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Physical topography is associated with human personality

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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 multilevel modelling 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 neighbourhoods, 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, both during the arrival of European settlers in the United States as well as across other countries and time periods (for example, settlement of Hokkaido, Japan during the Meiji restoration), 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]—non-conformists 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 United States[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 non-conformist, aloof settlers who initially moved to the mountain frontier[27], the territoriality and scepticism 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 of 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

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others have found no statistical relationship[32]. Likewise, although US mountain region residents score low on some aspects of conscientiousness (for example, civic obligation), they score high on others (for example, 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 probably 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, previous 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 underlying 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 others to move to mountainous areas because the psychological demands and affordances of these areas satisfy their personalities. For example, introverts may leave a city seeking the relative solitude of a frontier region, or a strongly independent person may thrive in the unstructured environment that such regions offer. (2) Ecological influence suggests that the conditions of mountainous environments could directly shape the personalities of residents. For example, the remoteness and isolation that come with the mountains might reinforce behaviours and traits associated with social withdrawal, self-reliance and introversion. (3) Sociocultural influence suggests that the unique local traditions, customs, lifestyles and daily practices of mountainous areas may shape specific social norms which, in turn, affect inhabitants' personalities. For example, the ethos of independence that may have originally developed as a response to the harsh environment might, over time, evolve and become deeply engrained in the collective mindset and culture of the mountainous regions. Subsequently, it might give rise to specific social and behavioural norms which then shape the personalities of people living in this independence-prone local culture. Of note, this theoretical framework further distinguishes two forms of sociocultural influences[7,22]: initial enculturation and acculturation. Initial enculturation posits that the experience of being born and raised in a mountainous area shapes people's personalities whereas acculturation posits that people's personalities may change as they move to a mountainous area later in their life.

Although previous research indicates that selective migration, ecological influence and sociocultural influence are important[7,8,22,40], it is difficult to determine the degree to which any of these contributes to the link between mountainousness and personality. While also unable to establish direct causality, the present investigation attempts to shed some light on the issue by adopting a twofold approach. In the first step, we zoom in on selective migration as well as the two forms of sociocultural influences (initial enculturation and acculturation); to do this, we compare associations between personality and the mountainousness of the places in which participants grew up versus the mountainousness of the places in which they lived when they participated in the study. In keeping with Kitayama and colleagues[7], a stronger 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 (for example the Rocky Mountains), whereas they should be absent in the eastern mountains (for example, the 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 United States 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 are hence well suited to capturing the hilliness, or the shape, of a landscape; the third indicator, elevation, is a marker of overall altitude (Figs. 1 and 2; see Methods and Supplementary Information for details). Because the average national commuting distance in the United States is 18.8 miles[42], 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 examine directly the degree to which physical topography is associated with individual personality. Specifically, using a sample of >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 United States. In doing so, we extend previous research[23,35] by (1) investigating all Big Five traits rather

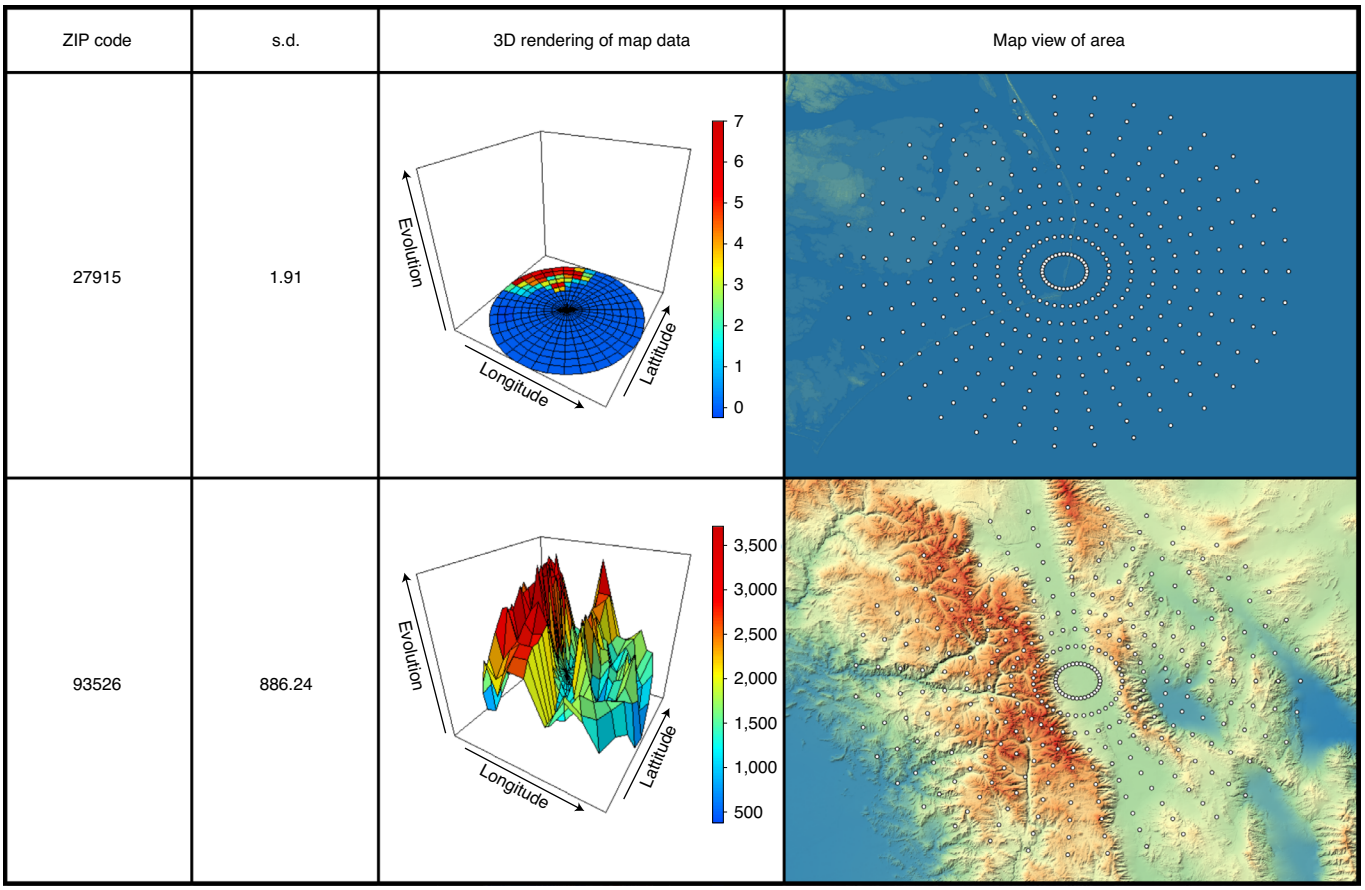

Fig. 1 | Illustration of mountainousness measure. Implementation of the default mountainousness measure, based on standard deviation in elevation above sea level. The two examples reflect the least mountainous ZIP code (27915 in Avon, NC) and the most mountainous (93526 in Independence, CA) represented in the present study. For illustration purposes the broader 50-mile radii are shown and the reported mountainousness estimates (s.d.) capture the 50-mile radius around the respective centroid of each ZIP code. 3D, three-dimensional.

than single traits, (2) using objective measures of mountainousness and (3) analysing data at the level of ZIP codes rather than states.

Results

For the default model (mountainousness, 20-mile radius, present place of living) multi-level modelling showed that mountainousness had negative associations with agreeableness (β[95% confidence interval (CI)] = −0.008[−0.010, −0.005], $P < 0.001$), conscientiousness (β[95% CI] = −0.007[−0.009, −0.005], $P < 0.001$), extraversion (β[95% CI] = −0.006[−0.008, −0.004], $P < 0.001$) and neuroticism (β[95% CI] = −0.013[−0.015, −0.011], $P < 0.001$), and a positive relationship with openness to experience (β[95% CI] = 0.034[0.031,0.037], $P < 0.001$). 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 previous 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 standardized 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 ordinary least squares regressions, is reported to assess the models' overall explanatory power. Further details on both Ω^2 and multi-level models for the mean squared successive difference measure (mountainousness–MSSD) and elevation, both of which identically replicated the patterns of the default model (see Supplementary Tables 3 and 4), can be found in the Supplementary Information.

Conditional random forests identified mountainousness as a meaningful predictor of personality. As can be seen in Fig. 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 zero-order correlations of personality with mountainousness were stronger than zero-order correlations with elevation (agreeableness, $Z = 6.78$, $P < 0.001$; conscientiousness, $Z = 9.49$, $P < 0.001$; extraversion, $Z = 3.62$, $P < 0.001$; neuroticism, $Z = 6.33$, $P < 0.001$; openness to experience, $Z = 49.76$, $P < 0.001$) and mountainousness–MSSD (agreeableness, $Z = 16.45$, $P < 0.001$; conscientiousness, $Z = 8.50$, $P < 0.001$; extraversion, $Z = 3.29$, $P < 0.001$; neuroticism, $Z = 1.92$, $P = 0.0549$; openness to experience, $Z = 22.49$, $P < 0.001$).

When exploring the relationship between mountainousness and personality with a broader operational definition of people's living

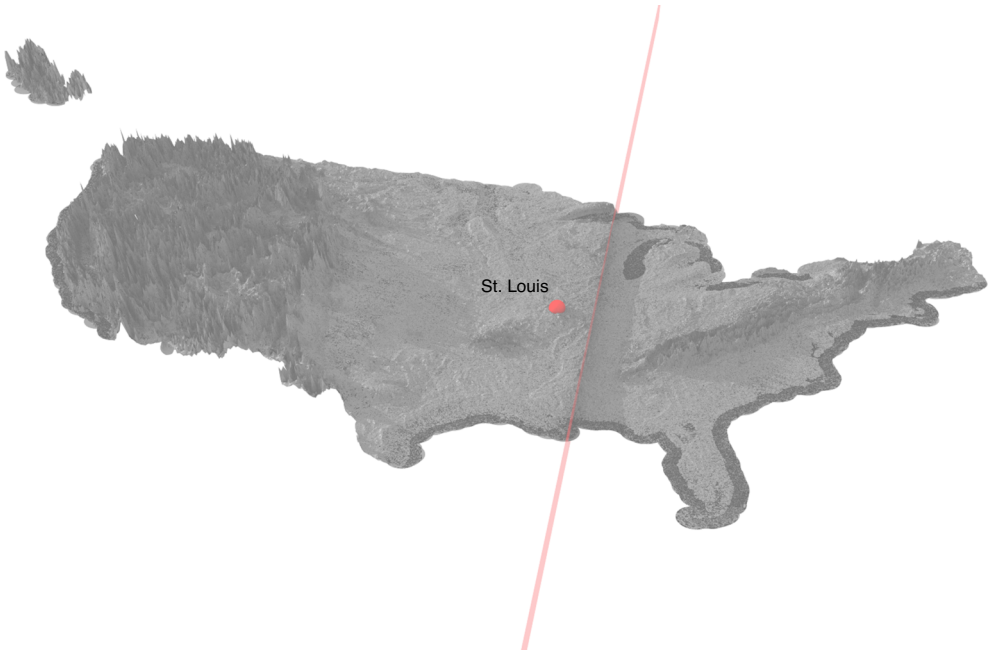

Fig. 2 | Topographical map of the United States based on mountainousness measure. Visualization of topographical estimates from the mountainousness measure across the United States, accurately reproducing the country's actual topography. To aid interpretation of east–west comparisons, the red axis at 87.86° W marks the longitude-based median split point in the current sample. Also shown is the location of St. Louis, 'the gateway to the west', just slightly to the west of the median split point.

environments (that is, 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 associations were larger for 50-mile rather than 20-mile radii for four of the Big Five traits (agreeableness, $Z=5.84$, $P<0.001$; conscientiousness, $Z=2.336$, $P=0.019$; neuroticism, $Z=6.54$, $P<0.001$; openness to experience, $Z=18.929$, $P<0.001$), with the exception of extraversion, where no significant difference was detected (extraversion, $Z=0.234$, $P=0.815$). 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 zero-order correlations were observed for place of youth and agreeableness ($Z=3.738$, $P<0.001$), conscientiousness ($Z=11.213$, $P<0.001$) and extraversion ($Z=2.803$, $P=0.005$), but the reverse pattern emerged for neuroticism ($Z=-11.212$, $P<0.001$) and openness ($Z=-15.583$, $P<0.001$). 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 multi-level models for the east versus west of the United States, notable differences were observed (see Supplementary Tables 5 and 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] = −0.007[−0.009,−0.005], $P<0.001$) and openness to experience (β[95% CI] = 0.005[0.001,0.008], $P=0.011$) mirrored the general model, agreeableness and extraversion were no longer significantly related to mountainousness, and neuroticism was positively associated with mountainousness (β[95% CI] = 0.006[0.004,0.009], $P<0.001$). Of note, in the west the relationship for openness to experience (β[95% CI] = 0.0431[0.039,0.047], $P<0.001$), which yielded the strongest effect in the general model, was almost ten times as high as in the east (β[95% CI] = 0.0046[0.001,0.008], $P<0.001$).

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 (that is, age, sex, educational status, race and perceived social class) and macro-environmental (latitude, population density, and median income) control variables. The patterns of results show substantial consistency across a series of robustness checks and cross-validation with a powerful machine learning algorithm. As such, people living in mountainous terrain tend to be lower on agreeableness, conscientiousness, extraversion and neuroticism, and higher on openness to experience, than people living in non-mountainous terrain (see Fig. 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 previous research indicating that mountain regions exhibit comparatively low levels of civic involvement[26] and obedience[24]. The low

Table 1 | Results from multi-level modelling, default model (20-mile radius around current place of living)

Predictor	Agreeableness	Conscientiousness	Extraversion	Neuroticism	Openness
	β (*P*) [95% CI]	*β* (*P*) [95% CI]	*β* (*P*) [95% CI]	*β* (*P*) [95% CI]	*β* (*P*) [95% CI]
Age	0.0856 (<0.001) [0.0838, 0.0874]	0.1379 (<0.001) [0.1361, 0.1397]	−0.0538 (<0.001) [−0.0556, −0.0519]	−0.0741 (<0.001) [−0.0759, −0.0724]	0.0382 (<0.001) [0.0364, 0.0399]
Sex	0.1078 (<0.001) [0.1063, 0.1094]	0.0595 (<0.001) [0.0579, 0.0610]	0.0638 (<0.001) [0.0623, 0.0654]	0.2110 (<0.001) [0.2095, 0.2126]	−0.0893 (<0.001) [−0.0908, −0.0877]
Education	0.0248 (<0.001) [0.0230, 0.0267]	0.1308 (<0.001) [0.1290, 0.1326]	−0.0228 (<0.001) [−0.0246, −0.0209]	−0.0336 (<0.001) [−0.0356, −0.0318]	0.0866 (<0.001) [0.0848, 0.0884]
Social class	−0.0091 (<0.001) [−0.0107, −0.0075]	0.0731 (<0.001) [0.0715, 0.0747]	0.1138 (<0.001) [0.1121, 0.1154]	−0.0991 (<0.001) [−0.1007, −0.0975]	0.0215 (<0.001) [0.0199, 0.0231]
White	0.0026 (0.125) [−0.0007, 0.0059]	−0.0069 (<0.001) [−0.0101, −0.0036]	−0.0114 (<0.001) [−0.0147, −0.0080]	0.0477 (<0.001) [0.0449, 0.0509]	−0.0873 (<0.001) [−0.0906, −0.0839]
Black	0.0887 (<0.001) [0.0859, 0.0914]	0.0705 (<0.001) [0.0678, 0.0733]	0.0149 (<0.001) [0.0122, 0.0178]	−0.0756 (<0.001) [−0.0783, −0.0728]	−0.0544 (<0.001) [−0.0572, −0.0516]
Asian	−0.0061 (<0.001) [−0.0079, −0.0043]	−0.0150 (<0.001) [−0.0168, −0.0132]	−0.0297 (<0.001) [−0.0315, −0.0278]	0.0127 (<0.001) [0.0109, 0.0145]	−0.0319 (<0.001) [−0.0338, −0.0301]
Hispanic	0.0278 (<0.001) [0.0254, 0.0303]	0.0153 (<0.001) [0.0128, 0.0177]	0.0092 (<0.001) [0.0067, 0.0117]	−0.0126 (<0.001) [−0.0150, −0.0102]	−0.0545 (<0.001) [−0.0569, −0.0520]
Mixed race	0.0110 (<0.001) [0.0093, 0.0127]	−0.0039 (<0.001) [−0.0055, −0.0022]	−0.0163 (<0.001) [−0.0179, −0.0146]	0.0016 (0.053) [−0.0001, 0.0033]	−0.0238 (<0.001) [−0.0255, −0.0221]
Latitude	−0.0027 (0.014) [−0.0049, −0.0005]	−0.0066 (<0.001) [−0.0088, −0.0043]	−0.0078 (<0.001) [−0.0098, −0.0057]	0.0032 (0.002) [0.0012, 0.0052]	−0.0245 (<0.001) [−0.0273, −0.0217]
Population density per square mile	−0.0368 (<0.001) [−0.0393, −0.0343]	−0.0336 (<0.001) [−0.0362, −0.0309]	−0.0016 (0.205) [−0.0038, 0.0006]	0.0177 (<0.001) [0.0154, 0.0199]	0.0781 (<0.001) [0.0746, 0.0816]
Median income	−0.0076 (<0.001) [−0.0098, −0.0055]	−0.0209 (<0.001) [−0.0231, −0.0187]	0.0132 (<0.001) [0.0113, 0.0152]	−0.0046 (<0.001) [−0.0066, −0.0026]	0.0217 (<0.001) [0.0189, 0.0244]
Mountainousness (20-mile radius)	−0.0076 (<0.001) [−0.0098, −0.0054]	−0.0070 (<0.001) [−0.0094, −0.0047]	−0.0063 (<0.001) [−0.0083, −0.0042]	−0.0131 (<0.001) [−0.0151, −0.0110]	0.0338 (<0.001) [0.0309, 0.0367]
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
$R^2_{conditional}$	0.038	0.082	0.023	0.078	0.050

n (level 1) = 1,538,404; *n* (level 2) = 29,764. AIC, Akaike information criterion; BIC, Bayesian information criterion.

levels of extraversion in mountainous areas converge with defining characteristics of individualism such as detachment, distance, and self-reliance[36], and also replicate 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 United States. 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 (that is, hilliness and elevation) yield noteworthy patterns of low levels of conscientiousness and—in direct contrast with the sociocultural effects—high neuroticism (Fig. 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 probably 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

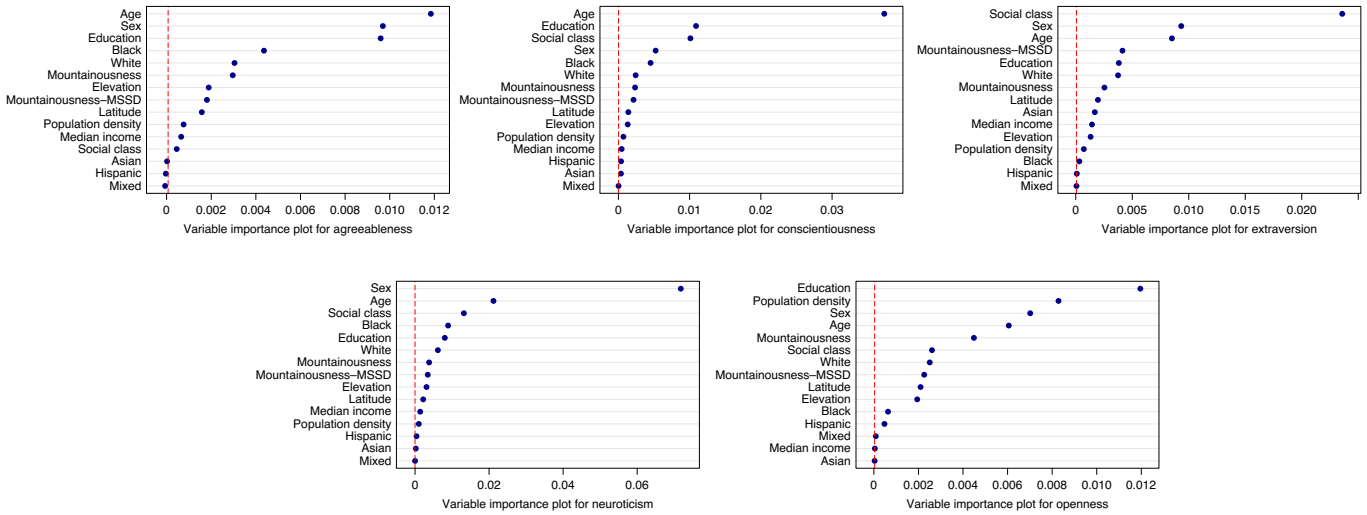

Fig. 3 | Variable importance value plots. Because variable importance values are a relative ranking of predictor importance, the absolute numbers on the *x*-axis serve for comparison purposes only and cannot be interpreted on their own. Values exceeding the red dashed vertical line are highly unlikely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

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 organized 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 (Fig. 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 multi-gene systems. Such approaches explicitly acknowledge that each individual gene will probably have a very small effect, accounting for <1% of variance[65,67] or even just 0.1% (ref. [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 socio-ecological 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. However, 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, 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

Table 2 | Results from multilevel modelling: comparison of 20- versus 50-mile radius around current versus place of residence during youth

Predictor	Agreeableness		Conscientiousness		Extraversion		Neuroticism		Openness	
	β (20-, 50-mile)		*β* (20-, 50-mile)		*β* (20-, 50-mile)		*β* (20-, 50-mile)		*β* (20-, 50-mile)	
Age	0.086	0.086	0.138	0.138	−0.054	−0.054	−0.074	−0.074	0.038	0.038
	0.089	0.089	0.139	0.139	−0.053	−0.053	−0.076	−0.076	0.031	0.030
Sex	0.108	0.108	0.059	0.059	0.064	0.064	0.211	0.211	−0.089	−0.089
	0.108	0.108	0.059	0.059	0.064	0.064	0.211	0.211	−0.091	−0.091
Education	0.025	0.025	0.131	0.131	−0.023	−0.023	−0.034	−0.034	0.087	0.087
	0.018	0.018	0.124	0.124	−0.024	−0.024	−0.031	−0.031	0.108	0.108
Social class	−0.009	−0.009	0.073	0.073	0.114	0.114	−0.099	−0.099	0.021	0.022
	−0.011	−0.011	0.073	0.073	0.114	0.114	−0.099	−0.099	0.021	0.021
White	0.003 ($P=0.125$)	0.002 ($P=0.155$)	−0.007	−0.007	−0.011	−0.011	0.048	0.047	−0.087	−0.087
	0.005 ($P=0.002$)	0.005 ($P=0.002$)	−0.004 ($P=0.011$)	−0.004 ($P=0.011$)	−0.010	−0.010	0.047	0.046	−0.092	−0.092
Black	0.089	0.089	0.071	0.071	0.015	0.015	−0.076	−0.076	−0.054	−0.054
	0.089	0.089	0.071	0.071	0.015	0.015	−0.077	−0.077	−0.055	−0.055
Asian	−0.006	−0.006	−0.015	−0.015	−0.029	−0.029	0.013	0.013	−0.032	−0.032
	−0.007	−0.007	−0.016	−0.016	−0.031	−0.031	0.014	0.014	−0.029	−0.029
Hispanic	0.028	0.028	0.015	0.015	0.009	0.009	−0.013	−0.012	−0.055	−0.055
	0.028	0.028	0.015	0.015	0.009	0.009	−0.013	−0.013	−0.056	−0.056
Mixed race	0.011	0.011	−0.004	−0.004	−0.016	−0.016	0.002 ($P=0.053$)	0.002 ($P=0.041$)	−0.024	−0.024
	0.011	0.011	−0.004	−0.004	−0.016	−0.016	0.002 ($P=0.058$)	0.002 ($P=0.039$)	−0.023	−0.024
Latitude	−0.003 ($P=0.014$)	−0.002 ($P=0.026$)	−0.007	−0.006	−0.008	−0.008	0.003 ($P=0.002$)	0.004	−0.024	−0.025
	−0.006	−0.006	0.002 ($P=0.031$)	0.002 ($P=0.031$)	−0.008	−0.008	−0.001 ($P=0.186$)	−0.001 ($P=0.379$)	−0.021	−0.021
Population density per square mile	−0.037	−0.036	−0.034	−0.033	−0.002	−0.001 ($P=0.234$)	0.018	0.018	0.078	0.076
	−0.022	−0.022	−0.015	−0.015	0.006	0.007	0.011	0.011	0.045	0.044
Median income	−0.008	−0.007	−0.021	−0.021	0.013	0.013	−0.005	−0.004	0.022	0.021
	−0.012	−0.012	−0.035	−0.035	0.017	0.017	−0.002 ($P=0.025$)	−0.002 ($P=0.084$)	0.043	0.042
Mountainousness	−0.008	−0.009	−0.007	−0.007	−0.006	−0.006	−0.013	−0.016	0.034	0.038
	−0.005	−0.005	−0.003 ($P=0.002$)	−0.003 ($P=0.014$)	−0.009	−0.007	−0.014	−0.018	0.020	0.023

First-line entries are analyses for place of residence at present, while second-line entries are analyses for place of residence at youth; all predictors were significant with $P<0.001$ unless indicated otherwise. Sex: 0, male; 1, female; *n* (level 1) = 1,538,404, *n* (level 2, present) = 29,764, *n* (level 2, youth) = 31,012.

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 (for example, 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 (for example, Hokkaido (Japan) versus Switzerland and Austria) would offer insights into the cultural specificity of the ethos of independence in the United States[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

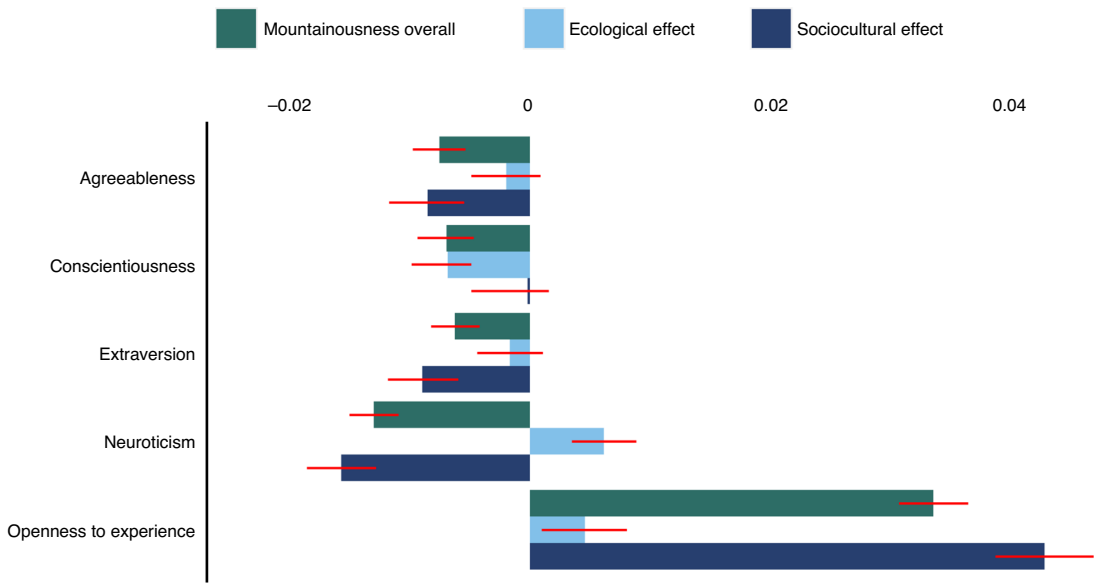

Fig. 4 | Effects of mountainousness on personality. The dark green bars show the overall effect of mountainousness on personality (n = 1,538,404). The light blue bars show the effects of mountainousness on the Big Five traits due to ecological features (observed in the east of the United States, n = 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 United States, n = 768,895). For each coefficient, 95% CIs are shown in red.

so, it underlines the relevance of geographical psychology and socio-ecological research for understanding the complex ways in which individuals and environments interact.

Methods

The present study was preregistered on the Open Science Framework (OSF) before the data were accessed (https://osf.io/y36wc/; date of preregistration, 21 May 2017). While we generally adhered to the preregistration, there are a few noteworthy deviations. Specifically, for our main analyses we employed multi-level modelling instead of multiple regressions and conditional random forests instead of dominance analyses, thus addressing the same questions as preregistered but with more sophisticated methods. In revising the manuscript, we also ran additional analyses that had not been preregistered (for example, east–west comparisons) and made some adjustments to the general narrative by incorporating recent research that had been published since our preregistration (see Supplementary Information for more details on deviations from preregistration)

The data were obtained from the Gosling–Potter Internet Personality Project[85] (see Supplementary Information for details), which is an ongoing, large-scale online project that has received ethical approval from institutional review boards at the University of California and the University of Texas. At the time of access, it contained self-reported personality data of 3,838,112 US residents who provided informed consent to their participation in the project. Several exclusion criteria were used for the current study. Specifically, participants with missing data for the personality measure or for the ZIP code of their place of residence at the time of participation were excluded. We also restricted the age range in our sample to participants who indicated being between the ages of 10 and 99 years. The selection criteria resulted in a sample of 3,387,014 US residents from 37,227 different ZIP codes across the 48 contiguous states, as well as from Washington, DC and Alaska. Respondents' mean age was 26.4 years (s.d. = 12.04), and 75% had at least graduated from high school. In terms of race, 71.7% identified as White/Caucasian whereas 9.4% identified as Black and 2.9, 8.2, 1.1 and 5.0% identified as Asian, Hispanic, Mixed or Other, respectively, which is broadly representative of the racial composition of the US general population[86]. Previous research on geographical psychology has shown that the present data are almost perfectly proportional to the United States 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 become 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 is typically associated with mountainousness.

Against this backdrop, we employed three indices to assess mountainousness. First, our default indicator of mountainousness, herein referred to as mountainousness, was defined as the standard deviation in elevation above sea level within a predefined radius (that is, 20 versus 50 miles) around a ZIP code's centroid. A standard deviation of 0 indicates no mountainousness at all (that is, flat land) whereas a large standard deviation indicates a hilly area (that is, 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, Fig. 1 shows the mountainousness assessment for these two ZIP codes. To further attest to its validity, based on our measure, Fig. 2 provides an independently reconstructed topographical map of the United States that neatly reproduces the country's actual topography.

Second, by accounting for the order of elevation values in the investigated radius, mountainousness–MSSD[89] also tracks topographical dynamics. This measure captures not only 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 level within the respective predefined 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 was 81433 in Silverton, CO. For the computation of all indices, elevation data were obtained from the National Aeronautics and Space Administration and the Consultative Group on International Agricultural Research Consortium for Spatial Information, and were subsequently linked to the geolocations (longitude, latitude) of all US 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 multi-level modelling to test our hypotheses and explore the 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 multi-level 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 multi-level models for the eastern and western subsamples. As shown in Fig. 2, the median split point of our sample was at 87.86° W, which is close to the actual median centre of the population of the

United States at 87.13° W in Pike County, IN[91]. In addition, and further attesting to the geographical representativeness of our sample, this split point also seems suitable because it neatly separates the big mountains in the west (for example, the Rocky Mountains) from those of the east (for example, the Appalachian Mountains). Moreover, the split point is fairly close to St. Louis, MO (at 90.18° W), 'the gateway to the west' and hence a useful demarcation of the former frontier.

For all multi-level models, level 1 control variables were the participant's sex, age, education, race and self-reported social class. Level 2 control variables included population density and median income, along with latitude, which is a widely used index of climatic stress and has previously been related to personality[6,16,20,92]. Two-tailed significance testing was applied for all analyses. Zero-order correlations between personality, mountainousness and all level 1 and 2 control variables are reported in the Supplementary Information (see Supplementary Tables 1 and 2).

Second, we employed supervised machine learning to measure the practical relevance of mountainousness compared to controls and test the explanatory power of the three mountainousness indices against each other. Conditional random forests are a powerful data-driven ensemble learning method[48] that assesses the relative contribution of each predictor by exploring all possible relationships within the model structure between predictors and the outcome variable, through a multitude of decision trees. Variable importance is assessed by randomly permutating (or shuffling) the values of one predictor and examining the resulting loss in prediction accuracy: little loss indicates low importance. As a non-parametric, bootstrapping-type, repeat-sampling method, conditional random forests yield highly accurate estimates that are robust to nonlinearity, higher-order interactions, heterogeneity, oversampling and correlated predictors[50,93]. The latter is especially important in this context. Because the three mountainousness indices are highly correlated (mountainousness–mountainousness–MSSD, $r=0.89$; mountainousness–elevation, $r=0.66$; mountainousness–MSSD–elevation, $r=0.61$), entering them simultaneously into multi-level models would most probably produce substantial bias due to multicollinearity. However, entering them simultaneously into conditional random forests allows for a fair and unbiased test of their relative contribution to the prediction of personality.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

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 enquire about access to these proprietary data, please contact S.D.G. (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 images and geocoordinates. 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 OSF (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).

Code availability

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

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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 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.

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Software and code

Policy information about availability of computer code

Data collection	The personality data from the Gosling-Potter Internet Personality Project were made available by the third and fourth other and had been cleaned and preprocessed so as to facilitate their usage. The research team wrote the code to generate the mountainousness measures (based on standard deviation in elevation across a 20/50 mile radius from one's ZIP code of living) from satellite image and geo-coordinates, which are available on our project page on the Open Science Framework (https://osf.io/y2mdw/).
Data analysis	Data was analyzed using R (multilevel modelling; conditional random forest machine learning algorithms) STATA Version 15.1 (preprocessing of data) and SPSS Version 24 (preprocessing of data; multiple regression analyses).

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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 is 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 measures (based on standard deviation in elevation across a 20/50 mile radius from one's ZIP code of living) were newly developed by the research team, extracting topographical information from satellite image and geo-coordinates. As such, they are available on our project page on the Open Science Framework (https://osf.io/y2mdw/). Specifically, we provide code to recreate the measures along with a dataset that contains all three mountainousness measures for 40,781 U.S. ZIP codes. 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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Study description	The present study combines cross-sectional large-scale personality data that was collected via an online survey since 2002 with topographical data derived from satellite images and ZIP code level sociodemographic information obtained from the US census to examine the relationship between mountainousness and personality.
Research sample	As mentioned above, the current research used an existing dataset to obtain individual level self-reported personality estimates. Our sample contained 3,838,112 U.S. residents.
Sampling strategy	The Gosling-Potter Internet Personality Project was created as a large-scale online survey to collect data on as broad and diverse a sample as possible. Prior research has shown that the data are - to some extent - representative of the general U.S. population (Gosling et al., 2004; Rentfrow et al., 2008). As stated below, here we only included participants who (1) reported to be U.S. residents, (2) had no missing data for the personality measure or for the ZIP code of their place of residence at the time of participation, (3) were no younger than 10 or older than 99 years old. In addition, we applied listwise exclusion procedures to most of our focal analyses, which resulted in N (Level 1) = 1,538,404; N (Level 2) = 29,764, which still offers a statistical power that is able to detect even tiny effects.
Data collection	The personality data were collected between October 2002 and March 2015 as part of the Gosling-Potter Internet Personality Project (see Gosling, Vazire, Srivastava, & John, 2004), which hosts a noncommercial, advertisement-free website containing a variety of personality measures. Respondents could learn about the project through several channels, including search engines or links on such websites as www.socialpsychology.org. Respondents volunteered to participate in the study by clicking on the personality test icon and were then presented with a series of questions about their personality characteristics, demographics, and state of residence. After submitting their responses, participants received customized feedback about their personalities.
Timing	The most recent version of Gosling-Potter Internet Personality Project Big Five personality dataset which was used in current research , contains data collected between October 2002 and March 2015.
Data exclusions	We employed the following exclusion criteria for the current project: (1) , participants with missing data for the personality measure or for the ZIP code of their place of residence at the time of participation were excluded. (2) We restricted the age range in our sample to participants who indicated being between the ages of 10 and 99. (3) Due to the extraordinary size and hence statistical power of the personality dataset, we applied listwise exclusion procedures to most of our focal analyses, which resulted in N (Level 1) = 1,538,404; N (Level 2) = 29,764. (4) We also excluded mountainousness outliers, defined as mountainousness estimates that deviated from the mean by 2 standard deviations or more.
Non-participation	Due to the online-setting of the data collection and considering that only complete data were submitted, we have no information about how many participants dropped out / declined participation.
Randomization	N/A

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Methods

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☒	☐ ChIP-seq
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Human research participants

Policy information about studies involving human research participants

Population characteristics	See above.
Recruitment	The personality survey is freely accessible at https://www.outofservice.com/bigfive/ (for more information see above (data collection)). Participation is completely voluntary and there is no monetary compensation. However, upon completion of the questionnaire, respondents receive immediate customized feedback about their personalities. While some biases due to self-selection as well as the prerequisite of being able to connect to the Internet might be present, the sheer size of the sample and the diversity of the participants (e.g., in terms of age, place of residence, socioeconomic status, etc.) suggest a very broad and adequate data coverage.
Ethics oversight	The research project obtained ethical approval, including a waiver of parental consent, from the institutional review boards at the University of California and the University of Texas.

Note that full information on the approval of the study protocol must also be provided in the manuscript.