Physical topography is associated with human personality

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Abstract

Regional differences in personality are associated with a range of consequential outcomes. But which factors are responsible for these differences? Frontier settlement theory suggests that physical topography is a crucial factor shaping the psychological landscape of regions. Hence, we investigated whether topography is associated with regional variation in personality across the United States (*N* = 3,387,014). Consistent with frontier settlement theory, results from multi-level modeling revealed that mountainous areas were lower on agreeableness, extraversion, neuroticism, and conscientiousness, but higher on openness to experience. Conditional random forest algorithms confirmed mountainousness as a meaningful predictor of personality when tested against a conservative set of controls. East-West comparisons highlighted potential differences between ecological (driven by physical features) and sociocultural (driven by social norms) effects of mountainous terrain.

"The mountains, the forest, and the sea, render men savage; they develop the fierce, but yet do not destroy the human." Victor Hugo (Les Misérables) - For decades, research in the social and behavioural sciences has demonstrated that the neighborhoods, cities, and states in which people live are associated with a range of political, economic, social, and health outcomes[1-3]. Recent research in psychology is beginning to show that the places in which people live are also associated with psychological characteristics, including personality traits[4,5]. Specifically, there is growing evidence that personality traits are geographically clustered in particular areas[6-9], and that the prevalence of certain traits is related to a number of consequential outcomes[10-12].

The current study focuses on the mechanisms potentially driving geographical variation in personality, as captured by the Big Five, the most widely used personality taxonomy[7,13]: (1) agreeableness (tendency to be trusting, altruistic, and compliant) (2) conscientiousness (tendency to be responsible, organized and dutiful) (3) extraversion (tendency to be sociable, enthusiastic, and outgoing) (4) neuroticism (tendency to be anxious, tense, and emotionally unstable) and (5) openness to experience (tendency to be curious, imaginative, and unconventional)[14,15]. To understand how geographical differences in personality emerge, investigators have examined a variety of possible mechanisms, including climate[16,17], natural resources[11,18,19], pathogen prevalence[20], selective migration[6,21], and sociocultural legacies[7,22]. However, one potentially important factor that has received little attention is physical topography, particularly variability in elevation or "mountainousness."

Why might mountainousness be a factor in the geographical distribution of personality traits? Historically, mountainous areas were among the last to be inhabited because they tend to be remote, ecologically harsh, and inhospitable[7,22,23]. According to the voluntary settlement hypothesis[7,22], the ecologically challenging conditions of frontier regions foster an ethos of independence that can leave a distinct imprint on personality. One reason is that such frontier environments historically attracted a rather selective group of settlers[7,22]: nonconformists who were the least integrated within their old communities[24], strongly motivated by a sense of freedom and

independence, and willing to leave behind everything and everyone they knew[22]. Another reason is the harshness of the frontier terrain. With limited and unpredictable resources, the conditions may have favoured settlers low in prosociality, who closely guarded their resources and distrusted strangers, as well as those who engaged in risky explorations and novel ways to secure food and resources[25]. Over time, these processes may have led to an elevated prevalence of independent traits and social norms that were most conducive to survival[7]. Eventually, individualist values defined the local culture, continuously reproducing and cementing the ethos of independence[7], characterized by toughness, self-reliance[26], low levels of conformity[27], increased independent agency[7,28], and independence-related normative beliefs[29]. Even today the mountain states continue to exhibit the strongest individualist tendencies in the country[30] and have cultivated a cultural narrative as the "land of 'Don't fence me in', Gary Cooper in 'High Noon', and the Marlboro man"[26].

In Big Five terms, however, a more complex picture emerges. The self-selection of the nonconformist, aloof settlers who initially moved to the mountain frontier[27], the territoriality and skepticism towards others as a strategy to manage the scarcity of resources in the mountains[25], the persistent cultural emphasis on being left alone in mountainous former frontier regions[26], and previous research linking individualism to decreased agreeableness[31-33] would all seem to point to low levels of agreeableness in mountainous regions. On the other hand, the high mortality in the mountains might also have promoted stronger group relations, boosting everybody's chances for survival through mutual cooperation[25], thus rewarding heightened agreeableness.

Some researchers have found support for negative associations between individualism and markers of conscientiousness[34], but others have found no statistical relationship[32]. Likewise, although U.S. mountain region residents score low on some aspects of conscientiousness (e.g., civic obligation), they score high on others (e.g., being organized)[26].

With respect to extraversion, small-scale field experiments have shown that introverts have strong preferences for secluded, mountainous areas, whereas extraverts prefer flat and open surroundings, such as the seaside[35]. Moreover, on a cultural level, the ethos of independence would

likely manifest itself in low extraversion reflecting detachment, distance, and self-reliance as core elements of individualism[36]. However, empirically, the link between individualism and decreased extraversion has received mixed evidence[32] with some work even finding effects in the opposite direction[37].

In terms of neuroticism, the press to be autonomous and to survive on one's own highlights a clear need to be mentally resilient. Thus, it would appear that mountainous environments are attractive to individuals with certain independence-prone attributes, such as self-reliance and emotional stability, and that those traits may be especially adaptive for flourishing in such environments[6]. Consistent with that logic, residents of mountainous regions tend to be less worrying and nervous[26]. However, others have argued that, to a certain degree, chronic fear and permanently heightened vigilance might actually be adaptive in frontier topographies to help avoid physical threats, suggesting a potential positive relationship between neuroticism and mountainousness[25].

Regarding openness to experience, prior research has tied openness to individualism[31,33], portrayed openness both as a likely characteristic of the adventurous pioneers who first populated the mountain frontier[27] and an adaptive trait to master the environmental challenges of mountainous terrain[7,25] and has shown residents of mountain regions to be broad-minded and curious[26]. However, recent evidence examining governmental restriction has demonstrated that frontier topography may be as likely to produce autocratic close-mindedness as liberal openness[38,39].

Against this backdrop of mixed findings, we refrained from making specific predictions about the patterns of the associations and instead adopted an exploratory, data-driven approach to illuminate the relationships between mountainousness and personality.

There are other important questions about the relationship between mountainousness and personality that have yet to be examined empirically. In particular, what are the causal mechanisms responsible for the relationship? Research in cultural[7,22] and geographical psychology[8,40] has identified three mechanisms that could shed light on the origins of the mountainousness-personality relationship: 1) Selective migration suggests that people with certain traits might be more likely than

109 others to move to mountainous areas because the psychological demands and affordances of these
110 areas satisfy their personalities. For example, introverts may leave a city seeking the relative solitude
111 of a frontier region or a strongly independent person may thrive in the unstructured environment
112 such regions offer. 2) Ecological influence suggests that the conditions of mountainous
113 environments could directly shape the personalities of residents. For example, the remoteness and
114 isolation that come with the mountains might reinforce behaviors and traits associated with social
115 withdrawal, self-reliance, and introversion. 3) Sociocultural influence suggests that the unique local
116 traditions, customs, lifestyles, and daily practices of mountainous areas may shape specific social
117 norms, which in turn affect inhabitants' personalities. For example, the ethos of independence, that
118 may have originally developed as a response to the harsh environment, might over time evolve and
119 become deeply engrained in the collective mindset and culture of the mountainous regions.
120 Subsequently, it might give rise to specific social and behavioral norms, which then shape the
121 personalities of people living in this independence-prone local culture. Of note, this theoretical
122 framework further distinguishes two forms of sociocultural influences[7,22]: Initial enculturation and
123 acculturation. Initial enculturation posits that the experience of being born and raised in a
124 mountainous area shapes people's personalities whereas acculturation posits that people's
125 personalities may change as they move to a mountainous area later in their life.

126 Although previous research indicates that selective migration, ecological influence, and
127 sociocultural influence are important[7,8,22,40], it is difficult to determine the degree to which any of
128 them contribute to the link between mountainousness and personality. The present investigation
129 attempts to shed some light on the issue by adopting a twofold approach. In the first step, we zoom
130 in on selective migration as well as the two forms of sociocultural influences (initial enculturation,
131 acculturation); to do this, we compare associations between personality and the mountainousness
132 of the places in which participants grew-up versus the mountainousness of the places in which they
133 lived when they participated in the study. In keeping with Kitayama and colleagues[7], a stronger
134 association between mountainousness and personality for the place in which people grew up

compared to where they lived when they participated would suggest a stronger role for initial enculturation, rather than selective migration or acculturation.

In the second step, we seek to disentangle the effect of ecological influences and sociocultural influences. Generally, due to the deeply engrained ethos of independence that continues to characterize the former frontier regions in the Mountain West[22,26,27] it seems reasonable to assume that the relationship between mountainousness and personality is driven, at least in part, by historical and sociocultural influences, rather than by ecological influences alone. However, sociocultural influences should occur only along the former frontier, that is, in the Western Mountains (e.g. Rocky Mountains), whereas they should be absent in the Eastern Mountains (e.g. Appalachian Mountains) which are not generally regarded as part of the American frontier. Following this rationale, to isolate the effects of ecological features (mountainous topography, which is found in both the East and West) from sociocultural norms (frontier culture, which is found only in the West) we ran separate analyses for the West versus East of the U.S. and compared the association patterns between mountainousness and personality across both parts of the country.

Another important question concerns the operationalization of physical topography. According to the Nordic Centre for Spatial Development[41], mountainousness is defined by two elements—hilliness (slope, shape) and area elevation (altitude). In keeping with this distinction, we measured the mountainousness of people's residential environments using three different indices: 1) standard deviation in elevation, 2) mean squared successive difference in elevation, and 3) mean elevation. The first two indicators are sensitive to variation in elevation and hence well-suited to capture the hilliness, or the shape of a landscape; the third indicator, elevation, is a marker of overall altitude (see Methods and Supplementary Information for details). The average national commuting distance in the U.S. is 18.8 miles[42]; so, to delineate people's living environment for our primary analyses, we drew a 20-mile radius from the centroid of one's ZIP code of residence. To capture the broader surroundings in which people spend their lives, we also ran all our analyses with a 50-mile

radius. Comparing these two radii can inform our understanding of suitable ways to represent people's living environments.

The current investigation set out to directly examine the degree to which physical topography is associated with individual personality. Specifically, using a sample of over 3 million individuals, the present work investigates the relationships between the Big Five personality traits and objective measures of physical topography across 37,227 ZIP codes in the U.S. In doing so, we extend previous research[23,35] by 1) investigating all Big Five traits, rather than single traits, 2) using objective measures of mountainousness, and 3) analyzing data at the level of ZIP codes rather than states.

Results

For the default model (mountainousness, 20-mile radius, present place of living) multilevel modelling showed that mountainousness had negative associations with agreeableness (β[95%-CI] = -.008[-.010,-.005], $p < .001$,), conscientiousness (β[95%-CI] = -.007[-.009, -.005], $p < .001$), extraversion (β[95%-CI] = -.006[-.008, -.004], $p < .001$) and neuroticism (β[95%-CI] = -.013[-.015, -.011], $p < .001$) and a positive relationship with openness to experience (β[95%-CI] = .034[.031,.037], $p < .001$). Variance partition coefficients[43] indicated that almost all variance was at the individual-level (agreeableness = 99.05%, conscientiousness = 98.79%, extraversion = 99.36%, neuroticism = 99.11%, openness = 97.33%) with variance at the superordinate spatial ZIP code level ranging from 0.64% (extraversion) to 2.67% (openness), which mirrors prior research[44,45] and may at least be partially due to common-method variance inflating the individual-level estimates[46,47]. Table 1 exhibits full models for all five traits, reporting standardised β-coefficients, which allow for direct comparisons among individual predictors. Ω^2, which is conceptually similar, if more conservative, to a traditional R^2 statistic in OLS-regressions, is reported to assess the models' overall explanatory power. Further details on Ω^2 as well as multilevel models for mountainousness-MSSD and elevation, both of which identically replicated the patterns of the default model (see Supplementary Table 3

and Supplementary Table 4), can be found in the Supplementary Information.

Conditional random forests identified mountainousness as a meaningful predictor of personality. As can be seen in Figure 3, for all three indices mountainousness importance scores consistently exceeded the customary, conservative random noise benchmark[48-50], to signal practical relevance for all Big Five traits. Mountainousness was particularly strongly associated with openness to experience, outperforming income, social class, race, latitude, and extraversion, where mountainousness-MSSD outperformed income, education, race, latitude, and population density. With the exception of extraversion, where mountainousness-MSSD ranked first, mountainousness consistently outperformed mountainousness-MSSD and elevation, which was the least relevant mountainousness index in all models. This finding was corroborated by results from Steiger's *Z*-tests[51] indicating that the zero-order correlations of personality with mountainousness were stronger than the zero-order correlations with elevation (agreeableness: $Z = 6.78$, $p < .001$; conscientiousness: $Z = 9.49$, $p < .001$; extraversion: $Z = 3.62$, $p < .001$; neuroticism: $Z = 6.33$, $p < .001$; openness to experience: $Z = 49.76$, $p < .001$) and mountainousness-MSSD (agreeableness: $Z = 16.45$, $p < .001$; conscientiousness: $Z = 8.50$, $p < .001$; extraversion: $Z = 3.29$, $p < .001$; neuroticism: $Z = 1.92$, $p = .0549$; openness to experience: $Z = 22.49$, $p < .001$).

When exploring the relationship between mountainousness and personality with a broader operational definition of people's living environments (i.e., 50-mile radius) and place of living when they grew up (versus where they lived when they participated in the study), the directions of the effects generally remained stable across all four sets of analyses (see Table 2). Nonetheless, minor differences in effect size were observed. Specifically, Steiger's *Z*-tests[51] indicated, that effect sizes were larger for 50-mile rather than 20-mile radii for four of the Big Five traits (agreeableness: $Z = 5.84$, $p < .001$; conscientiousness: $Z = 2.336$, $p = .019$; neuroticism: $Z = 6.54$, $p < .001$; openness to experience: $Z = 18.929$, $p < .001$), with the exception of extraversion, where no significant difference was detected (extraversion: $Z = 0.234$, $p = .815$). More mixed results were found when comparing the associations between mountainousness and personality for current place of residence versus

place of residence during youth. Stronger associations were observed for place of youth and agreeableness (Z = 3.738, p < .001), conscientiousness (Z = 11.213, p < .001) and extraversion (Z = 2803, p = .005), but the reversed pattern emerged for neuroticism (Z = -11.212, p < .001) and openness (Z = -15.583, p < .001). Thus, for agreeableness, conscientiousness, and extraversion, the results suggest that initial enculturation may be at work, whereas selective migration and acculturation may be responsible for the links to neuroticism and openness. That is, the experience of being born and raised in a mountainous area might make people less agreeable, less conscientious, and less extraverted, whereas people who move to mountainous areas later in life might either become more open and less neurotic upon moving there or – at least in part – move there because they are open and emotionally stable.

Lastly, when running separate multilevel models for the East versus West of the U.S., notable differences were observed (see Supplementary Table 5 and Supplementary Table 6). In the West, the general pattern was reproduced, with the exception of conscientiousness, which was no longer significantly associated with mountainousness. Meanwhile, in the East while the effects for conscientiousness (β[95%-CI] = -.007[-.009,-.005], p < .001) and openness to experience (β [95%-CI]= .005[.001,.008], p = .011) mirrored the general model, agreeableness and extraversion were no longer significantly related to mountainousness and neuroticism was positively associated with mountainousness (β[95%-CI] =.006[.004,.009], p < .001). Of note, in the West the relationship for openness to experience (β[95%-CI] = .0431[.039,.047], p < .001), which yielded the strongest effect in the general model, was almost 10 times as high as in the East (β[95%-CI] = .0046[.001,.008], p = .011).

Discussion

The current study used advanced analysis techniques to determine whether mountainousness is meaningfully related to personality. Significant associations emerged in the presence of a conservative set of individual-level (i.e., age, sex, educational status, perceived social

class, race) and macro-environmental (latitude, population density, median income) control variables. The patterns of results show substantial consistency across a series of robustness checks and a cross-validation with a powerful machine learning algorithm. As such, people living in mountainous terrain tend to be lower on agreeableness, conscientiousness, extraversion, neuroticism, and higher on openness to experience than people living in non-mountainous terrain (see Figure 4, dark green bars).

How should we interpret the associations between mountainousness and personality? Previous research on frontier culture offers a number of clues. The relationship between mountainousness and low agreeableness suggests that residents of mountainous areas are less trusting, caring, forgiving, and kind compared to residents of flatter areas. These findings converge with previous research indicating that the original settlers of mountainous environments benefited from territorial, self-focused survival strategies[25], which contributed to a strong cultural emphasis on isolation and independence in the mountainous former frontier region[26]. The low levels of conscientiousness in relation to mountainousness point to elevated rates of rebelliousness, indifference, and non-compliant behaviours in mountainous areas, which accords with the self-focused, egocentric attitude of individualism[34]. This notion is backed up by prior research indicating that mountain regions exhibit comparatively low levels of civic involvement[26] and obedience[24]. The low levels of extraversion in mountainous areas converge with the defining characteristics of individualism as detachment, distance, and self-reliance[36], and also replicates small-scale field experiments, showing that introverts have strong preferences for secluded, mountainous areas[35]. The association between mountainousness and low levels of neuroticism dovetails with the idea of independent, assertive, and self-confident mountain settlers who cannot afford to rely on anyone but themselves[26].

Finally, heightened openness to experience might be construed as another prerequisite for successful mastery of the tough ecological conditions of mountainous areas[7,25]. As such, moving from the comforts of civilisation to the harsh terrains of the mountains arguably demands

preparedness to confront unknown challenges and experiences in unchartered territory. Moreover, as a hallmark of individualism[31,33], openness is a strong predictor of residential mobility[21], and has been suggested to serve as an impetus to pursue goals that cannot be fulfilled in one's present environment[52], such as the quest for economic affluence and personal freedom that drove many original North American frontier settlers[7,22].

In an attempt to further elucidate the observed mountainousness–personality associations, we tried to isolate the effects of ecological features (mountainous topography, which is found in both the East and West) from sociocultural norms (frontier culture, which is found only in the West) by running separate analyses for the West versus East of the U.S.. These exploratory analyses suggest that whether the effects are driven by the topography itself (hilliness, elevation) or by the frontier culture that has come to be associated with the mountainous regions of the Western US states seems to depend on the trait. Specifically, when examined in isolation, the ecological effects of mountainousness (i.e., hilliness, elevation) yield noteworthy patterns of low levels of conscientiousness and – in direct contrast with the sociocultural effects – high neuroticism (see Figure 4, light blue bars). Consistent with previous work[23,35], these findings suggest that the mountains are still an isolating terrain with formidable barriers to many aspects of life, and even if humankind has managed to overcome them in many respects, they remain a defining element of one's physical surroundings that affects personality. However, these findings also suggest that the role of the mountains for humans – while still impactful – has likely changed since the original settlement of the United States.

Indeed, with the advent of modern transportation, mountainous regions have become more accessible, opening more channels of interaction between mountain settlers and suppliers, service providers, and visitors. Moreover, recent advancements in technology have removed many of the communication barriers that had maintained the isolation of mountain settlers from each other and from third parties[35]. Hence, while choosing to live in the mountains today is likely to reflect a desire

for solitude and quietness[35], doing so no longer requires the same degree of self-reliance and autonomous mastery.

As such the purely ecological effects that the mountains continue to exhibit today better fit with the notion of the hermit alone in the mountains[35] who favours social withdrawal (high neuroticism[53,54]) and freedom from civic responsibilities (low conscientiousness[55,56]), than with the iron-willed, mentally-resilient pioneer (low neuroticism), who, while being rebellious and non-compliant (low conscientiousness[24,26]), also has to be organised and self-disciplined (high conscientiousness) to survive along the frontier.

While the importance of ecological effects should thus clearly be acknowledged, it appears that, in general, the sociocultural effects are decidedly more powerful and dominant in shaping the observed associations between mountainousness and personality (see Figure 4, dark blue bars). As such, they attest to the power of deeply rooted regional sociocultural narratives, such as the ethos of independence, and their perpetuation through education and socialization[22,57]. Indeed, there is ample evidence pointing to the longevity of the effects of regional ecologies on personality that persist long after the original determining ecological factors have ceased to be relevant[11,18,19,24,27,58]. Put differently, there is a good chance that in Independence, CA, the most mountainous of the 37,227 ZIP codes in our study, the ethos of independence is still alive and well.

It should be noted that the magnitude of the effects is generally quite small and the overall explanatory power of the models is modest. However, complex psychological phenomena such as personality, are likely to be influenced by hundreds, if not thousands, of factors[59,60], so small effects are to be expected, especially when examined in the uncontrolled context of real-world settings[61-63]. This expectation of small but robust effects has strong parallels in the field of genetics, where researchers have essentially abandoned reductionist one-gene-one-outcome approaches in favour of quantitative trait loci approaches[64-66] that identify multigene systems. Such approaches explicitly acknowledge that each individual gene will likely have a very small effect, accounting for

less than 1% of variance[65,67] or even just 0.1%[68]. Thanks to the digital revolution and the age of big data[69-71], psychology now also has the means to undertake large-scale, computationally powerful research that cumulatively advances our understanding of complex phenomena such as personality, identifying small, yet robust predictive factors[59,72].

Does the small magnitude of the effects render them unimportant? Not at all. Small effects can make a big difference when considered at scale[59,73-75]. This is especially true for personality, where the effects accumulate over long periods of time[76,77] and across most major life domains, including occupational attainment, personal relationships, financial security, and mortality[78-80]. This cumulative effect is especially likely for socioecological influences, which usually bear on large groups of people that share the same environmental milieu[39,46,57,81]. For instance, our research shows that an increase of one standard deviation in mountainousness is associated with a change of approximately 1% in personality, which may seem insignificant. But when scaled to hundreds of thousands of people, such an increase would translate into substantial changes in highly consequential political, economic, social and health outcomes[8,12].

In addition to exploring the associations between mountainousness and personality, our research tried to shed light on the mechanisms underlying these associations. Aside from isolating ecological and sociocultural effects, our preliminary attempts to separate the individual contributions of selective migration, initial enculturation, and acculturation suggest that the associations with mountainousness may be primarily due to initial enculturation for agreeableness, conscientiousness and extraversion and due to selective migration and acculturation for neuroticism and openness. One possible explanation for this pattern could be that in order to either move to an area that aligns well with one's own personality or to become culturally assimilated in a new place, one needs to be able to judge the ambiance, culture, and vibe of a place. In that vein, people exhibit considerable accuracy in inferring regional levels of openness and neuroticism but not the other three Big Five traits[82]. This understanding of regional characteristics is true for the United States as a

whole, but the effect might be particularly strong in the mountain states, where low neuroticism and high openness have been shown to be the most salient regional personality characteristics[12]. Furthermore, as noted above, openness, which shows the strongest difference in effect size between youth and present place of living is a strong predictor of residential mobility[21]. As such, it might drive people to seek out environments that offer a better fit for their personalities[52], which would be another plausible argument for linking the trait to selective migration. However, our data do not allow us to draw any firm conclusions on how exactly the mechanisms operate and affect different personality traits differently. For example, we have no way of knowing whether people who moved since their youth deliberately chose their new place of residence or ended up there for reasons unrelated to their personal preferences (e.g., job posting, moving to live with a partner). Also, we do not know when participants moved away from their place of youth, how long they have lived at their current residence, or where they lived in between. Thus, we cannot control for possible prolonged exposure to other ecological and sociocultural environments. More generally, due to the correlational nature of our study, we are unable to provide causal evidence in the current work. To overcome these limitations, longitudinal studies monitoring both individual- and community-level changes in personality in mountainous areas would help to tease apart the effects of selective migration, initial enculturation, and acculturation[7,52] and offer a basis for causal inference. Likewise, cross-cultural triangulation research[7] replicating the present study in other mountainous regions with and without frontier legacies (e.g. Hokkaido (Japan) versus Switzerland, Austria) would offer insights into the cultural specificity of the ethos of independence in the U.S.[38,39] and further illuminate the ecological versus sociocultural effects of mountainousness. Finally, future research should also look at the specific effects of other challenging terrains such as deserts, coastlines, and swamplands[35] and examine more nuanced associations at the level of personality facets[83,84].

Taken together, the present study demonstrated robust effects of objective physical environments on personality. In doing so, it underlines the relevance of geographical psychology and

363 socioecological research for understanding the complex ways in which individuals and environments
364 interact.

365 Methods

366 The present study was preregistered on the OSF before the data were accessed
367 (https://osf.io/y36wc/ date of preregistration: 21st of May 2017). While we generally adhered to the
368 preregistration there are a few noteworthy deviations. Specifically, for our main analyses we
369 employed multilevel modelling instead of multiple regressions and conditional random forests
370 instead of dominance analyses, thus addressing the same questions as preregistered with more
371 sophisticated methods. In revising the manuscript, we also ran additional analyses that had not been
372 preregistered (e.g., East-West comparisons) and made some adjustments to the general narrative by
373 incorporating recent research that had been published since our preregistration (see Supplementary
374 Information for more details on deviations from preregistration)

375 The data were obtained from the Gosling-Potter Internet Personality Project[85] (see
376 Supplementary Information for details) which is an ongoing large-scale online project that has
377 received ethical approval from institutional review boards at the University of California and the
378 University of Texas. At the time of access, it contained self-reported personality data of 3,838,112
379 U.S.-residents who provided informed consent to their participation in the project. Several exclusion
380 criteria were used for the current study. Specifically, participants with missing data for the
381 personality measure or for the ZIP code of their place of residence at the time of participation were
382 excluded. We also restricted the age range in our sample to participants who indicated being
383 between the ages of 10 and 99. The selection criteria resulted in a sample of 3,387,014 U.S.
384 residents from 37,227 different ZIP codes across the 48 contiguous states, as well as Washington,
385 D.C., and Alaska. Respondents' mean age was 26.4 (*SD* = 12.04) and 75% had at least graduated from
386 high school (of those who reported their sex, 64% were female). In terms of race, 71.7% identified as
387 White/ Caucasian, whereas 9.4% identified as Black and 2.9%, 8.2%, 1.1% and 5.0% identified as
388 Asian, Hispanic, Mixed, or Other, respectively, which is broadly representative of the racial

composition of the U.S. general population[86]. Prior research in geographical psychology has shown that the present data are almost perfectly proportional to the U.S. Census Bureau's estimates of racial composition, population size, and social class membership of each state, concluding that the "data are generally representative of the population at large"[8].

In addition to individual-level data, we obtained ZIP code level data on latitude, mean household income[87], and population density[88] from the United States Census Bureau. Following current standards laid out by the Nordic Centre for Spatial Development[41], in measuring mountainousness we considered both, altitude (elevation) and topography (hilliness). Accounting for altitude is important because ecological conditions per se get rougher as altitude increases, due to the accompanying changes in climatic harshness[41]. However, a mountainousness measure assessing altitude alone would be incomplete and misleading. For instance, such a measure would interpret flat meadows at high elevation as mountainous, but low-elevation steep ravines would be interpreted as low in mountainousness. Hence, to properly capture both reasonable conceptualizations of mountainousness, it is critical to account for actual topography, which encompasses a landscape's shape; such measures should pick up on the physical elements of an area that may contribute to the sense of remoteness, isolation, and ecological roughness that are typically associated with mountainousness.

Against this backdrop, we employed three indices to assess mountainousness. First, our default indicator of mountainousness, hereafter referred to as mountainousness, was defined as the standard deviation in elevation above sea level within a pre-defined radius (i.e., 20 vs. 50 miles) around a ZIP code's centroid. A standard deviation of 0 indicates no mountainousness at all (i.e., flat land) whereas a large standard deviation indicates a hilly area (i.e., mountains). The least mountainous ZIP code was 27915 in Avon, NC and the most mountainous, was 93526 in Independence, CA. To illustrate the mechanics and implementation of our measure, Figure 1 shows the mountainousness assessment for these two ZIP codes. To further attest to its validity, based on our measure Figure 2 provides an independently reconstructed topographical map of the U.S., which

neatly reproduces the country's actual topography.

Second, by accounting for the order of elevation values in the investigated radius, the mean squared successive difference measure[89], hereafter called mountainousness-MSSD, also tracks topographical dynamics. This measure not only captures overall variability (hilliness) but also stability in variability, or evenness of hilliness[90]. A higher value of mountainousness-MSSD indicates less stability in elevation and hence more extreme mountains[90]. Mountainousness-MSSD was highest in Marblemount, WA (ZIP code: 98267) and lowest in Avon, NC (ZIP code: 27915).

Third, mean elevation above sea within the respective pre-defined radius around a ZIP code's centroid was used to assess altitude. The least elevated ZIP code, actually below sea level, was 92281 in Westmorland, CA, and the most elevated ZIP code was 81433 in Silverton, Colorado. For the computation of all indices, elevation data were obtained from NASA and CGIAR Consortium for Spatial Information and subsequently linked to the geolocations (longitude, latitude) of all U.S. ZIP codes (technical details are provided in the Supplementary Information).

In keeping with our research goals outlined above, we adopted a two-pronged analysis strategy: First, we applied multilevel modelling to test our hypotheses and explore potential effects of mountainousness. Following the hierarchical data structure, participants (level 1) were nested in ZIP codes (level 2), to account for statistical dependence within each ZIP code as well as ZIP code differences in the observed relationships[43]. In accordance with previous research[17, 19, 57] we specified random-intercept fixed slope models for all our multilevel analyses.

To separate purely ecological effects of mountainousness (which are found in both the East and West) from sociocultural effects due to frontier culture (which should be present only in the Mountain West), we conducted a longitude-based median split of our sample and ran independent multilevel models for the Eastern and Western subsample. As marked in Figure 2, the median split point of our sample was at 87.86° West, which is close to the actual median center of the population of the United States at 87.13° West in Pike County, Indiana[91]. In addition, and further attesting to the geographical representativeness of our sample, this split point also seems suitable because it neatly

441 separates the big mountains in the West (e.g. Rocky Mountains) from those of the East (e.g.,
442 Appalachian Mountains). Moreover, the split point is fairly close to St. Louis, MO (at 90.18° West),
443 "the Gateway to the West" and hence a useful demarcation of the former frontier.
444 For all multilevel models, level 1 control variables were participant's sex, age, education,
445 race, and self-reported social class. Level 2 control variables included population density and median
446 income, along with latitude, which is a widely used index of climatic stress and has previously been
447 related to personality[6, 16,20, 92]. Two-tailed significance testing was applied for all analyses. Zero-order
448 correlations between personality, mountainousness, and all level 1, and level 2 control variables are
449 reported in the Supplementary Information (see Supplementary Table 1, Supplementary Table 2).
450 Second, we employed supervised machine learning to measure the practical relevance of
451 mountainousness compared to controls and test the explanatory power of the three
452 mountainousness indices against each other. Conditional random forests are a powerful data-driven
453 ensemble learning method[48] that assesses the relative contribution of each predictor by exploring all
454 possible relationships within the model structure between predictors and the outcome variable
455 through a multitude of decision trees. Variable importance is assessed by randomly permutating (or
456 shuffling) the values of one predictor and examining the resulting loss in prediction accuracy: little
457 loss indicates low importance. As a non-parametric bootstrapping-type repeated-sampling method,
458 conditional random forests yield highly accurate estimates that are robust to nonlinearity, higher-
459 order interactions, heterogeneity, over sampling, and correlated predictors[50,93]. The latter is
460 especially important in this context. The three mountainousness indices are highly correlated
461 (mountainousness/mountainousness-MSSD r = .89, mountainousness/elevation r = .66,
462 mountainousness-MSSD/elevation r = .61) so entering them simultaneously into multilevel models
463 would most likely produce substantial bias due to multicollinearity. However, entering them
464 simultaneously into conditional random forests allows for a fair and unbiased test of their relative
465 contribution to the prediction of personality.
466

Code availability statement

The analysis scripts are available as R code and SPSS syntax files on our project page on the Open Science Framework (https://osf.io/y2mdw/).

Data availability statement

The data that support the findings of this study are available from the corresponding author upon request. The personality data from the Gosling-Potter Internet Personality Project are propriety data and may not currently be shared publicly. To inquire about access to these proprietary data, please contact Samuel D. Gosling (samg@austin.utexas.edu). The mountainousness measure (based on standard deviation in elevation across a 20/50 mile radius from one's ZIP code of living) was developed by the research team, extracting topographical information from satellite image and geo-coordinates. As such, a dataset containing the three mountainousness measures for the United States, as well as corresponding code are available on our project page on the Open Science Framework (https://osf.io/y2mdw/). The sociodemographic ZIP code-level data are freely available from the United States Census Bureau and can be publicly accessed (https://www.census.gov/programs-surveys/acs).

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Acknowledgements

The present research was supported by doctoral scholarships of the Economic and Social Research Council (ESRC) and the Cambridge Trust to Friedrich M. Götz. We would like to thank Selina Volsa (Karl-Landsteiner University of Health Sciences, Austria) for her great assistance with the visualisation of our mountainousness measure as well as Andrés Gvirtz (University of Cambridge, United Kingdom) for aesthetic and moral support. Furthermore, we are grateful to Andreas Nehrlich (University of Koblenz-Landau, Germany) for kindly allowing us to run some of the more computationally-heavy analyses remotely. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of

the manuscript.

Author contributions

F.M.G. and S.S. conceived the core research idea and designed the study. S.D.G. and J.P. collected and preprocessed the data from the Gosling-Potter Internet Personality Project. S. S. developed the mountainousness measure and collected the corresponding topographical information. F.M.G. analysed the data. F.M.G., S.D.G. and P.J.R. wrote the manuscript. S.S. contributed to the interpretation of the results and provided critical revisions. All authors approved the final version of this manuscript.

Competing interests

The authors declare no competing interests.

Figure Legends

Figure 1. Illustration of mountaionusness measure. Figure 1 demonstrates the implementation of the default mountainousness measure, based on standard deviation in elevation above sea. The two examples reflect the least mountainous ZIP code (27915 in Avon, NC) and the most mountainous ZIP code (93526 in Independence, CA) represented in the present study. For illustration purposes the broader 50-mile radii are shown and the reported mountainousness estimates (SD) capture the 50-mile radius around the respective centroid of each ZIP code.

Figure 2. Topographical map of the United States based on mountainousness measure. Visualising the topographical estimates from the mountainousness measure across the U.S., Figure 2 accurately reproduces the country's actual topography. Moreover, to aid with the interpretation of the East-West comparisons, Figure 2 features a red axis at 87.86° West that marks the longitude-based median split point in the current sample. Figure 2 also shows the location of St. Louis, "the Gateway to the West", just slightly to the West of the median split point.

Figure 3. Variable importance plots. As variable importance values are a relative ranking of predictor importance, the absolute numbers on the X-axis serve for comparison purposes only and cannot be interpreted on their own. Values exceeding the red dashed vertical line are highly unlikely to be random noise and predictors with higher variable importance values are considered more important than those with lower variable importance values (N = 15,313).

Figure 4. Effects of mountainousness on personality. The green bars show the overall effect of mountainousness on personality (N = 1,538,404). The light blue bars show the effects of mountainousness on the Big Five traits due to ecological features (observed in the East of the U.S., N = 769,010). The dark blue bars show the effect of mountainousness on the Big Five traits due to sociocultural norms (frontier culture, observed only in the West of the U.S., N = 768,895). For each coefficient 95% confidence intervals are shown in red.

Table 1. *Results from Multilevel Modelling, Default Model (20-Mile Radius / Current Place of Living)*

Predictor	A β (*p*) [95% CI]	C β (*p*) [95% CI]	E β (*p*) [95% CI]	N β (*p*) [95% CI]	O β (*p*) [95% CI]
Age	.0856(<.001) [.0838, .0874]	.1379(<.001) [.1361, .1397]	-.0538(<.001) [-.0556, -.0519]	-.0741(<.001) [-.0759, -.0724]	.0382(<.001) [.0364, .0399]
Sex	.1078(<.001) [.1063, .1094]	.0595(<.001) [.0579, .0610]	.0638(<.001) [.0623, .0654]	.2110(<.001) [.2095, .2126]	-.0893(<.001) [-.0908, -.0877]
Education	.0248(<.001) [.0230, .0267]	.1308(<.001) [.1290, .1326]	-.0228(<.001) [-.0246, -.0209]	-.0336(<.001) [-.0356, -.0318]	.0866(<.001) [.0848, .0884]
Social Class	-.0091(<.001) [-.0107, -.0075]	.0731(<.001) [.0715, .0747]	.1138(<.001) [.1121, .1154]	-.0991(<.001) [-.1007, -.0975]	.0215(<.001) [.0199, .0231]
White	.0026 (.125) [-.0007, .0059]	-.0069(<.001) [-.0101, -.0036]	-.0114(<.001) [-.0147, -.0080]	.0477(<.001) [.0449, .0509]	-.0873(<.001) [-.0906, -.0839]
Black	.0887(<.001) [.0859, .0914]	.0705(<.001) [.0678, .0733]	.0149(<.001) [.0122, .0178]	-.0756(<.001) [-.0783, -.0728]	-.0544(<.001) [-.0572, -.0516]
Asian	-.0061(<.001) [-.0079, -.0043]	-.0150(<.001) [-.0168, -.0132]	-.0297(<.001) [-.0315, -.0278]	.0127(<.001) [.0109, .0145]	-.0319(<.001) [-.0338, -.0301]
Hispanic	.0278(<.001) [.0254, .0303]	.0153(<.001) [.0128, .0177]	.0092(<.001) [.0067, .0117]	-.0126(<.001) [-.0150, -.0102]	-.0545(<.001) [-.0569, -.0520]
Mixed	.0110(<.001) [.0093, .0127]	-.0039(<.001) [-.0055, -.0022]	-.0163(<.001) [-.0179, -.0146]	.0016(.053) [-.0001, .0033]	-.0238(<.001) [-.0255, -.0221]
Latitude	-.0027(.014) [-.0049, -.0005]	-.0066(<.001) [-.0088, -.0043]	-.0078(<.001) [-.0098, -.0057]	.0032(.002) [.0012, .0052]	-.0245(<.001) [-.0273, -.0217]
Population density per square mile	-.0368(<.001) [-.0393, -.0343]	-.0336(<.001) [-.0362, -.0309]	-.0016(.205) [-.0038, .0006]	.0177(<.001) [.0154, .0199]	.0781(<.001) [.0746, .0816]
Median income	-.0076(<.001) [-.0098, -.0055]	-.0209(<.001) [-.0231, -.0187]	.0132(<.001) [.0113, .0152]	-.0046(<.001) [-.0066, -.0026]	.0217(<.001) [.0189, .0244]
Mountainousness (20-mile radius)	-.0076(<.001) [-.0098, -.0054]	-.0070(<.001) [-.0094, -.0047]	-.0063(<.001) [-.0083, -.0042]	-.0131(<.001) [-.0151, -.0110]	.0338(<.001) [.0309, .0367]
Model Fit Statistics					
AIC	3,076,551	3,129,913	3,770,803	3,647,463	3,026,028

BIC	3,076,747	3,130,109	3,770,999	3,647,659	3,026,224
Ω^2	0.041	0.084	0.026	0.080	0.057
R^2_{marginal}	0.032	0.074	0.019	0.073	0.032
$R^2_{\text{conditional}}$	0.038	0.082	0.023	0.078	0.050

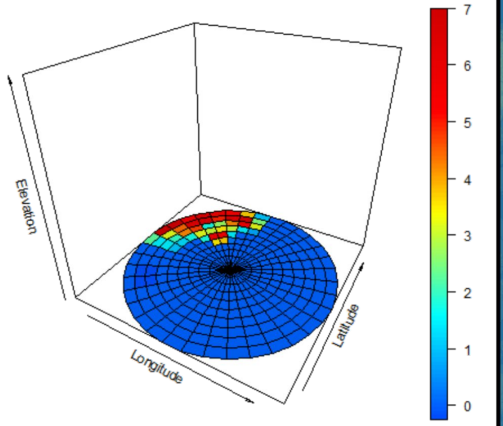
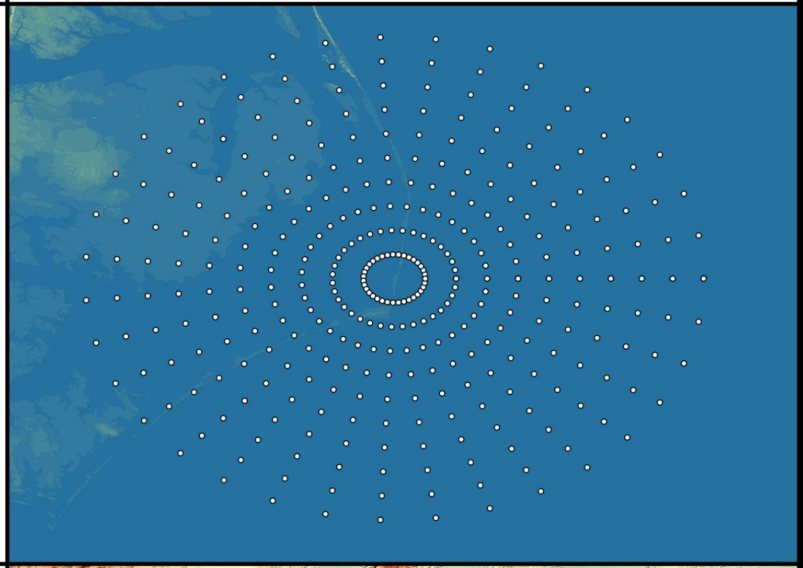
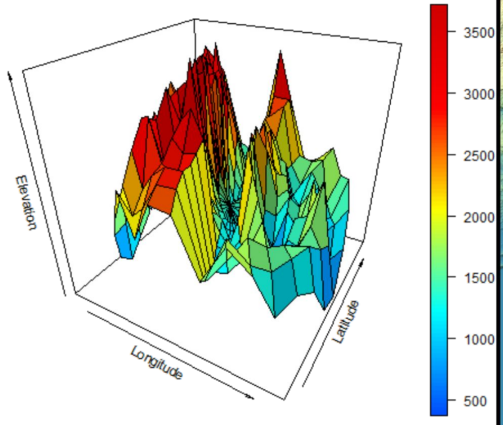
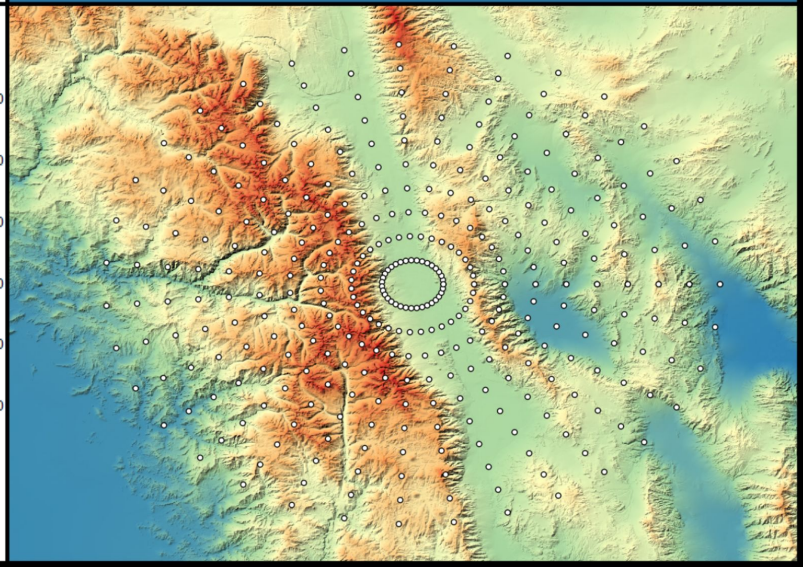
Note. A = Agreeableness, C = Conscientiousness, E = Extraversion, N = Neuroticism, O = Openness, *N* (Level 1) = 1,538,404; *N* (Level 2) = 29,764.

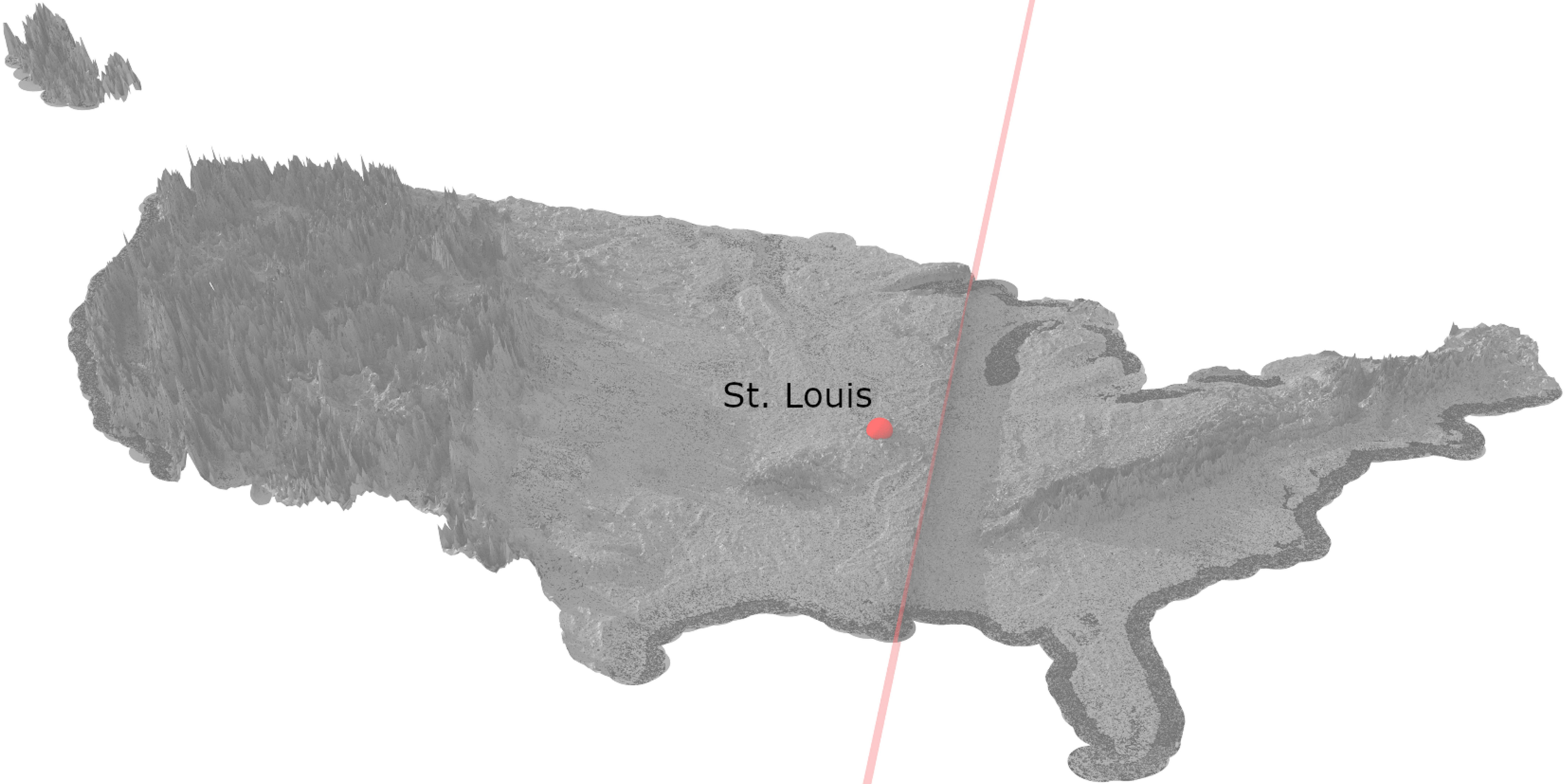
Table 2. *Results from Multilevel Modelling, Comparison of 20 versus 50-Mile Radius / Current vs. Place of Residence During Youth*

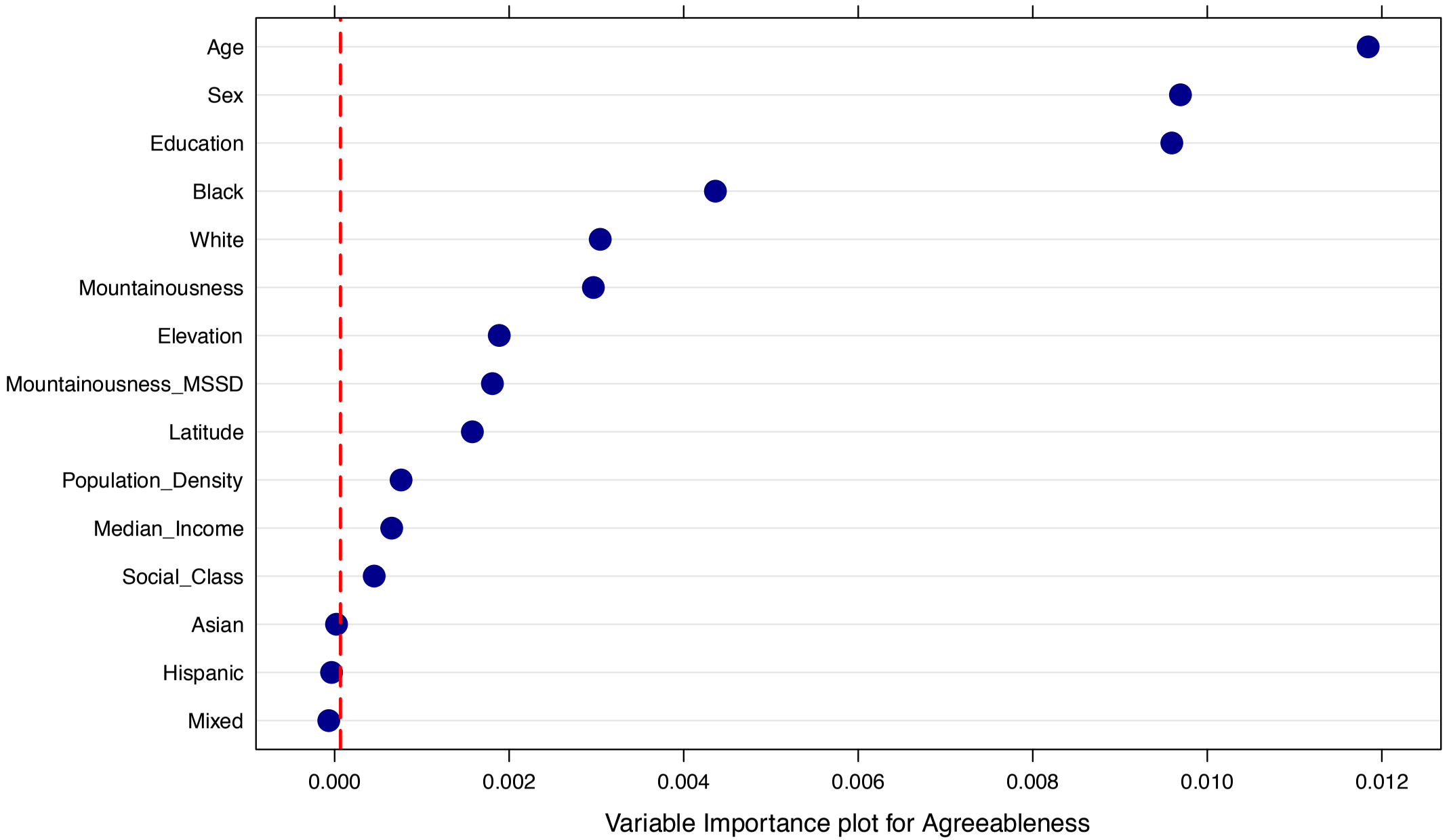
Predictor	A		C		E		N		O	
	β (20m, 50m)		β (20m, 50m)		β (20m, 50m)		β (20m, 50m)		β (20m, 50m)	
Age	.086	.086	.138	.138	-.054	-.054	-.074	-.074	.038	.038
	.089	.089	.139	.139	-.053	-.053	-.076	-.076	.031	.030
Sex	.108	.108	.059	.059	.064	.064	.211	.211	-.089	-.089
	.108	.108	.059	.059	.064	.064	.211	.211	-.091	-.091
Education	.025	.025	.131	.131	-.023	-.023	-.034	-.034	.087	.087
	.018	.018	.124	.124	-.024	-.024	-.031	-.031	.108	.108
Social Class	-.009	-.009	.073	.073	.114	.114	-.099	-.099	.021	.022
	-.011	-.011	.073	.073	.114	.114	-.099	-.099	.021	.021
White	.003 (p=.125)	.002 (p=.155)	-.007	-.007	-.011	-.011	.048	.047	-.087	-.087
	.005 (p=.002)	.005 (p=.002)	-.004 (p=.011)	-.004 (p=.011)	-.010	-.010	.047	.046	-.092	-.092
Black	.089	.089	.071	.071	.015	.015	-.076	-.076	-.054	-.054
	.089	.089	.071	.071	.015	.015	-.077	-.077	-.055	-.055
Asian	-.006	-.006	-.015	-.015	-.029	-.029	.013	.013	-.032	-.032
	-.007	-.007	-.016	-.016	-.031	-.031	.014	.014	-.029	-.029
Hispanic	.028	.028	.015	.015	.009	.009	-.013	-.012	-.055	-.055
	.028	.028	.015	.015	.009	.009	-.013	-.013	-.056	-.056
Mixed	.011	.011	-.004	-.004	-.016	-.016	.002 (p=.053)	.002 (p=.041)	-.024	-.024
	.011	.011	-.004	-.004	-.016	-.016	.002 (p=.058)	.002 (p=.039)	-.023	-.024
Latitude	-.003 (p=.014)	-.002 (p=.026)	-.007	-.006	-.008	-.008	.003 (p=.002)	.004	-.024	-.025
	-.006	-.006	.002 (p=.031)	.002 (p=.031)	-.008	-.008	-.001 (p=.186)	-.001 (p=.379)	-.021	-.021
Population density per square mile	-.037	-.036	-.034	-.033	-.002	-.001 (p=.234)	.018	.018	.078	.076
	-.022	-.022	-.015	-.015	.006	.007	.011	.011	.045	.044
Median Income	-.008	-.007	-.021	-.021	.013	.013	-.005	-.004	.022	.021
	-.012	-.012	-.035	-.035	.017	.017	-.002 (p=.025)	-.002 (p=.084)	.043	.042
Mountainousness	-.008	-.009	-.007	-.007	-.006	-.006	-.013	-.016	.034	.038
	-.005	-.005	-.003 (p=.002)	-.003 (p=.014)	-.009	-.007	-.014	-.018	.020	.023

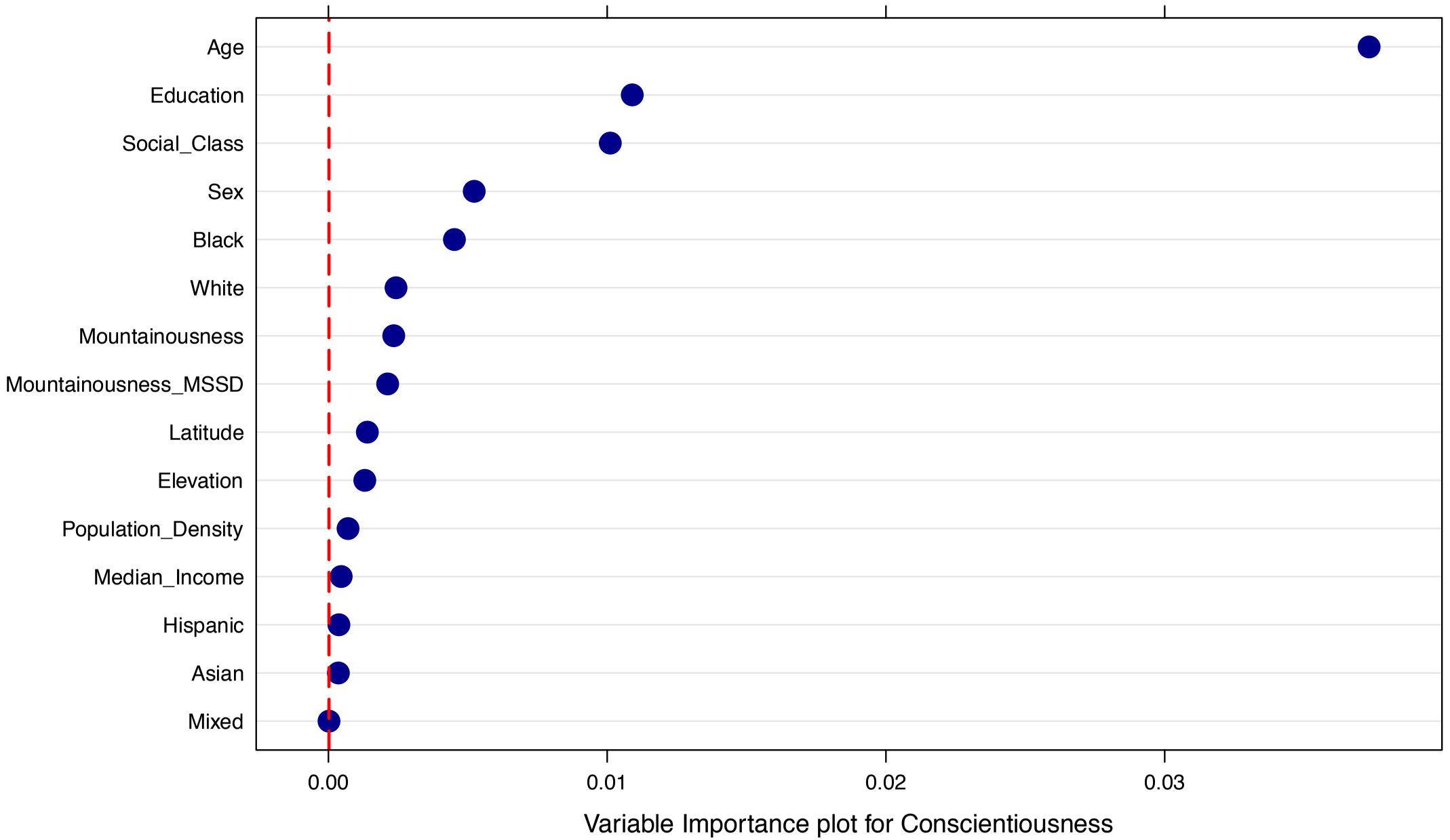
Note. First-line entries = analyses for place of residence at present, second-line entries = analyses for place of residence at youth; all predictors were significant with $p < .001$ unless

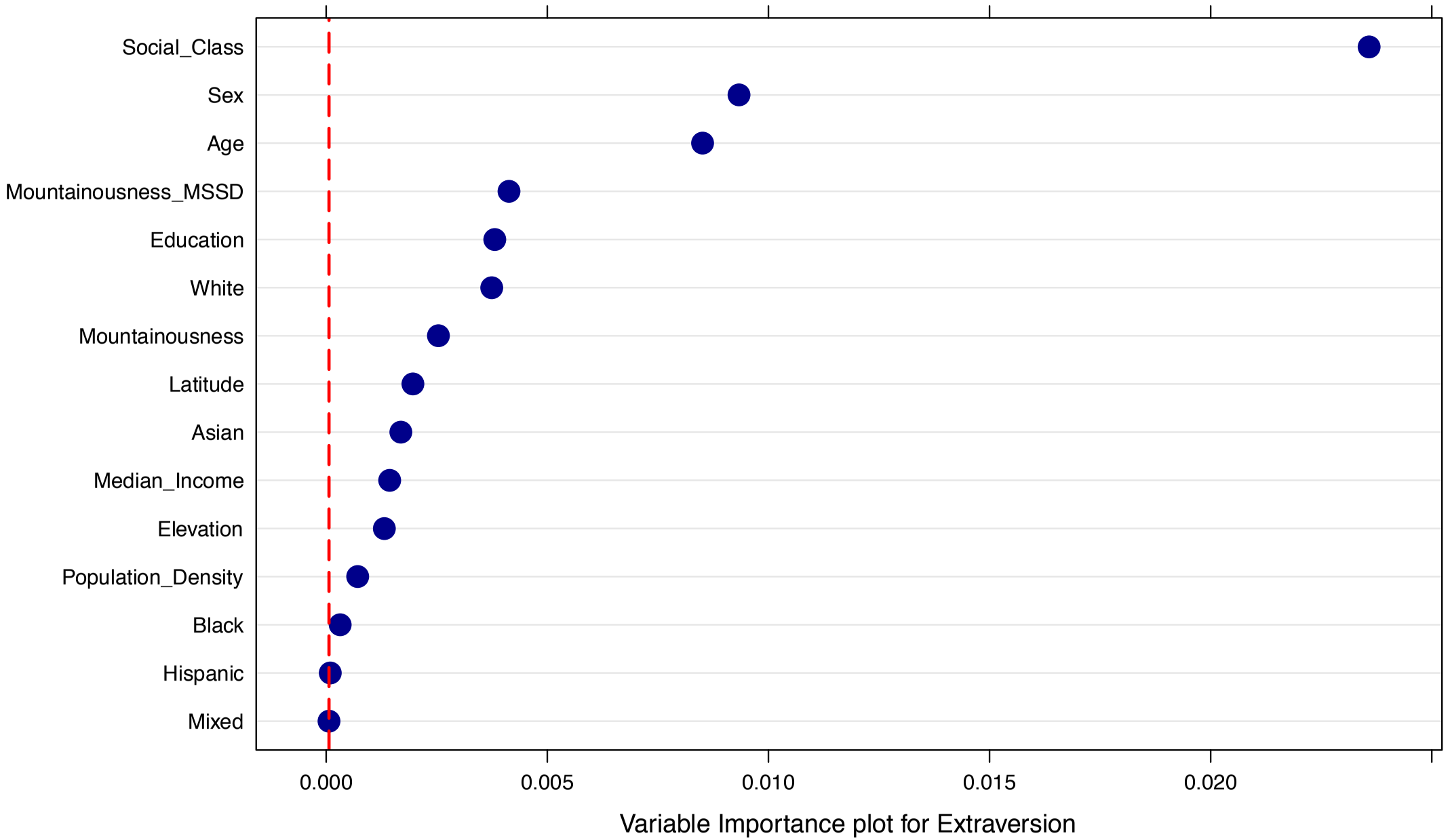
indicated otherwise; A = Agreeableness, C = Conscientiousness, E = Extraversion, N = Neuroticism, O = Openness to experience; sex: 0 = male, 1 = female; N (Level 1) = 1,538,404, N (Level 2, present) = 29,764, N (Level 2, youth) = 31,012.

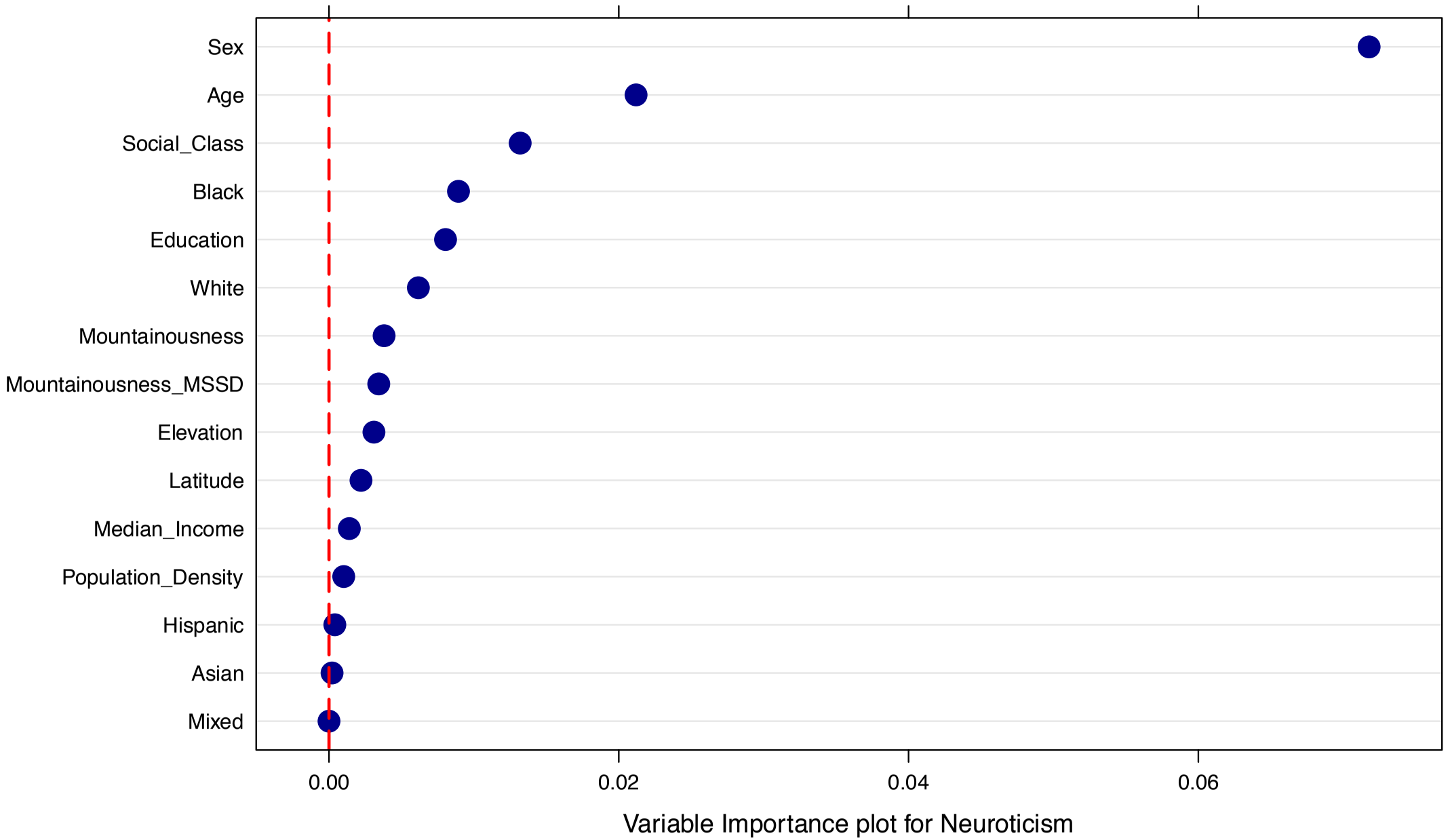
ZIP Code	SD	3D rendering of map data	Map view of area
27915	1.91		
93526	886.24		

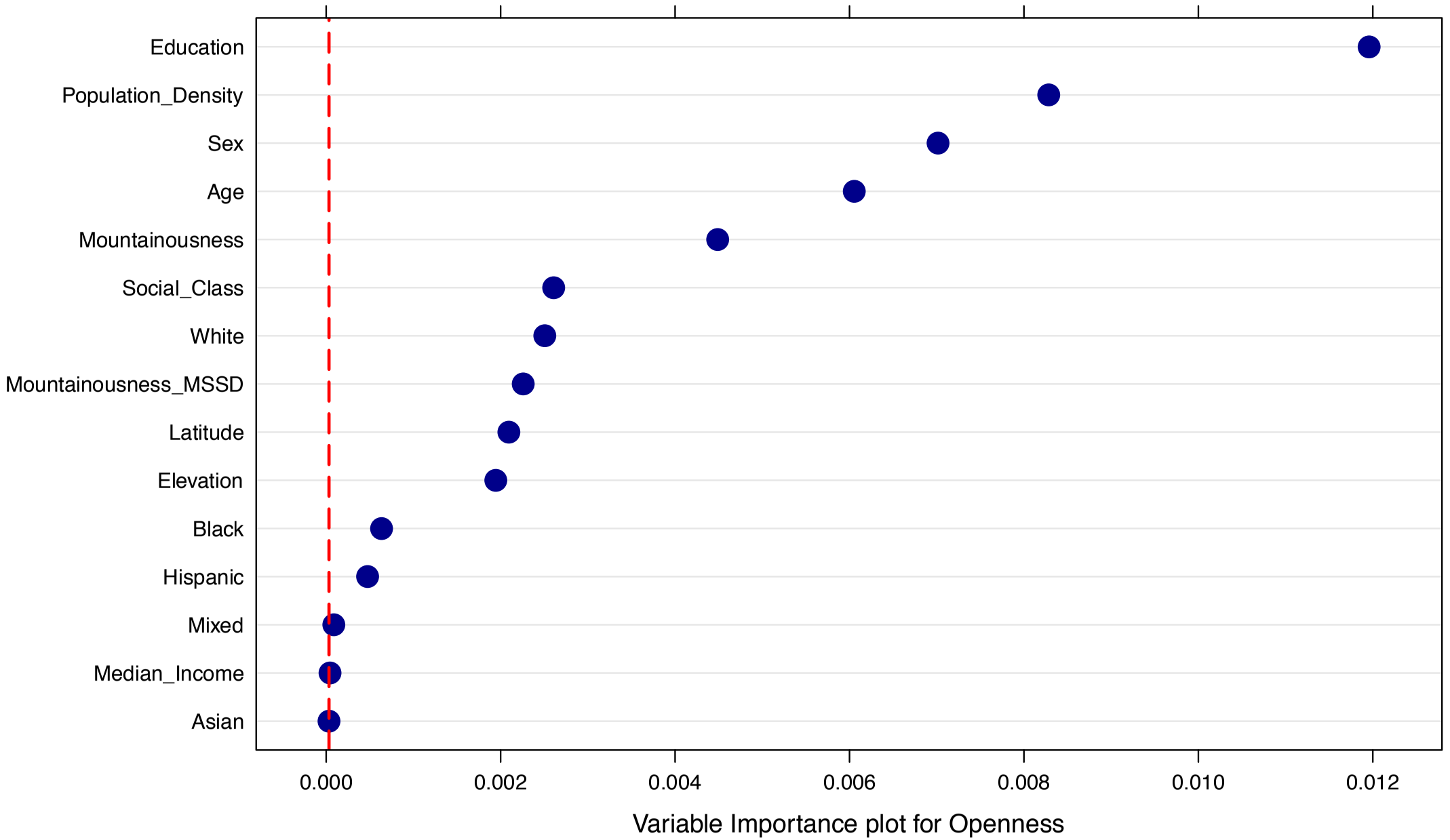

St. Louis

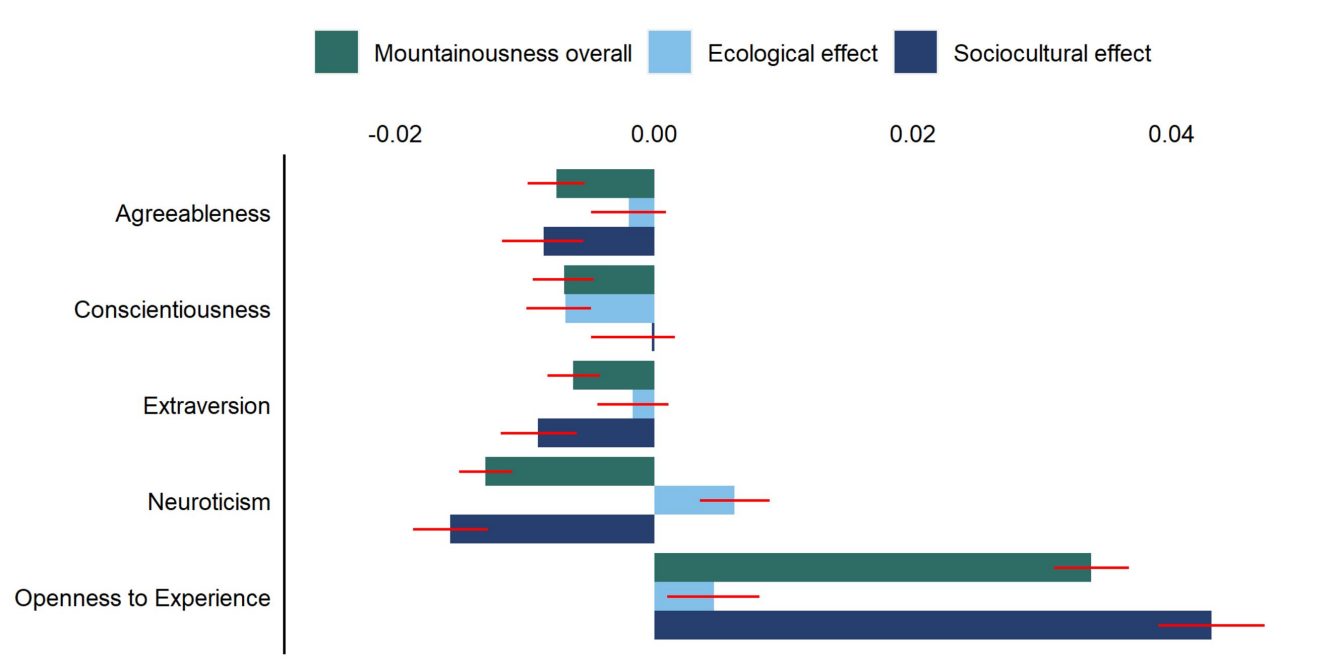

Age
Sex
Education
Black
White
Mountainousness
Elevation
Mountainousness_MSSD
Latitude
Population_Density
Median_Income
Social_Class
Asian
Hispanic
Mixed
0.000
0.002
0.004
0.006
0.008
0.010
0.012
Variable Importance plot for Agreeableness


Age
Education
Social_Class
Sex
Black
White
Mountainousness
Mountainousness_MSSD
Latitude
Elevation
Population_Density
Median_Income
Hispanic
Asian
Mixed
0.00
0.01
0.02
0.03
Variable Importance plot for Conscientiousness


Social_Class
Sex
Age
Mountainousness_MSSD
Education
White
Mountainousness
Latitude
Asian
Median_Income
Elevation
Population_Density
Black
Hispanic
Mixed
0.000
0.005
0.010
0.015
0.020
Variable Importance plot for Extraversion


Sex
Age
Social_Class
Black
Education
White
Mountainousness
Mountainousness_MSSD
Elevation
Latitude
Median_Income
Population_Density
Hispanic
Asian
Mixed
0.00
0.02
0.04
0.06
Variable Importance plot for Neuroticism


Education
Population_Density
Sex
Age
Mountainousness
Social_Class
White
Mountainousness_MSSD
Latitude
Elevation
Black
Hispanic
Mixed
Median_Income
Asian
0.000
0.002
0.004
0.006
0.008
0.010
0.012
Variable Importance plot for Openness


Mountainousness overall
Ecological effect
Sociocultural effect
-0.02
0.00
0.02
0.04
Agreeableness
Conscientiousness
Extraversion
Neuroticism
Openness to Experience