslo, Norway. Electronic mail may be sent to lia.ferschmann@psykologi.uio.no

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Abstract

How personality traits relate to structural brain *changes* in development is an important, but understudied question. In the present study, cortical thickness (CT) and surface area (SA), estimated using magnetic resonance imaging (MRI) were investigated in 99 participants aged 8 to 19 years. Follow-up MRI data were collected after on average 2.6 years for 74 individuals. The Big Five personality traits were related to longitudinal regional CT or SA development, while limited cross-sectional relations were observed. Conscientiousness, Emotional Stability and Imagination were associated with more age-expected cortical thinning over time. The results suggest that the substantial individual variability observed in personality traits may partly be explained by cortical maturation across adolescence, implying a developmental origin for personality-brain relations observed in adults.

Keywords: Brain development, Adolescence, Personality

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Personality traits refer to broad dimensions of human individuality, i.e. individual differences in how one typically thinks, feels and acts, which are relatively stable across situations from childhood to adulthood as well as throughout adulthood (McAdams & Pals, 2006; Wängqvist, Lamb, Frisén, & Hwang, 2015). The most widely accepted taxonomy for personality traits in children and adults, and across cultures has been the Five Factor Model [FFM (Digman, 1990; McCrae & Costa, 1997)] which proposes five broad factors: Neuroticism, Extraversion, Openness to Experience, Agreeableness and Conscientiousness.

Genetic, environmental and cultural factors guide the development and expression of personality (Vukasović & Bratko, 2015), and brain structure is one possible mediator of these manifold influences (Yarkoni, 2015). It is well established that traumatic brain injuries, and lesions and atrophy caused by neurodegenerative diseases are associated with personality trait changes (Cipriani, Borin, Del Debbio, & Di Fiorino, 2015; Norup & Mortensen, 2015). Neuroimaging techniques such as magnetic resonance imaging (MRI) have enabled the study of brain-personality relations in healthy individuals. Despite the growing number of neuroimaging studies of personality traits, very few have investigated samples of youths (Blankstein, Chen, Mincic, McGrath, & Davis, 2009). Consequently, little is known about the neuroanatomical correlates of personality traits in childhood and adolescence, periods characterized by marked developmental changes in neural architecture (Walhovd, Tamnes, & Fjell, 2014). Structural MRI studies conducted with adults have revealed associations between personality traits and cortical thickness [CT; (Holmes et al., 2012; Rauch et al., 2005; Riccelli, Toschi, Nigro, Terracciano, & Passamonti, 2017; Wright et al., 2006)], surface area [SA; (Bjørnebekk et al., 2013; Riccelli et al., 2017)], brain volumes (Coutinho, Sampaio, Ferreira, Soares, & Gonçalves, 2013; Cremers et al., 2011; DeYoung et al., 2010; Forsman, de Manzano, Karabanov, Madison, & Ullén, 2012; Jackson, Balota, & Head, 2011; Kapogiannis, Sutin, Davatzikos, Costa, & Resnick, 2013), and white matter microstructure (Bjørnebekk, Westlye, Fjell, Grydeland, & Walhovd, 2012; Lewis et al., 2016; Westlye, Bjørnebekk, Grydeland, Fjell, & Walhovd, 2011). These studies show inconsistent results which may be attributed to factors such as small sample sizes, or methodological and statistical model differences (Allen & DeYoung, 2015; Hu et al., 2011).

Current knowledge would greatly benefit from longitudinal studies including children and adolescents. Longitudinal designs have several strengths; they inform about intraindividual change, facilitate stronger inferences about developmental processes, and may extend or clarify initial findings generated by cross-sectional studies (Brown, 2017; Horga, Kaur, & Peterson, 2014). Such studies could potentially cast light on the ontogeny and temporal dynamics of personality-brain relations. Additionally, most of the existing studies on cortical structure have investigated volume, which is the product of CT and SA of the cortex. There are good reasons to consider CT and SA separately. Their relative contribution to volume is complex which makes interpretation of volumetric studies challenging (Winkler et al., 2010), and they are largely genetically independent (Panizzon et al., 2009) and differentially associated with neurodevelopment and disease (Winkler et al., 2017). Across adolescence, CT shows widespread regionally heterogeneous reductions with increasing age, while SA shows relatively smaller developmental decreases (Tamnes et al., 2017; Wierenga, Langen, Oranje, & Durston, 2014), see Supporting Information for more details on surface area development. Distinct features of these cortical measures imply they may relate to personality traits differently. Indeed, Riccelli et al. (2017) demonstrated that CT and SA were inversely related to each other as a function of personality traits in adults. Cross-sectional studies of healthy adults point to patterns of inverse relations between SA and CT, i.e. cortical stretching whereby SA increases relate to cortical thinning (Hogstrom, Westlye, Walhovd, & Fjell, 2012). However, longitudinal changes in SA and CT and their relations show more complex regional and topological patterns of associations across adolescence (Tamnes et al., 2017).

The present study investigated relations between personality traits and CT and SA in children and adolescents. First, we tested age-independent associations cross-sectionally, using MRI data from time point 1 (TP1). Second, we assessed how personality traits were related to longitudinal changes in cortical structure by calculating annual percentage change (APC) between time points. Additionally, we explored age effects in these relations due to the large age range of the sample. Although this study was primarily exploratory, several hypotheses were made. We hypothesized that Emotional Stability would be positively related to frontotemporal SA and Conscientiousness would be positively associated with SA in lateral temporal lobe regions, as found in adults (Bjørnebekk et al., 2013; Riccelli et al., 2017). We also expected Extraversion to be associated with larger SA in orbitofrontal cortex (OFC). Positive associations between this trait and OFC volumes have been reported previously (Cremers et al., 2011; DeYoung et al., 2010). Although voxel- and surface-based studies are difficult to compare, SA more closely relates to volume than CT (Winkler et al., 2010). Furthermore, we hypothesized that higher Emotional Stability would be linked to thicker medial prefrontal and cingulate cortices, as found in adults (Holmes et al., 2012). Based on previous research on adolescents (Dennison et al., 2015; Urošević, Collins, Muetzel, Lim, & Luciana, 2012; Vijayakumar et al., 2014a), we hypothesized that higher scores on Emotional Stability, Conscientiousness and Extraversion would be associated with greater developmental change in SA and CT.

Method

Participants

Participants were drawn from the longitudinal study *NeuroCognitive Development, s*ee Supporting Information for details on recruitment, informed consent and how eligibility criteria were ascertained. Eligibility criteria included right handedness, fluency in Norwegian, normal or corrected to normal hearing and vision, term birth, no history of injury or disease known to affect the central nervous system (CNS), no history of treatment for mental disorders, no current medication known to affect CNS, and absence of MRI contraindications. A senior neuroradiologist evaluated all MRI scans at both time points, and only participants free of significant injury or conditions were included in the study.

At TP1, 99 participants [54 females, age mean 14.2 (*SD* = 3.3) years, age range 8.3-19.7 years] met the eligibility criteria, had parent-reported personality measure, and MRI data deemed satisfactory after quality control (see below), and were thus included in our cross-sectional analyses. At time point 2 (TP2), these participants were invited to a follow-up MRI scan. See Supporting Information for details on attrition. The longitudinal sample included 74 participants [37 females, age mean 14.0 (*SD* = 3.3) years, age range 8.4-19.4 years] with the parent-reported personality measure at TP1 and MRI from TP1 and TP2. The mean interval between TP1 and TP2 was 2.6 years (*SD* = 0.2, range = 2.4-3.2), which neither correlated with age *(r* = -.05, *p* = .704), nor differed between males and females (*t* = 0.70, *p* = .493). Independent samples *t*-tests were conducted to assess group differences between participants with TP1 and TP2 data and those who dropped out (*n* = 25, 17 females). No significant differences between completers and dropouts were observed (Supplementary Table 1). General cognitive ability was assessed using the Wechsler Abbreviated Scale of Intelligence (WASI). Supplementary Table 2 provides demographic and intellectual characteristics of the cross-sectional and the longitudinal samples.

Measures

Personality Assessment. Personality traits were assessed using the parent-report version of the Hierarchical Personality Inventory for Children [HiPIC; (Mervielde & De Fruyt, 1999)]. This 144-item observer-based inventory has been deemed suitable for personality assessment in children and adolescents (Shiner & Caspi, 2003), and repeatedly provides valid and reliable measurements (Mervielde & De Fruyt, 2002; Watt, Hopkinson, Costello, & Roodenburg, 2016), including in Norway (Vollrath, Hampson, & Torgersen, 2016). The HiPIC has concurrent validity with the NEO-PI-R (De Fruyt, Mervielde, Hoekstra, & Rolland, 2000), and yields dimension scores for traits that closely resemble the FFM (see Supporting Information for details on the HiPIC); Imagination (corresponding to Openness), Benevolence (similar to Agreeableness), Emotional Stability (corresponding to low Neuroticism), Conscientiousness, and Extraversion. Cronbach's alphas for the five broad trait scales were satisfactory (Supplementary Table 3).

General Cognitive Ability. General cognitive ability was assessed using the Wechsler Abbreviated Scale of Intelligence [WASI; (Wechsler, 1999)].

Cortical Structure. At TP1 and TP2, MRI data were collected using the same 12-channel head coil on the same 1.5 T Siemens Avanto scanner (Siemens Medical Solutions, Erlangen, Germany). The pulse sequence used for morphological analyses was a 3D T1-weighted magnetization prepared rapid gradient echo. MRI acquisition and processing are described in more detail in the Supporting Information. Briefly, CT and SA were first estimated for each scan independently on a point-by-point (vertex-wise) basis across the surface using the FreeSurfer image analysis suite version 5.3 (http://surfer.nmr.mgh.harvard.edu/), described in detail elsewhere (Fischl, 2012). Second, the longitudinal sample was processed with the longitudinal stream in FreeSurfer 5.3. Longitudinal change in CT and SA were calculated on a point-by-point basis across the surface as APC, i.e. the annual rate of change with respect to the average SA and CT across the time points. Surface maps for CT and SA, as well as APC for each measure, were smoothed with a Gaussian kernel of full-width at half-maximum of 15 mm. This relatively high kernel was chosen because we did not expect very localized effects.

Statistical Analyses

Sex differences in personality traits were tested with independent samples t-tests and relations between personality traits, age, and general cognitive ability were tested with Pearson's bivariate correlations. Considering the dearth of past studies on associations between personality traits and cortical structure in developmental samples, analyses were not restricted to a priori hypothesized regions, but instead, a whole-brain point-by-point approach across the cortical surface was applied to minimize type II errors. Analyses were performed vertex-wise using general linear models (GLMs) in FreeSurfer. First, the cross-sectional data (n=99) from TP1 were used to investigate the relations between personality traits and CT and SA. This step involved fitting separate GLMs of the effects of each personality trait on CT and SA at each vertex, controlling for sex, age and their interaction. Second, the longitudinal data (n=74) were used to investigate the relations between personality traits at TP1 and APC in CT and SA. Before performing these analyses, we tested whether the APC rates in CT and SA were significantly different from zero when controlling for sex, and whether the observed structural cortical development in our sample replicated previous findings in this age range, e.g. work by Wierenga et al. (2014). GLMs were then performed to examine the effects of each personality trait on APC of CT and SA separately, while controlling for age, sex and their interactions. To describe and illustrate effect sizes, we extracted SA and CT respectively from identified significant clusters and performed multiple regression analyses with each personality trait, age and sex. To test if effects were independent of cognitive ability, we reran these analyses with cognitive ability measured at TP1 as a covariate. Finally, using both cross-sectional and longitudinal data, we tested whether brain-personality trait relations differed as a function of age by including the interaction term age × personality. To minimize the risk of type I error, all analyses on cortical measures were tested against an empirical null distribution of maximum cluster size across 10,000 iterations using Z Monte Carlo simulations in FreeSurfer (Hagler, Saygin, & Sereno, 2006; Hayasaka & Nichols, 2003), synthesized with a cluster-forming threshold of $p < 0.05$ (two-sided), yielding clusters fully corrected for multiple comparisons across the surfaces. Clusterwise corrected $p < 0.05$ (two-sided) was regarded significant.

Results

Personality Traits, Sex and Age

Sample characteristics for the five personality traits are summarized in Supplementary Table 4. There were no significant sex differences in these traits, neither in the cross-sectional sample nor in the longitudinal sample. Correlations between personality traits, age and general cognitive ability are presented in Supplementary Table 5. Age was negatively correlated with Extraversion and general cognitive ability was positively correlated with Imagination.

Cross-sectional analyses: Personality traits, CT and SA

Independent of age, vertex-wise surface analyses yielded significant relations between personality traits and SA in three clusters (Figure 1, Supplementary Table 6). Specifically, Emotional Stability was positively associated with SA in two clusters in the left temporal lobe; one in the posterior inferior temporal lobe and one in the temporal pole, while Benevolence was negatively associated with SA in a cluster in the right occipital lobe. No significant relations were found for CT. Relations between SA and Extraversion and Imagination, respectively (Supplementary Figure 1, Supplementary Table 7), and between CT and Benevolence and Imagination, respectively (Supplementary Figure 2, Supplementary Table 8), differed as a function of age in regions other than the ones where main effects were identified.

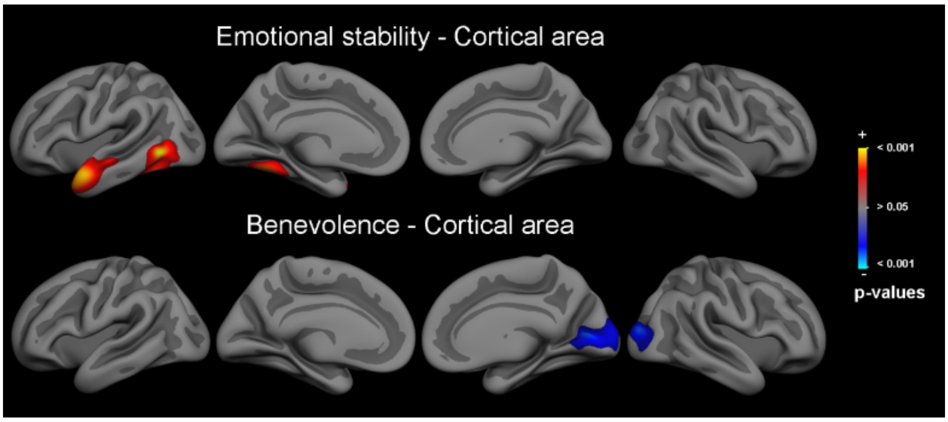

Figure 1. Personality traits and SA at TP1. Uncorrected p values within the corrected significant clusters are shown.

Longitudinal analyses: Personality traits and cortical development

Analyses of longitudinal cortical development showed widespread significant cortical thinning and SA reductions, and minimal increases with increasing age (Supplementary Figure

3). Maps showing mean APC for CT and SA illustrate how the change rates varied across the cortex; however, they exceeded -0.5% in many regions for both measures. Overall, more widespread and greater changes were observed for CT than for SA.

The effects of personality traits on APC in CT showed negative associations for Conscientiousness, Emotional Stability and Imagination in multiple clusters (Figure 2, Supplementary Table 9). Conscientiousness was related to more negative APC in CT in the superior parietal cortex in the left hemisphere, and in dispersed parietal and frontal regions in the right hemisphere. Emotional Stability was negatively associated with APC in CT in the superior frontal cortex in the left hemisphere and in multiple frontal and lateral temporoparietal regions in the right hemisphere. Finally, Imagination was negatively associated with APC in CT in the postcentral gyrus in the right hemisphere.

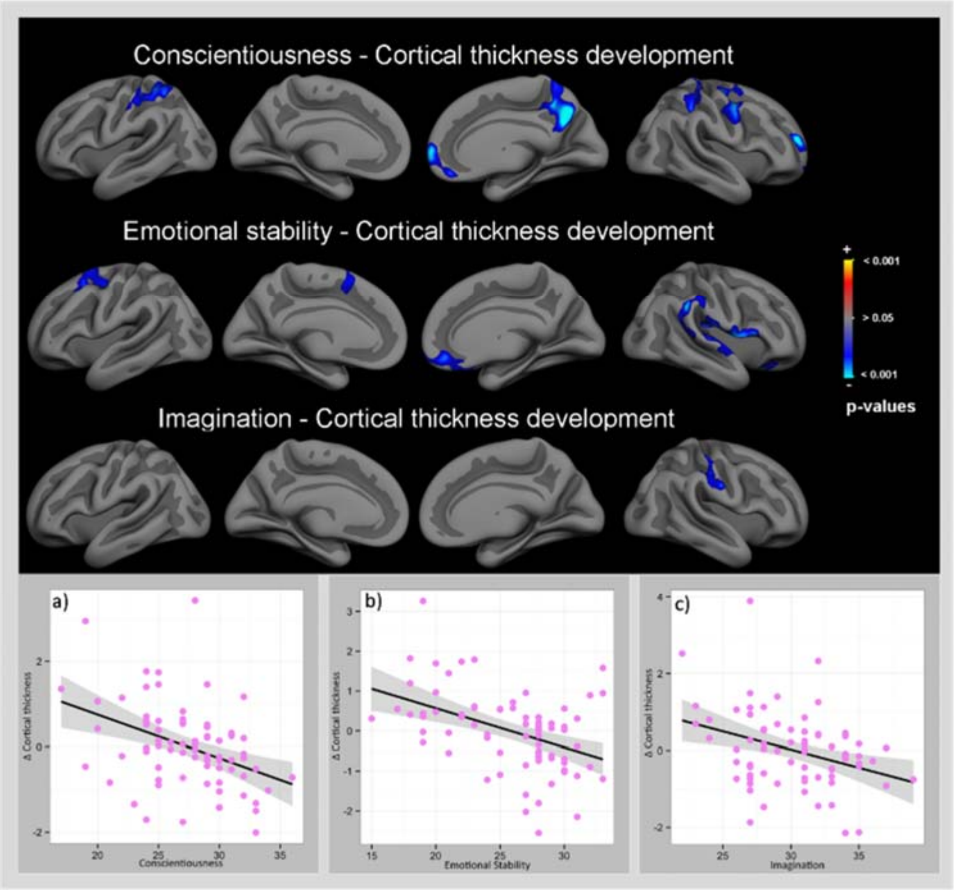

Figure 2. Personality traits and APC in CT. Uncorrected p values within the corrected significant clusters are shown. For each analysis, average APC in CT across significant regions was calculated and relations with (a) Conscientiousness, (b) Emotional Stability, and (c) Imagination are illustrated in plots showing raw data (in contrast to the statistical analyses, where age and sex were included as covariates). Shaded area represents 95% confidence interval.

No significant age and sex independent associations were found between the other personality traits and APC in CT. Supplementary Table 10 presents details on effect sizes. Note that the betas are inflated because they are based on already-identified significant clusters from the previous surface-based analyses.

The effects of personality traits on APC in SA showed associations for Benevolence, Conscientiousness and Extraversion in several clusters (Figure 3, Supplementary Table 9). Benevolence was positively related to APC in SA in the left postcentral gyrus, meaning that high scores were associated with less SA reductions. Conscientiousness and APC in SA was found to be positively related in a small cluster in left lateral occipital lobe and negatively related in a cluster in the right medial occipital lobe. Finally, Extraversion was positively related to APC in SA in the superior parietal cortex in the right hemisphere. No significant age and sex independent associations were found between the other personality traits and SA. Supplementary Table 11 shows details on effect sizes. Also in this case, caution is warranted when interpreting the reported beta values as they are based on already-identified significant clusters.

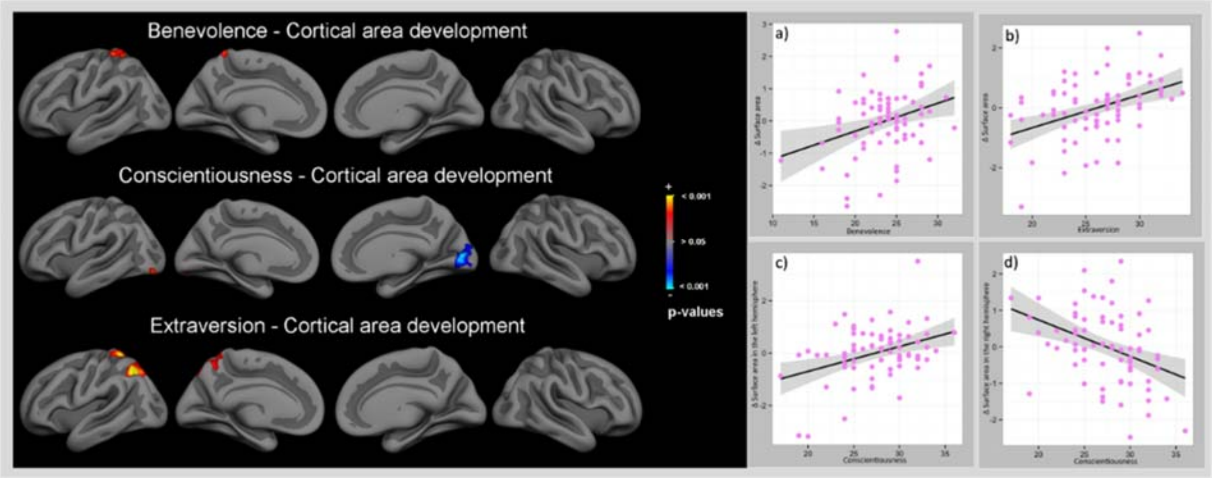

Figure 3. Personality traits and APC in SA Uncorrected p values within the corrected significant clusters are shown. Within significant regions, relations between (a) Benevolence and area expansion, (b) Extraversion and area expansion, (c) Conscientiousness and area expansion, and (d) Conscientiousness and area contraction are illustrated in plots showing raw data (in contrast to the statistical analyses, where age and sex were included as covariates). Shaded area represents 95% confidence interval.

Relations between CT change and Conscientiousness, Emotional Stability, Extraversion and Imagination (Supplementary Table 12, Supplementary Figure 4), and relations between SA change and Conscientiousness, Extraversion and Imagination (Supplementary Table 13, Supplementary Figure 5) differed as a function of age in regions other than those where main effects were identified. Finally, general cognitive ability as an additional covariate did not change the relations between personality traits and CT or SA (Supplementary Tables 14 and 15).

Discussion

The current study investigated relations between personality traits and both cortical structure and its longitudinal development in a sample of children and adolescents. All five HiPIC personality dimensions were associated with regional structural cortical development over time, while limited cross-sectional relations were observed. Given that numerous studies have investigated personality-brain structure associations in adults, our study enriches existing knowledge by providing insight into the ontogeny and temporal dynamics of these relations by examining these relations in younger and longitudinal samples. Furthermore, exploring these associations in young samples may inform broader developmental questions because personality traits not only predict major life outcomes and individual levels of general functioning (Ozer & Benet-Martinez, 2006; Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007), they are also risk factors for a range of psychiatric disorders (Krabbendam et al., 2002).

We controlled for age (and sex) in our cross-sectional analyses, as it is reasonable to hypothesize age-independent associations might reflect not only individual differences, but also developmental variability, i.e. variability in the phase of brain maturation among adolescents of similar age (Jernigan, Baaré, Stiles, & Madsen, 2011). We found that, independent of age and sex, Emotional Stability was positively associated with SA in temporal cortical regions in the left hemisphere, which aligned with our hypothesis based on past research on adults (Bjørnebekk et al., 2013; Riccelli et al., 2017). Reduced SA in temporal cortices have also been identified in adolescents with mood disorders (Schmaal et al., 2016) suggesting that at least some associations found in adults or clinical groups are observable already in children and adolescents. However, it should be noted that Neuroticism represents a much broader trait than depression, and likely serves as a general risk factor for internalizing disorders (Griffith et al., 2010). In contrast to studies of adults, Emotional Stability was not linked to SA in frontal cortices in the present study.

Moreover, Benevolence was negatively associated with SA in a region in the right occipital lobe. Past studies have identified negative associations between Agreeableness and gray matter volume in occipital areas; this may reflect the role of visual regions in processing of social stimuli although it is unlikely that occipital areas alone are implicated in Benevolence (Coutinho et al., 2013; Kapogiannis et al., 2013). Overall, these findings correspond with work (Vuoksimaa et al., 2016) demonstrating that relatively greater SA in evolutionally and developmentally high-expanded areas are associated with positive developmental outcomes, whereas the opposite holds for low-expanded areas. In our study, relatively larger SA in lateral temporal cortices (high-expanded area) was associated with higher Emotional Stability, while relatively smaller SA in occipital cortices (low-expanded area) was related to higher Benevolence.

None of the five personality traits showed age-independent associations with CT. This contrasts with previous results on adults, some of which have reported links between CT and Neuroticism, Extraversion, Openness and Conscientiousness (Bjørnebekk et al., 2013; Holmes et al., 2012; Riccelli et al., 2017; Wright et al., 2006). The relative lack of cross-sectional findings in the current study may be due to the study's sample size or because it can be more difficult to detect such relations in samples of youth with wide age ranges. Another explanation, although speculative, pertains to the possible bidirectionality of the brain-personality relations. Brain structure is likely to predict personality traits. However, it is also possible that certain personality traits influence both life style factors and the individual's environments, which in turn can affect brain structure. Support for the latter is mixed (Booth et al., 2014; Westlye et al., 2011), and it is reasonable to assume that these effects would be more prevalent over time in adults than in children and adolescents whose choices are to a larger extent restrained by their guardians.

In some cortical regions, both SA and CT relations with personality traits differed as a function of age. For example, younger individuals high on Benevolence and Imagination had thicker cortices in several regions, while older children high on these traits had thinner cortices. This may be interpreted as faster rate of cortical thinning in individuals with high scores on Benevolence and Imagination. Indeed, greater cortical thinning in individuals with higher scores on Imagination was also found in our longitudinal data, albeit not in the same cortical regions.

Our longitudinal analyses of MRI data tested whether personality traits were associated with structural cortical development over time. Background analyses showed widespread and pronounced cortical thinning with increasing age across adolescence and comparably smaller decreases in SA, strongest in sulcal regions. Although clear inconsistencies exist across studies on cortical development (Walhovd, Fjell, Giedd, Dale, & Brown, 2016), the present longitudinal results were in accordance with the majority of the existing studies. Longitudinal analyses yielded more substantial results than cross-sectional analyses, and showed that all five personality traits were associated with cortical development. Benevolence and Extraversion were positively associated with development of SA in parietal regions, while Conscientiousness showed both positive and negative associations with change rates in SA in occipital regions. Overall, these relations were identified in only a few and not very large clusters which may be related to the short interval between scans and relatively smaller changes in SA compared with CT in this age range (Tamnes et al., 2017), i.e., longer intervals may be necessary to register more substantial associations between personality traits and SA development.

The most compelling longitudinal results were found for Conscientiousness, Emotional Stability, Imagination, and CT development, with these traits being associated with a greater rate of cortical thinning in multiple regions. Higher scores on these personality traits predicted more age-expected cortical thinning over time. Apart from Imagination, which was an unexpected finding, these results were in line with our hypotheses. Emotional Stability was related to cortical thinning in the right superior temporal cortex, as well as in several prefrontal regions. Interestingly, CT in these areas was found to positively relate to Neuroticism in adults in Riccelli et al.(2017), but not in Holmes et al. (2012). Although not directly comparable, previous studies have linked delays and slower rate of cortical maturation in these regions to symptoms of anxiety and depression in healthy young individuals and those with major depression (Ducharme et al., 2014; Schmaal et al., 2016). Moreover, attenuated development in adolescence, albeit in subcortical structures, has previously been associated with depression onset (Whittle et al., 2014). It is possible that highly neurotic adolescents demonstrate slower rate of cortical maturation resulting in thicker cortex in these brain regions in adulthood. Furthermore, higher scores on Conscientiousness were related to greater cortical thinning in medial and lateral prefrontal cortices, as well as in a few other regions, particularly the precuneus. Prefrontal regions are involved in processes required for goal-directed behavior (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Precuneus, a functional hub of the default mode network, plays an important role in many higher-order functions (Utevsky, Smith, & Huettel, 2014). This structure has also been implicated in intentional causality; referring to causal links between one’s own intentions and actions (Den Ouden, Frith, Frith, & Blakemore, 2005), which also may be essential for planning and execution of goal-directed behavior. Additionally, longitudinal studies on adolescents have related superior performance in cognitive control (Vijayakumar et al., 2014b), a concept related to Conscientiousness (Fleming, Heintzelman, & Bartholow, 2015), to greater cortical thinning of the right anterior cingulate cortex. Finally, Imagination, the only personality trait consistently associated with measures of intelligence (DeYoung & Gray, 2009), was negatively related to the CT change in the right postcentral gyrus. It has previously been suggested that steeper cortical thinning, albeit primarily in frontal regions, may be associated with higher intelligence scores (Shaw et al., 2006). Despite the links between Imagination and estimated general cognitive ability, the effect held even after including IQ as a covariate, which points to a unique contribution of the broader Imagination domain.

Overall, children and adolescents with higher levels of Emotional Stability, Imagination and Conscientiousness showed regionally more rapid rate of cortical thinning. It is tempting to conclude that exaggeration of the patterns associated with normative brain structural development is adaptive. Although some studies lend support to this notion (Dennison et al., 2015), others (Vijayakumar et al., 2014b) point out that specific patterns of cortical development, e.g., increases or decreases in CT in particular periods, may be related to specific developmental outcomes. Indeed timing, e.g., delays rather than complete deviation from normal cortical development, may be crucial for developmental outcomes (Ducharme et al., 2014). Moreover, these associations may depend on the brain area in question (Vuoksimaa et al., 2016); changes in one direction may be adaptive in some regions, but the opposite may be true for other regions. Finally, individual differences in size of particular brain structures at young ages may be predictive of later development (Cheetham et al., 2017). Future studies need to address these aspects of cortical maturation in relation to personality traits.

Finally, the relations between both CT and SA development and personality traits differed as a function of age in several cortical regions. For example, higher scores on Conscientiousness, Emotional Stability and Imagination were all associated with more pronounced cortical thinning in older children as opposed to attenuated thinning in younger children. Taken together, the main effects and interaction effects suggest that anatomical location and timing of structural changes may play role in behavioral outcomes.

Limitations

The current study has several limitations. First, personality traits were measured only at TP1. Even though personality traits are relatively stable in childhood and adolescence, they are more likely to change earlier than in adulthood (Shiner & Caspi, 2003). Second, the personality measure used in this study was a parent-report instrument which may be prone to biases, e.g. the desirability bias (Haines, Neumark-Sztainer, Hannan, & Robinson-O'Brien, 2008). However, personality research often depends on observer-reports because younger children may lack cognitive skills needed to make accurate judgments regarding their own personality (Barenboim, 1981; De Fruyt & Vollrath, 2003). Third, we used the parent report version of the HiPIC which has only been validated for children up to age 14 (Hopkinson, Watt, & Roodenburg, 2014; Vollrath et al., 2016), while many of our participants were older. A self-report version exists for older adolescents, but mixture of self- and parent-report data could have introduced a systematic bias. Fourth, longitudinal changes in CT and SA were measured in terms of APC over two time points, a commonly used approach. Other methods for modeling longitudinal data such as mixed-effect regression models or generalized estimating equation models are available (Gibbons, Hedeker, & DuToit, 2010). However, since we only had two time points, and we wanted to differentiate cross-sectional and longitudinal effects, APC was preferred over mixed effects models. Moreover, relating personality traits with the local gyrification index and its longitudinal changes is potentially highly interesting, but was beyond the scope of the current study. Furthermore, it is possible that the study was underpowered due to a relatively small sample size. Low statistical power can undermine the ability to detect true effects, but also cause inflation of statistically significant effects (Allen & DeYoung, 2015). Especially for the cross-sectional results, power is an important issue which may explain the relatively few cross-sectional findings in this study, as well as the partial discrepancy between the effects reported in the present study and what has been reported in previous studies on adults. Longitudinal studies may in some instances require smaller sample sizes to obtain sufficient statistical power (Steen, Hamer, & Lieberman, 2007). Still, we encourage readers to interpret the results with these limitations in mind, and the conclusions should be confirmed with analyses of independent samples.

Conclusion

The current study showed that all five major personality traits were related to longitudinal structural cortical development, either to changes in CT or in SA, across adolescence. In contrast, only a few age-independent associations were observed between personality traits and concurrent cortical measures. These results suggest that the large individual variations in personality traits may partly be related cortical maturation across adolescence, and imply a developmental origin for personality-brain relations previously observed in adults.

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Supporting Information

Participants

Recruitment. Participants were drawn from the longitudinal study *NeuroCognitive Development* (Tamnes et al., 2013). The study was approved by the Regional Committee for Medical and Health Research Ethics. Children and adolescents aged 8-19 were recruited through local schools, the university and newspaper advertisements. Participants 12 years of age or older and legal guardians of participants under the age of 16 provided written informed consent. Children under the age of 12 gave oral informed assent. At both baseline and follow-up, eligibility was ascertained through standardized screening interviews with a parent of participants aged 15 years or less, and with participants 16 years of age or older. Data were collected between June 2007 and January 2011.

Socioeconomic status. Parental education and parental income were assessed at time point 1 (TP1). Average values of both parents were used when available, whereas the value of either parent's education or income was used if a value for the other parent was missing. Parental education (cross-sectional sample: *n* = 97 had data for maternal education, *n* =89 had data for paternal education; longitudinal sample: *n* = 73 had data for maternal education, *n* = 67 had data for paternal education) was indicated as the highest educational level attained at the time of data collection, where *1* = 9 years of primary school, *2* = 3 years of high school, *3* = up to 4 years at university/college level, and *4* = greater than 4 years of higher education at university/college level. Annual parental income (cross-sectional sample: *n* = 90 had data for maternal income, *n* = 78 had data for paternal income; longitudinal sample: *n* = 68 had data for maternal income, *n* =

59 had data for paternal income) was indicated in NOK as follows: *1* = less than 200 000, *2* = 200 000 – 299 999, *3* = 300 000 – 399 999, *4* = 400 000 – 499 999, *5* = 500 – 599 999, *6* = 600 000 – 699 999, *7* = more than 700 000.

Attrition. Individuals that participated in the study at time point 1 were invited to a follow-up MRI scan at time point 2; 19 were unable or did not wish to participate, 1 was not located, 2 had dental braces, and 3 were excluded due to neurological or psychiatric condition.

Personality Assessment

The **Hierarchical Personality Inventory for Children [**HiPIC; (Mervielde & De Fruyt, 1999)] yields five personality dimension scores for traits that closely resemble the FFM; Imagination (corresponding to Openness), Conscientiousness, Extraversion, Benevolence (similar to Agreeableness), and Emotional Stability (corresponding to low Neuroticism). Eighteen facets, each measured by eight questions, are hierarchically structured under these traits. Intellect, Curiosity and Creativity constitute the domain of Imagination. Conscientiousness is formed by the following facets: Achievement motivation, Orderliness, Concentration and Perseverance. Shyness (reversed), Expressiveness, Optimism, and Energy comprise Extraversion, while Benevolence consists of the facets Egocentrism (reversed), Irritability (reversed), Compliance, Dominance (reversed) and Altruism. Finally, Anxiety (reversed) and Self-confidence are structured under Emotional Stability.

Each item of the HiPIC describes an overt behavior, making the questionnaire well-suited as an observer-report instrument. For example, "[He or She] tends to cry over setbacks". Each item is rated on a five-point Likert scale reaching from 'barely characteristic' to 'highly characteristic'.

General Cognitive Ability Assessment.

General cognitive ability was assessed using the Wechsler Abbreviated Scale of Intelligence [WASI; (Wechsler, 1999)].

MRI Acquisition

MRI data were at both time points collected using the same 12-channel head coil on the same 1.5 T Siemens Avanto scanner (Siemens Medical Solutions, Erlangen, Germany). The pulse sequence used for morphological analyses from both time points was a 3D T1-weighted magnetization prepared rapid gradient echo (MPRAGE) with the following parameters: repetition time (TR)/echo time (TE)/time to inversion (TI)/flip angle (FA) = 2400 ms/3.61 ms/1000 ms/8°, matrix = 192 x 192 x 160, sagitally acquired, field of view (FOV) = 240 mm, bandwidth = 180 Hz/pixel, voxel size 1.25 × 1.25 × 1.2 mm. Acquisition time was 7 min, 42 seconds. The protocol also included a 176-slice sagittal 3D T2-weighted turbo spin-echo sequence (TR/TE = 3390/388 ms) and a 25-slice coronal FLAIR sequence (TR/TE = 7000–9000/109 ms), used for radiological evaluation.

MRI Processing and Analysis

Cross-sectional processing. First, cortical thickness (CT) and surface area (SA) were estimated for each TP1 and Time-point 2 (TP2) scan independently on a point-by-point (vertex-wise) basis across the surface using the FreeSurfer image analysis suite version 5.3 (http://surfer.nmr.mgh.harvard.edu), a freely available and documented tool described in detail elsewhere (Dale, Fischl, & Sereno, 1999; Fischl, 2012; Fischl, Sereno, & Dale, 1999a). Briefly, cortical reconstruction is performed in several stages. A method that combines watershed algorithms and deformable surface models is used to remove all non-brain tissue (for example eye sockets and dura) from the T1-weighted images (Ségonne et al., 2004).This is followed by Talairach transformation, white matter segmentation (whereby voxels are classified as white matter or not on basis of location, intensity and neighbor constrains), topology correction (Fischl, Liu, & Dale, 2001; Ségonne, Pacheco, & Fischl, 2007) and automatic correction for intensity non-uniformity (Sled, Zijdenbos, & Evans, 1998). A spherical atlas is used to generate an average folding pattern mapped to a sphere based on large number of individuals and each individual is aligned with this average. This spherical surface-based coordinate system facilitates point-to-point correspondence between subjects, takes into account the highly folded nature of the human cerebral cortex and enables improved localization of structural features of the brain (Fischl, Sereno, Tootell, & Dale, 1999b). The grey/white matter boundary and the grey matter/cerebrospinal boundary which correspond to the pial surface (the outer boundary of the cortex) are identified, and both cortical thickness and area are then measured by reconstructing the grey/white matter and pial surfaces. More specifically, the distance between these two surfaces yields the thickness of the grey matter at any point across the cortical mantel with submillimeter accuracy (Fischl & Dale, 2000). This method for assessing CT has been validated by comparing in vivo FreeSurfer estimations of cortical thickness with histological measurements (Cardinale et al., 2014). For SA (white surface), the triangular area at each point in native space was compared with the area of the analogous point in registered space to give an estimate of area expansion or contraction continuously along the surface [“local arealization”; (Fischl et al., 1999a)].

Longitudinal processing. In contrast to cross-sectional studies, longitudinal studies have the advantage of reducing the confounding effect of inter-individual morphological variability by using each subject as his or her control (Reuter & Fischl, 2011), i.e. the longitudinal stream uses a within-subject template space and image, which is unbiased with respect to any time point, and is created by means of robust, inverse consistent registration. The longitudinal stream in FreeSurfer proceeds in several stages (Reuter, Schmansky, Rosas, & Fischl, 2012). The first step involves cross-sectional processing as described above, during which all time points of all subjects are processed independently. During the second stage, a within-subject template is created for each individual based on all time points and full segmentation and surface reconstruction is performed in order to estimate average subject anatomy. The final stage involves using information from both the within-subject template and cross-sectional individual runs and each time point is processed longitudinally through a series of algorithms. This approach avoids bias often present in longitudinal image processing (Reuter & Fischl, 2011). Firstly, biased registration is avoided by applying a robust and inverse consistent registration whereby the inverse transform is obtained when registering TP2-TP1 as opposed to TP1-TP2, and by reducing the impact of outlier regions. A common approach to achieve spatial correspondence across time points is to register all follow-up scans to the baseline image. By using the baseline image as a reference frame, it will be treated differently than any other time point which may introduce bias, for example steeper slopes in the rate of change from baseline to TP2 due to interpolation asymmetry. In contrast, FreeSurfer treats all time points identically and avoids this bias by creating a within-subject template which is based on all available time points. The final source of bias in longitudinal image processing relates to information transfer; processing steps often involve number of optimization problems, usually solved by iterative methods where the solutions depend on the choice of starting point. Starting later time points with the baseline results will inherently cause bias, again because baseline is treated differently than later time points. FreeSurfer avoids this bias by employing a within-subject template which can be used to initialize all the time points independently.

Statistical Analyses

In this study, We did not statistically account for global brain and cranial measures, as whether and how one does this impacts models of region brain development (Mills et al., 2016).

MRI Image Quality Control

In-scanner head motion may introduce bias in morphological analyses and is more likely to occur with children (Alexander-Bloch et al., 2016; Reuter et al., 2015). To reduce the risk of such bias, all raw and processed MRI images were manually inspected by an experienced graduate level user trained at MRI processing at the laboratory of the Center for Lifespan Changes in Brain and Cognition, University of Oslo, and only images rated as adequate quality were used for analyses. Scans with substantial movement artifacts were excluded from analyses.

Surface Area Development

In most studies, SA shows relatively small developmental decreases (Brown et al., 2012; Tamnes et al., 2017; Wierenga, Langen, Oranje, & Durston, 2014), except for one study demonstrating regional area expansion (Vijayakumar et al., 2016).

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Supplementary Table 1. Group differences between participants in both data collection waves and those who dropped out

	Stayers		Drop outs		Group difference
	Mean (*SD*)	N	Mean (*SD*)	N	*t* (*p*)
Age	13.9 (3.3)	74	14.8 (3.5)	25	1.17 (0.247)
WASI score	109.8 (10.9)	74	109.2 (9.6)	25	- 0.25 (0.801)
Parental education	3.2 (.8)	73	3.0 (.7)	24	-1.29 (0.197)
Parental income	4.1 (1.2)	73	4.1(1.2)	23	0.04 (0.968)

Supplementary Table 2. Demographic and intellectual sample characteristics

	Cross-sectional sample Time point 1	Longitudinal sample Time point 1	Longitudinal sample Time point 2
Sample size	99	74	74
Number of females	54	37	37
Age in years	14.2 (3.3)	14.0 (3.3)	16.6 (3.3)
Age in years, range	8.3-19.7	8.4-19.4	10.8-21.9
Parental education	3.2 (0.7)	3.2 (0.8)	
Parental income	4.1 (1.2)	4.1 (1.2)	
WASI score	109.7 (10.6)	109.8 (10.9)	112.9 (10.3)
WASI score, range	87-141	87-141	88-136

Note: Values are means (*SD*), unless otherwise specified. For parental education and income, average values of both parents were used. Detailed description of the scales used can be found in the *Supporting Information*.

Supplementary Table 3. The Cronbach alpha coefficients for the domain and facet scales of the Hierarchical Personality Inventory for Children (HiPIC).

Domain scale	Facet scale	Cross-sectional sample (α)	Longitudinal sample (α)
Extraversion		.91	.91
	Shyness	.82	.84
	Expressiveness	.86	.85
	Optimism	.83	.84
	Energy	.73	.70
Benevolence		.94	.93
	Egocentrism	.82	.82
	Irritability	.91	.92
	Compliance	.82	.79
	Dominance	.78	.78
	Altruism	.84	.83
Conscientiousness		.91	.92
	Achievement motivation	.78	.78
	Orderliness	.88	.87
	Concentration	.65	.69
	Perseverance	.77	.76
Emotional stability		.88	.88
	Anxiety	.76	.73
	Self-confidence	.83	.85
Imagination		.89	.89
	Creativity	.85	.84
	Curiosity	.78	.77
	Intellect	.77	.82

Table 4. HiPIC scores and sex differences in the cross-sectional and longitudinal samples

	Cross-sectional sample		Longitudinal sample	
	Mean (*SD*)	*t* (*p*)	Mean (*SD*)	*t* (*p*)
Extraversion	26.2 (3.9)	1.1 (0.29)	26.1 (3.9)	1.2 (0.23)
Emotional Stability	25.5 (4.5)	-0.6 (0.55)	25.8 (4.5)	-0.2 (0.82)
Benevolence	24.0 (3.9)	1.2 (0.24)	23.7 (3.7)	1.4 (0.17)
Conscientiousness	27.7 (3.9)	0.9 (0.40)	27.4 (3.9)	0.4 (0.66)
Imagination	30.4 (3.8)	0.3 (0.76)	30.3 (3.7)	0.5 (0.59)

Note: Sex differences were tested with independent samples t-tests (females – males).

Supplementary Table 5. Correlations of HiPIC scores, age and general cognitive ability

	Cross-sectional sample					Longitudinal sample				
	E	ES	B	C	I	E	ES	B	C	I
Extraversion (E)										
Emotional stability (ES)	**.55**					**.54**				
Benevolence (B)	.16	**.25**				.16	**.30**			
Conscientiousness (C)	.15	**.23**	**.39**			.17	**.26**	**.44**		
Imagination (I)	**.44**	**.29**	.07	**.41**		**.43**	**.34**	.13	**.39**	
Age	**-.21**	.06	.01	-.05	-.16	**-.24**	.13	.01	-.07	-.13
WASI score	-.15	.07	-.11	-.04	**.34**	-.13	.04	-.09	-.03	**.40**

Note: Bold numbers indicate correlations that were significant at $p < .05$.

Supplementary Table 6. Details on clusters showing significant associations between personality traits and surface area

Personality trait	Hemisphere	Cluster size (mm^2)	Cluster-wise *p*	Talairach max vertex (X, Y, Z)	Annotation max vertex
B	R	3755.87	0.000	17.5, -74.3, 8.2	pericalcarine
ES	L	3017.38	0.002	-52.1, -62.1, -2.9	inferiortemporal
ES	L	1860.99	0.048	-48.5, 1.2, -23.1	superiortemporal

Notes: Details of clusters showing significant associations between personality traits and surface area (SA), while controlling for the effects of age and sex. B: Benevolence, ES: Emotional stability. Corrections for multiple comparisons were performed by means of cluster size inference and a cluster-wise *p* < .05 was used.

Supplementary table 7. Details on clusters showing significant interaction effects in cross-sectional data on SA

Personality trait	Hemisphere	Cluster size (mm^2)	Cluster-wise *p*	Talairach max vertex (X, Y, Z)	Annotation max vertex
E	L	2153.85	0.003	-50.1, -45.8, 8.8	bankssts
E	L	2810.36	0.005	-15.3, 36.3, -22.2	lateralorbitofrontal
E	R	4251.66	0.000	32.8, -21.1, 44.7	precentral
E	R	4076.88	0.000	37.7, 38.2, -8.5	parsorbitalis
E	R	2038.15	0.042	7.9, 33.1, 45.0	superiorfrontal
I	L	5484.46	0.000	-52.3, -45.6, 9.7	bankssts
I	L	2425.76	0.015	-20.3, 10.6, 59.2	superiorfrontal
I	R	3642.62	0.001	23.8, 33.8, -10.1	lateralorbitofrontal
I	R	5650.58	0.000	47.5, 3.4, -20.4	superiortemporal
I	R	2826.11	0.006	34.2, -21.9, 42.8	precentral
I	R	3106.40	0.002	7.4, 46.3, 38.5	superiorfrontal

Notes: Details of clusters showing significant effects of age on the relations between cortical area and personality traits. E: Extraversion, I: Imagination. Corrections for multiple comparisons were performed by means of cluster size inference and a cluster-wise $p < .05$ was used.

Supplementary Table 8. Details on clusters showing significant interaction effects in cross-sectional data on CT

Personality trait	Hemisphere	Cluster size (mm^2)	Cluster-wise *p*	Talairach max vertex (X, Y, Z)	Annotation max vertex
B	R	1496.22	0.026	38.8, 37.4, 5.0	parstriangularis
B	R	1333.60	0.048	20.0, -44.1, -9.3	lingual
B	R	1512.25	0.024	12.1, 40.0, 2.0	rostralanteriorcingulate
I	L	2485.79	0.001	-5.8, -70.2, 42.1	precuneus
I	R	2609.61	0.000	8.0, -92.7, 14.4	cuneus

Notes: Details of clusters showing significant effects of age on the relations between cortical thickness and personality traits. B: Benevolence, I: Imagination. Corrections for multiple comparisons were performed by means of cluster size inference and a cluster-wise $p < .05$ was used.

Supplementary Table 9. Details on clusters showing significant associations between personality traits and change in cortical thickness and surface area

Cortical measure	Personality trait	Hemisphere	Cluster size (mm^2)	Cluster-wise *p*	Talairach max vertex (X, Y, Z)	Annotation max vertex
CT	C	L	1324.33	0.003	-27.9, -45.4, 57.9	superiorparietal
CT	C	R	1530.52	0.001	5.8, -63.1, 36.4	precuneus
CT	C	R	1118.63	0.014	22.9, 54.5, 17.7	rostralmiddlefrontal
CT	C	R	1536.23	0.001	45.4, -3.7, 46.4	precentral
CT	C	R	915.37	0.050	27.3, -32.5, 69.3	postcentral
CT	ES	L	1650.16	0.000	-27.1, 11.9, 43.0	caudalmiddlefrontal
CT	ES	R	1018.85	0.026	54.8, -41.2, 32.0	supramarginal
CT	ES	R	1695.38	0.000	55.3, -13.3, 19.1	postcentral
CT	ES	R	1207.23	0.009	10.2, 42.7, -12.2	medialorbitofrontal
CT	ES	R	940.26	0.042	55.8, -4.1, -3.7	superiortemporal
CT	I	R	1204.03	0.009	45.5, -18.6, 45.7	postcentral
SA	B	L	626.69	0.034	-20.8, -36.0, 65.0	postcentral
SA	C	L	604.42	0.043	-15.8, -92.3, -8.8	lateraloccipital
SA	C	R	983.80	0.001	13.4, -83.6, 9.6	pericalcarine
SA	E	L	2279.50	0.000	-19.6, -46.9, 61.8	superiorparietal

Notes: Details of clusters showing significant associations between personality traits and annual percentage change in cortical thickness (CT) or surface area (SA), while controlling for the effects of age and sex. C: Conscientiousness, ES: Emotional stability, I: Imagination, B: Benevolence, E: Extraversion. Corrections for multiple comparisons were performed by means of cluster size inference and a cluster-wise $p < .05$ was used.

Supplementary Table 10. Cortical thickness development effects on personality

Personality trait	*β*	*t (p)*	Hemispheric cluster locations
C	-0.42	-3.92 (< 0.001)	L (superiorparietal) + R (precuneus, rostral middle frontal, precentral, postcentral)
ES	-0.41	-3.91 (< 0.001)	L (caudal middle frontal) + R (supramarginal, postcentral, medial orbital frontal, superior temporal)
I	-0.36	-3.29 (0.002)	R (postcentral)

Notes: The table shows standardized regression coefficient for each personality trait. Multiple regression analyses were performed on annual percentage change in weighted mean cortical thickness across significant clusters, where each personality trait, age and sex were entered into the model. Only the effects of personality trait are included in the table. C: Conscientiousness, ES: Emotional stability, I: Imagination. L: left hemisphere, R: right hemisphere, L + R: weighted mean of APC in CT multiple clusters across both hemisphere showing the same trend were entered into the model.

Supplementary Table 11. Cortical surface area development effects on personality

Personality trait	*β*	*t (p)*	Hemispheric cluster locations
B	0.36	3.20 (0.002)	L (postcentral)
E	0.47	4.39 (< 0.001)	L (superior parietal)
C	0.36	3.31 (0.001)	L (lateral occipital)
C	-0.41	-3.80 (< 0.001)	R (pericalcarine)

Notes: The table shows standardized regression coefficient for each personality trait. Multiple regression analyses were performed on annual percentage change in surface area in each cluster, where each personality trait, age and sex were entered into the model. Only the effects of personality trait are included in the table. B: Benevolence, E: Extraversion, C: Conscientiousness. L: left hemisphere, R: right hemisphere.

Supplementary Table 12. Details on clusters showing significant interaction effects in longitudinal data on CT.

Personality trait	Hemisphere	Cluster size (mm^2)	Cluster-wise *p*	Talairach max vertex (X, Y, Z)	Annotation max vertex
C	L	889.73	0.027	-10.6, 15.0, 32.8	caudalanteriorcingulate
C	R	1101.48	0.016	55.4, -55.9, 8.5	middletemporal
E	L	4306.10	0.000	-51.0, -4.2 7.6	precentral
E	L	1143.53	0.005	-49.2, -12.5, -16.0	superiortemporal
E	R	916.91	0.050	33.3, 11.5 12.7	insula
E	R	1518.55	0.002	16.0, 44.6, -17.9	lateralorbitofrontal
E	R	945.40	0.042	7.4, -52.9 9.6	isthmuscingulate
I	L	1123.18	0.006	-35.3 38.0 9.1	rostralmiddlefrontal
I	L	909.43	0.024	-18.0, -51.1 2.6	isthmuscingulate
I	L	987.26	0.014	-39.1 11.2 10.2	parsopercularis
I	R	1126.44	0.014	11.5, -57.4 0.1	lingual
ES	R	916.74	0.050	13.6, -48.5 39.7	precuneus

Notes: Details of clusters showing significant effects of age on the relations between cortical thickness development and personality traits. C: Conscientiousness, E: Extraversion, I: Imagination, ES: Emotional Stability. Corrections for multiple comparisons were performed by means of cluster size inference and a cluster-wise $p < .05$ was used.

Supplementary Table 13. Details on clusters showing significant interaction effects in longitudinal data on SA.

Personality trait	Hemisphere	Cluster size (mm^2)	Cluster-wise *p*	Talairach max vertex (X, Y, Z)	Annotation max vertex
C	L	1338.32	0.000	-31.2, -26.3 9.3	insula
C	R	1234.79	0.000	49.0, -38.2 8.8	bankssts
C	R	1284.16	0.000	39.0, 5.3 12.8	precentral
E	L	1019.73	0.000	-22.1, -97.6 11.1	lateraloccipital
I	L	825.44	0.002	-43.1, -36.4 23.7	supramarginal
I	R	1128.99	0.000	43.8, -53.6 24.7	inferiorparietal
I	R	747.31	0.014	45.9, 10.6, -28.1	superiortemporal

Notes: Details of clusters showing significant effects of age on the relations between cortical thickness development and personality traits. C: Conscientiousness, E: Extraversion, I: Imagination. Corrections for multiple comparisons were performed by means of cluster size inference and a cluster-wise *p* < .05 was used.

Supplementary Table 14. Effects of general cognitive ability in clusters where personality traits were significantly associated with cortical thickness development

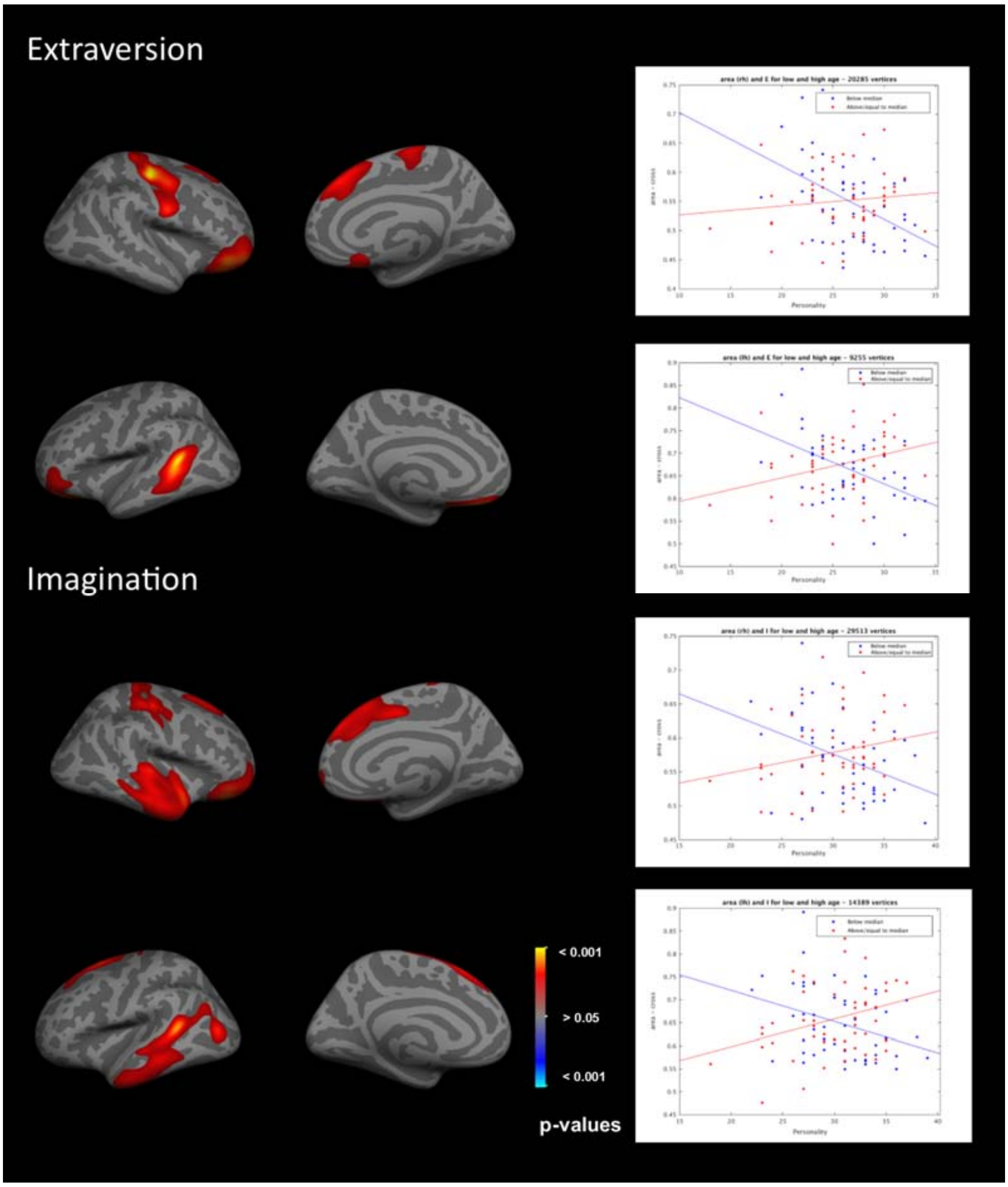
Personality trait	*Hemispheric cluster locations*	*β*	*t (p)*
C	L (superiorparietal) + R (precuneus, rostral middle frontal, precentral, postcentral)	0.01	0.04 (0.970)
ES	L (caudal middle frontal) + R (supramarginal, postcentral, medial orbital frontal, superior temporal)	0.54	0.46 (0.651)
I	R (postcentral)	-0.13	-1.08 (0.286)

Notes: The table shows standardized regression coefficient for estimated IQ as measured at time point 1. IQ was included as a covariate in analyses on already identified significant clusters. C: Conscientiousness, ES: Emotional stability, I: Imagination. L: left hemisphere, R: right hemisphere, L + R: weighted mean of APC in CT multiple clusters across both hemisphere showing the same trend were entered into the model.

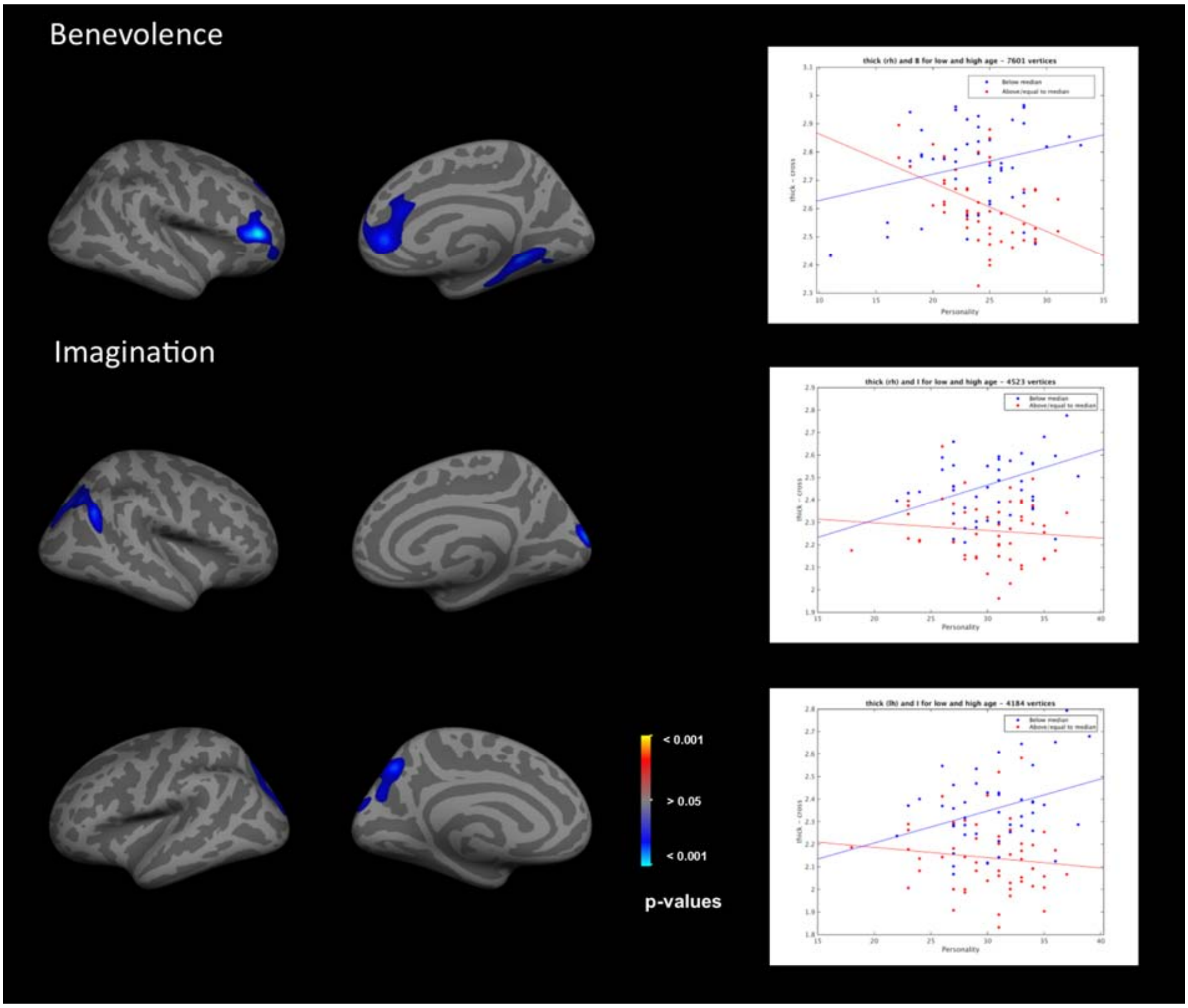
Supplementary Table 15. Effects of general cognitive ability in clusters where personality was significantly associated with cortical surface development

Personality trait	*Hemispheric cluster locations*	*β*	*t (p)*
B	L (postcentral)	-0.98	-0.80 (0.424)
E	L (superior parietal)	-0.053	-0.44 (0.661)
C	L (lateral occipital)	-.101	-0.84 (0.402)
C	R (pericalcarine)	-.072	-0.60 (0.552)

Notes: The table shows standardized regression coefficient for estimated IQ as measured at time point 1. IQ was included as a covariate in already identified significant clusters. C: Conscientiousness, ES: Emotional stability, I: Imagination. L: left hemisphere, R: right hemisphere, L + R: weighted mean of APC in CT multiple clusters across both hemisphere showing the same trend were entered into the model.



Supplementary Figure 1. Personality by age interactions and SA. Clusters of significant interaction of age with the associations between personality traits and SA. Uncorrected *p* values within the corrected significant clusters are shown. Scatter plots describe associations between SA and personality traits. Blue bar represents younger individuals, red bar represents older individuals.



Supplementary Figure 2. Personality by age interactions and CT. Clusters of significant interaction of age with the associations between personality traits and CT. Uncorrected *p* values within the corrected significant clusters are shown. Scatter plots describe associations between CT and personality traits. Blue bar represents younger individuals, red bar represents older individuals.

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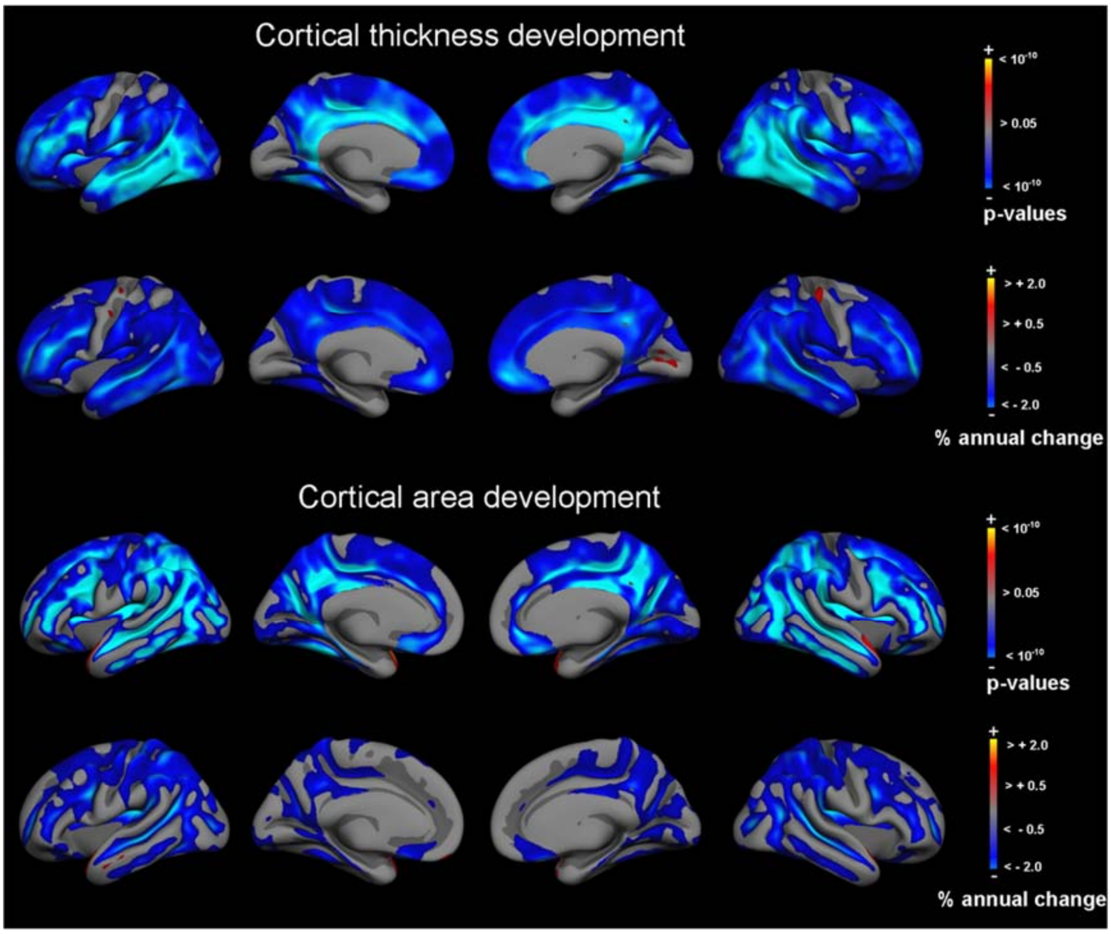
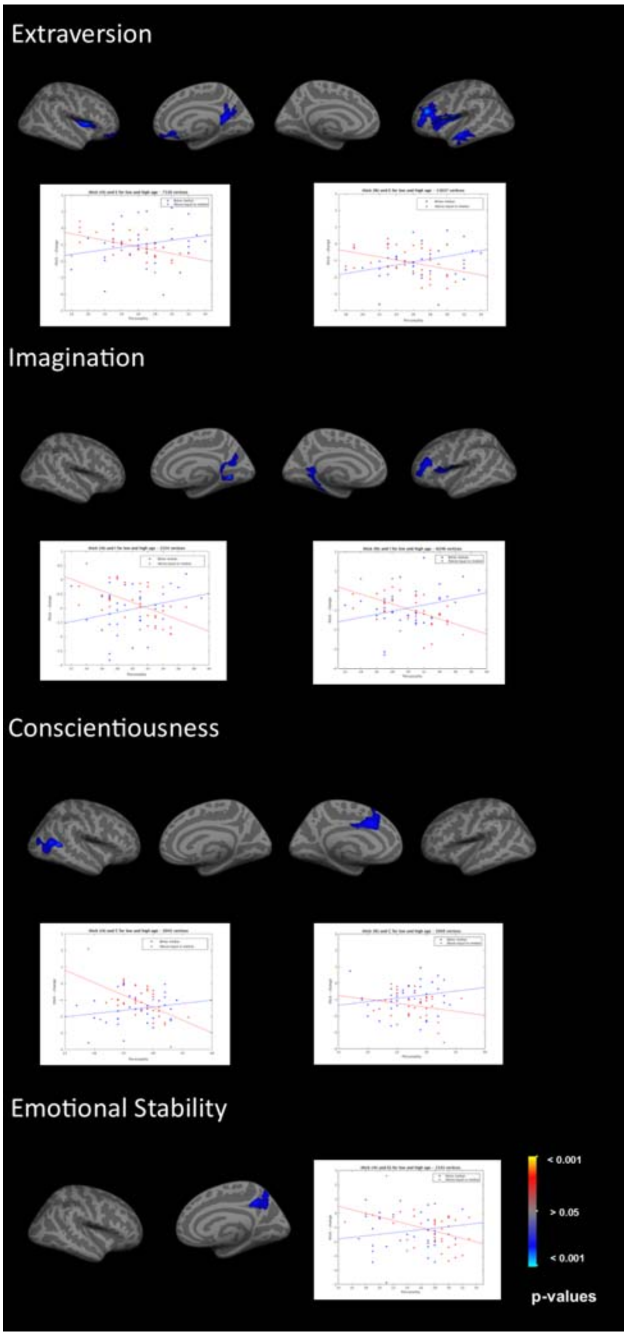
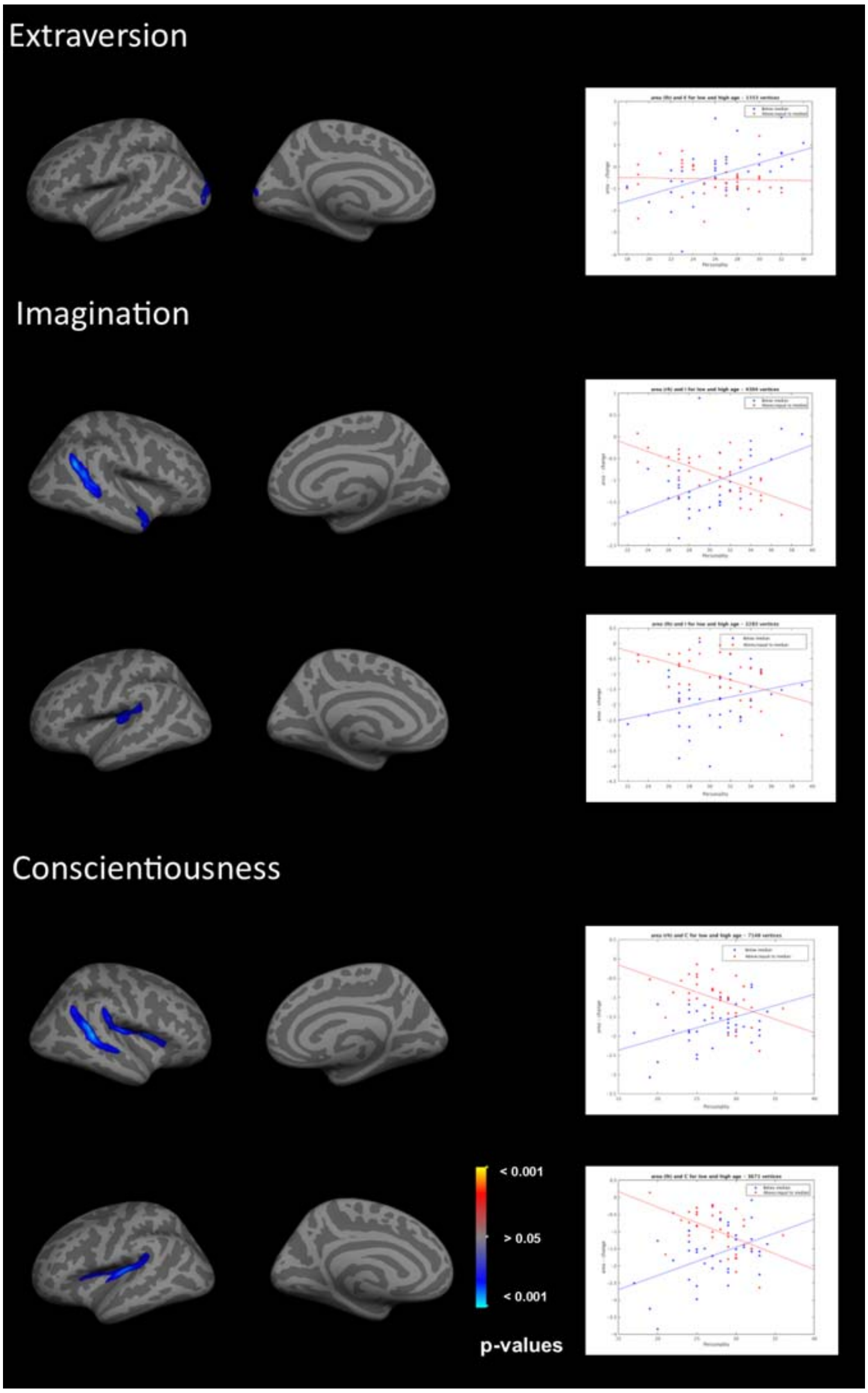


Supplementary Figure 3. Longitudinal development of cortical thickness and surface area. For each measure, the significance of annual percentage change, controlled for sex and corrected for multiple comparisons, and the average rate of change is shown. Blue represents decreases with increasing age, while red-yellow represent increases.



Supplementary Figure 4: Personality by age interactions and CT development. Clusters of significant interaction of age with the associations between personality traits and CT development. Uncorrected *p* values within the corrected significant clusters are shown. Scatter plots describe associations between APC in CT and personality traits. Blue bar represents younger individuals, red bar represents older individuals.



Supplementary Figure 5: Personality by age interactions and SA development. Clusters of significant interaction of age with the associations between personality traits and SA development. Uncorrected *p* values within the corrected significant clusters are shown. Scatter plots describe associations between APC in SA and personality traits. Blue bar represents younger individuals, red bar represents older individuals.