Genetic Contribution to Concern for Nature and Proenvironmental Behavior

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Earth is undergoing a devastating extinction crisis caused by human impacts on nature, but only a fraction of society is strongly concerned and acting on the crisis. Understanding what determines people's concern for nature, environmental movement activism, and personal conservation behavior is fundamental if sustainability is to be achieved. Despite its potential importance, the study of the genetic contribution to concern for nature and proenvironmental behaviors has been neglected. Using a twin data set (N = 2312), we show moderate heritability (30%–40%) for concern for nature, environmental movement activism, and personal conservation behavior and high genetic correlations between them (.6–.7), suggesting a partially shared genetic basis. Our results shed light on the individual variation in sustainable behaviors, highlighting the importance of understanding both the environmental and genetic components in the pursuit of sustainability.

Keywords: sustainability, conservation, environmental crisis, behavioral genetics, twins

Solving the current multifaceted global environmental crisis—with its prominent climate and biodiversity dimensions—is a formidable challenge (Díaz et al. 2020a). International conventions and agreements intended to drive action have variously failed to be signed, ratified, or adhered to. The associated targets have often been inadequate for the severity of the problems and, even then, typically have still not been met by even a minority of nations (Convention on Biological Diversity 2020). A recurrent response from the scientific community has been the determination of revised and often more stringent targets, backed by improved data and models and better evidence of the opportunities for their delivery and of the consequences of failing to do so (Díaz et al. 2020b). However, the fundamental obstacle of a lack of adequate support to address the environmental crisis remains.

Although not sufficient in itself, important drivers of action to address systemic issues are the extent of popular public support and its manifestation through the decisions that individuals make (e.g., voting, donations, purchasing). Presently, large fractions of society seem unconcerned and unwilling or unable to take action in addressing environmental problems (Markowitz and Shariff 2012, Scruggs and Benegal 2012). A lack of concern from voters was, for example, among the reasons that the US government withdrew from the Paris Agreement (Urpelainen and Van de Graaf 2018). Understanding the sources of variance for such attitudes and behaviors is arguably a critical step toward the resolution of the environmental crisis.

To date, research into why some people are concerned about and act on the environmental crisis, whereas others do not, has been focused principally on the environmental, social, and psychological aspects of proenvironmental behavior (e.g., personality, identity, cognition, emotion; Dietz et al. 1998, Gifford 2011, Gifford and Nilsson 2014, Cazalis and Prévot 2019), without delving deeper into the biological bases of concern for nature. As such, the possible genetic influences on concern for nature and proenvironmental behavior have remained unexplored. This is despite genetic components having been highlighted in the context of attitudes and behavior with regard to other issues, such as educational achievement, social class mobility, and smoking behaviors (Polderman et al. 2015, Belsky et al. 2018, Engzell and Tropf 2019, Erzurumluoglu et al. 2020, Harden and Koellinger 2020). The possibility of genetic components of concern for nature and proenvironmental behavior is suggested by evolutionary studies in altruistic and cooperative behavior for the benefits of future generations (Apicella and Silk 2019, Lehmann 2007) and human's tendency to affiliate with nature for resources (Wilson 1984).

In the present article, we use data from TwinsUK ($N = 2312$), the largest adult twin registry in the United Kingdom and the

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most clinically detailed twin registry in the world (Verdi et al. 2019), to disentangle the genetic and environmental factors that drive individual variation in concern for nature, environmental movement activism, and personal conservation behaviors. Using the difference in the genetic similarity of monozygotic twins (100%, also called identical twins) and dizygotic twins (50%, also called nonidentical or fraternal twins), a twin approach offers an opportunity to estimate the amount of individual variation attributed to additive genetic influence, shared environmental influence (the environments that twins share—e.g., activities performed together during childhood), and unique environmental influence (environments that are unique to each twin—e.g., one twin joins a volunteering organization, but the other does not, including measurement errors).

Data collection and variables measured

The participants were recruited from TwinsUK (Verdi et al. 2019). The zygosity of the participants was assessed by the “Peas in a Pod” questionnaire and confirmed via genotyping or sequencing. All of the participants currently live in the United Kingdom. An online survey of concern for nature, environmental movement activism, and personal conservation behavior measurement was carried out through TwinsUK. We did not predetermine our sample size. We obtained responses from 1165 twin pairs as the result of the participation rate in the study. These were 677 pairs of monozygotic (MZ) female twins, 351 pairs of dizygotic (DZ) female twins, 98 pairs of MZ male twins, 30 pairs of DZ male twins, and 9 DZ opposite sex twin pairs. Of these 1165 twin pairs, only 3 were reared apart. The DZ opposite sex twins were excluded from the analyses because the sample size was too small to reliably detect the genetic correlation across sexes. No other data were excluded. The average age of the participants was 60.31 years old (standard deviation = 14.3 years).

For the measurement of concern for nature, we used the nature relatedness perspective subscale (Nisbet et al. 2009). We collected data using the nature relatedness (NR) scale but only the NR-perspective subscale was used in this analysis for its connection with personal conservation behavior and environmental movement activism. Other subscales of the NR scale, NR-self (identification with nature) and NR-experience (desire to experience nature), do not correlate well with NR-perspective (Nisbet et al. 2009). This weak correlation might be expected, because spending time in nature for recreation does not consistently suggest one’s environmental concern (Teisl and O’Brien 2003, Oh et al. 2021). Environmental movement activism and personal conservation behavior were two subscales in the environmental attitudes inventory (Milfont and Duckitt 2010). The responses were collected on a five-point Likert scale (1, *strongly disagree*; 5, *strongly agree*). The average score of each measurement from each participant was used. We also measured participants’ nature orientation, nature experiences and opportunities, which were not analyzed in this study.

The distributions of phenotypes (concern for nature, environmental movement activism, and personal conservation behavior) are shown in supplemental figure S1. Males and older individuals tended to show less concern for nature, environmental movement activism, and personal conservation behavior (supplemental table S1). The correlations partitioned by sexes and zygosities are shown in supplemental table S2. The intraclass correlations for MZ and DZ twins were calculated with one-way ANOVA fixed effects models using the *psych* package (Revelle 2014) in R 4.0.2 (R Core Team 2020).

Our measurements had acceptable internal consistency (DeVellis 2012) and were similar to the original studies; we used the Cronbach’s alpha score (using the *psych* package; Revelle 2014). For concern for nature, the Cronbach’s alpha score was .66 (it was .66 in Nisbet et al. 2009), .86 for environmental movement activism (.89 and .86 in Milfont and Duckitt 2010), and .78 for personal conservation behavior (.80 and .71 in Milfont and Duckitt 2010). Full statements are included in supplemental table S3.

Twin data analyses

A twin analysis assumes that the genetic similarity of MZ twins is 100% and that of DZ twins is 50%. The correlation between twins for shared environment is assumed to be 1 for both MZ and DZ twins, and unique environmental influences are assumed to be uncorrelated between twins and contribute to the phenotypic differences between the twins. Under these assumptions, we partitioned the phenotypic variance into additive genetic influence (A), shared environmental influence (C), and unique environmental influence (E).

We ran trivariate models, which allow us to estimate the genetic and environmental correlations between phenotypes (Neale and Cardon 2013). The genetic correlation represents the extent to which the genetic influence of each phenotype overlaps, with a correlation of 1 meaning complete genetic overlap between phenotypes. The same interpretation applies to the environmental correlation between phenotypes. The trivariate models included concern for nature, environmental movement activism, and personal conservation behavior.

We built the trivariate ACE models with Cholesky decomposition (supplemental figure S2a) and a direct symmetric approach (figure S2b). The Cholesky decomposition model simplifies the interpretation of the results with a lower bound of zero on variances (Verhulst et al. 2019). The direct symmetric approach estimates variances and covariances directly without the lower bound constraint (Verhulst et al. 2019). In both approaches, we ran two models: one controlling for age and sex (taking residuals from the linear regressions) and one without controlling for age and sex. All four models were run using the *OpenMx* package (Neale et al. 2016) in R 4.0.2 (R Core Team 2020).

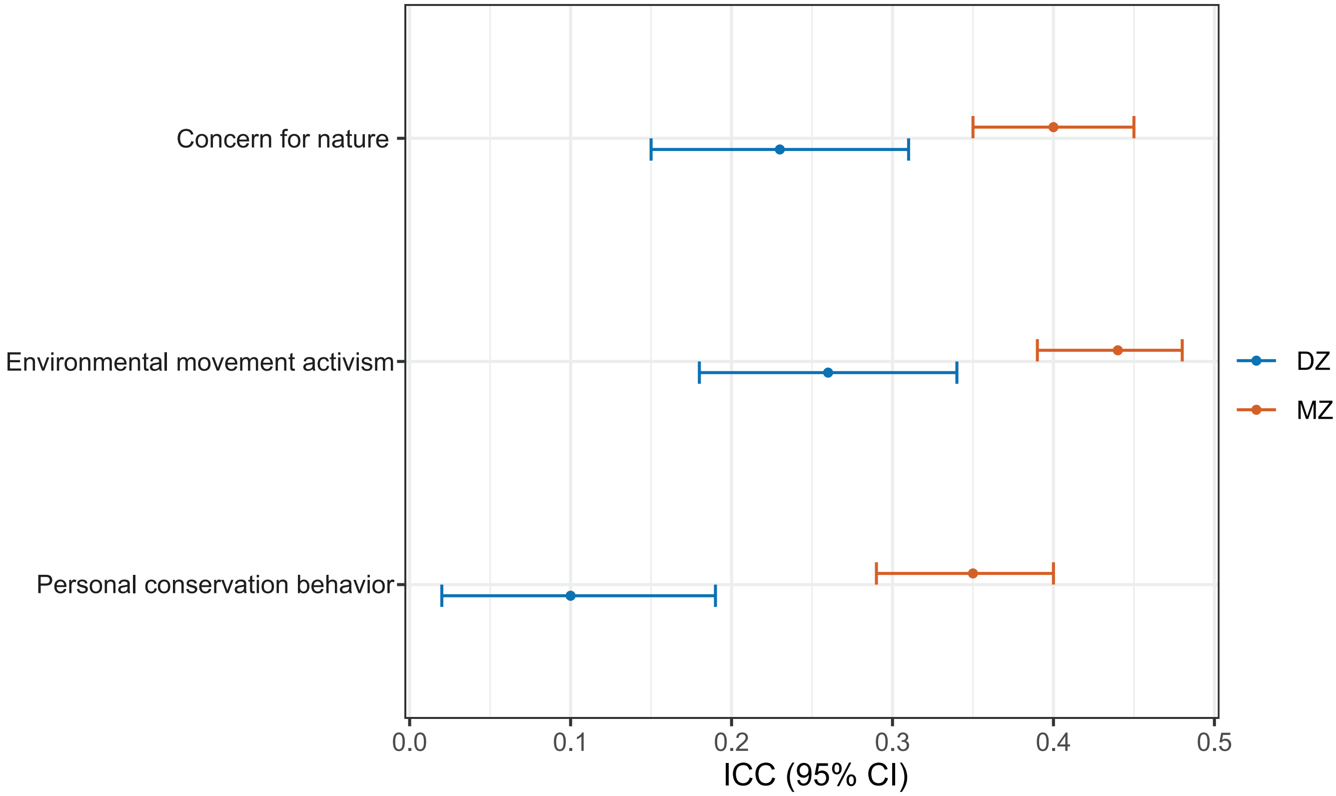

Figure 1. Intraclass correlation coefficients (ICC) between monozygotic (MZ) and dizygotic (DZ) twin pairs in concern for nature, environmental movement activism, and personal conservation behavior. The error bars represent 95% confidence intervals. The lack of overlap between MZ and DZ correlations implies genetic influences on the phenotypes.

Genetic and environmental influences on concern for nature and proenvironmental behavior

We found that MZ twins were consistently more similar to each other in concern for nature, environmental movement activism, and personal conservation behavior than were DZ twins, suggesting genetic influences on these phenotypes (figure 1). Consistently, our twin analyses showed that all three phenotypes were moderately heritable (figure 2a), and there were high genetic correlations among them (figure 2b). This indicates that the genetic bases of concern for nature, environmental movement activism, and personal conservation behavior are partially shared. The high genetic correlations among these phenotypes could explain to some extent why people who show greater concern for nature often make proenvironmental decisions (Nisbet et al. 2009, Rhead et al. 2015).

We detected negligible shared environmental influences on the phenotypes (figure 2a). However, unique environmental influences explained more than 50% of individual variation in all three phenotypes, making environmental influences the largest source driving individual variation in sustainable behaviors (figure 2a). There were relatively low environmental correlations across these phenotypes (figure 2b), suggesting these phenotypes may be influenced by different environmental factors and suggesting an important role for varied behavioral interventions. Interventions could focus on removing barriers such as a lack of knowledge to enhance concern for nature, making resource conservation convenient to encourage personal conservation behavior, and providing initiatives to engage in environmental movements.

Heritability of concern for nature and proenvironmental behavior

The heritability of concern for nature and proenvironmental behavior was similar to an average heritability of human personality traits (such as the big five personality traits, which have heritability of about 30%–40%; Vukasović and Bratko 2015). Concern for nature and proenvironmental behavior have also been found to be associated with several human behavioral and personality traits, such as altruism and agreeableness (Pavalache-Ilie and Cazan 2018, Gifford and Nilsson 2014, Lades et al. 2021). The genetic components of these traits (e.g., dopamine-related genes for altruism and agreeableness; Reuter et al. 2011, Kim et al. 2013) may be linked with concern for nature and proenvironmental behavior. In addition, we expect the genetic influences may be mediated through individual differences in emotional or cognitive processes, such as future discounting, social discounting, or risk aversion (Lorenzoni et al. 2007, Gifford 2011, Weber 2017), which may be also linked to personality.

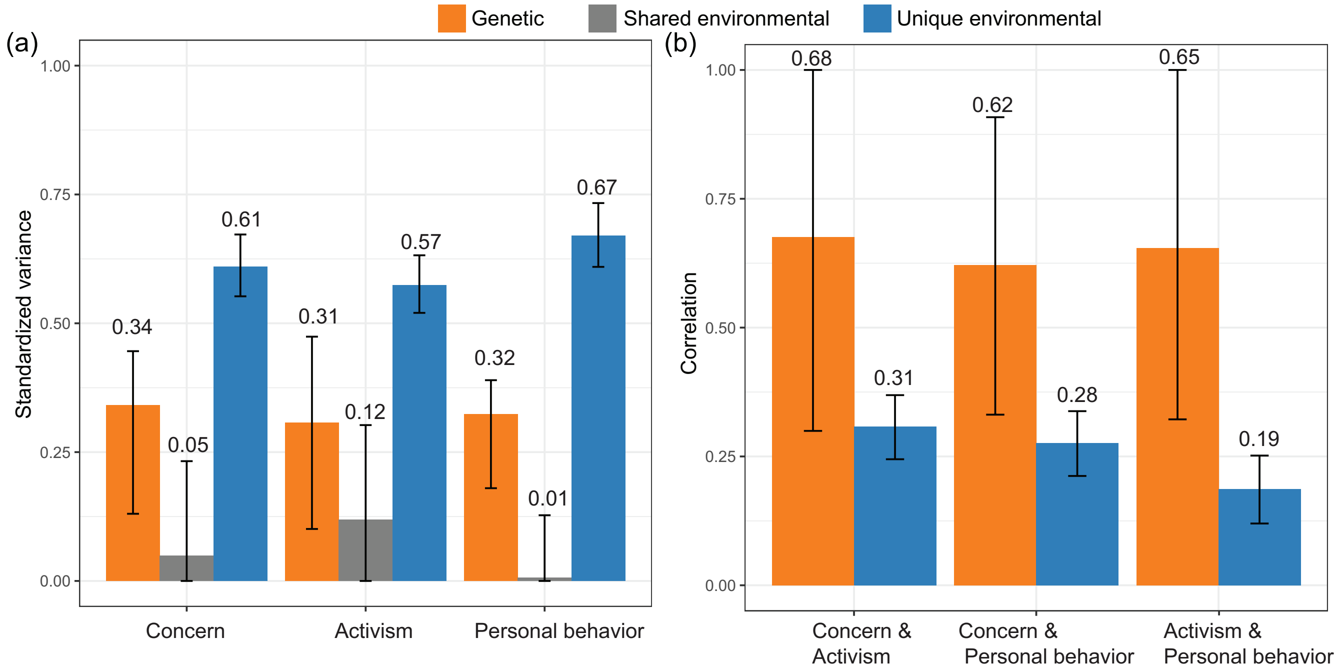

Figure 2. Standardized genetic and environmental variances (a) and correlations (b) in concern for nature (concern), environmental movement activism (activism), and personal conservation behavior (personal behavior) with the trivariate Cholesky decomposition model controlling for sex and age. The error bars represent 95% confidence intervals. The estimates from the Cholesky decomposition model without controlling for age and sex are shown in supplemental table S4, and estimates from a direct symmetric approach with and without controlling for age and sex are shown in supplemental table S5.

The genetic influences we found might have roots in evolutionary history. Cooperation is fundamental to sustaining natural common-pool resources; all individuals must limit their short-term self-interest for the long-term collective interest, including that of future generations (Gordon 1954, Hardin 1968, Chermak and Krause 2002). Kin selection, direct reciprocity, and reputation mechanisms have been proposed to drive the evolution of cooperative behavior (Apicella and Silk 2019). For example, kin selection favors individuals with sustainable behavior because the short-term loss will benefit their offspring, provided that the offspring are likely to continue to use the resource (Lehmann 2007, Palomo-Vélez et al. 2020). It has also been shown that parents are more likely to donate for climate change mitigation when their decisions are observed by their children as a reminder of genetic relatedness with future generations (Fornwagner and Hauser 2020). The fitness consequences for cooperators may be dependent on the context. For example, proenvironmental behavior will be less beneficial or costly when many people share the same pool of resource (Suzuki and Akiyama 2005, Chang et al. 2021). Context-dependent fitness trade-offs may allow for the coexistence of different resource use behaviors.

Heritability captures how much individual variation in a phenotype can be explained by individual differences in genes and describes the existing variations in a specific study population with its environment. The heritability estimated in this study can therefore not be directly transferred to other study populations. In addition, heritability may change with age (Visscher et al. 2008). In our age moderation analyses (supplemental note 1), genetic influences for concern for nature and personal conservation behavior slightly increased with age. This could be because people may actively choose their environments on the basis of their genetic predisposition (e.g., actively learn about climate change or spend time with people with similar interests), reinforcing their concern for nature and personal conservation behavior as they age (Rutter and Silberg 2002, Plomin and Deary 2015). As unique environmental influences also increased with age, heritability was stable across age groups.

High heritability does not suggest the insignificance of environments. Suitable educational policies have been found to mitigate the health problems arising from genetic background (e.g., obesity; Barcellos et al. 2018). Environmental interventions, such as policies, may influence heritability. For instance, a high-quality teaching environment, which reduces the variance associated with environmental factors, improves students' educational achievements and increases the heritability of educational achievement (Taylor et al. 2010). In countries with higher social class mobility, heritability of educational attainment is higher because of lower environmental variance (Engzell and Tropf 2019). Future studies with access to twin data sets from other populations could expand the understanding of genetic and environmental influences in other cultural or demographic contexts. We hypothesize that, all other things being equal, heritability of proenvironmental behavior will increase if the environmental barriers are lower for most people in a population.

Limitations and future research

There are several limitations in our study. First, twin analysis assumes that MZ twins do not have stronger environmental similarity than DZ twins for shared environmental factors (Horwitz et al. 2003). However, this assumption may be violated if, for example, MZ twins are more likely to have the same school activities or be treated more similarly by their parents than DZ twins. If this assumption is violated, heritability may be overestimated. Second, the scale used to measure one's concern for nature only shows a marginally acceptable level of internal consistency (DeVellis 2012). Future studies could use other scales with higher internal consistency. Similarly, unique environmental influences also include measurement error, and future studies could conduct repeated measures to address this issue (Ge et al. 2017). Third, our study population is biased toward females. Although we adjusted for this in our analyses, future studies using a more gender-balanced population would be beneficial and could test whether there is a sex difference in the genetic and environmental influences of these phenotypes. Fourth, our population is predominantly older individuals. How genetic and environmental influences change across age should be further investigated. With long-term repeated measurements (e.g., from child to adult stage) in the future, understanding of the development of a person's concern for nature and proenvironmental behavior could be improved.

Conclusions

Our results provide a first step toward unveiling the long-unexplored genetic components of concern for nature and proenvironmental behavior, opening up a new dimension of sustainable behavior research that bridges the social sciences and biological sciences. We find that concern for nature, environmental movement activism, and personal conservation behavior have moderate heritability and their genetic bases partially overlap. Although genetic effects contribute to sustainable behaviors, environmental interventions remain critical to widen the support base toward sustainability. Understanding the large variance in nature concern and its sources among individuals remains critical in the pursuit of global sustainability.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

References cited

Apicella CL, Silk JB. 2019. The evolution of human cooperation. Current Biology 29: 447–450.

Barcellos SH, Carvalho LS, Turley P. 2018. Education can reduce health differences related to genetic risk of obesity. Proceedings of the National Academy of Sciences 115: 9765–9772.

Belsky DW, et al. 2018. Genetic analysis of social-class mobility in five longitudinal studies. Proceedings of the National Academy of Sciences 115: 7275–7284.

Cazalis V, Prévot A-C. 2019. Are protected areas effective in conserving human connection with nature and enhancing pro-environmental behaviours? Biological Conservation 236: 548–555.

Convention on Biological Diversity. 2020. Global Biodiversity Outlook 5. Convention on Biological Diversity.

Chermak JM, Krause K. 2002. Individual response, information, and intergenerational common pool problems. Journal of Environmental Economics and Management 43: 47–70.

Chang C, Kristensen NP, Nghiem TPL, Tan CLY, Carrasco LR. 2021. Having a stake in the future and perceived population density influence intergenerational cooperation. Royal Society Open Science 8: 210206.

DeVellis RF. 2012. Scale Development: Theory and Applications, 3rd ed. Sage.

Díaz S, et al. 2020a. Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Díaz S, Zafra-Calvo N, Purvis A, Verburg PH, Obura D, Leadley P, Chaplin-Kramer R, De Meester L, Dulloo E, Martín-López B. 2020b. Set ambitious goals for biodiversity and sustainability. Science 370: 411–413.

Dietz T, Stern PC, Guagnano GA. 1998. Social structural and social psychological bases of environmental concern. Environment and Behavior 30: 450–471.

Engzell P, Tropf FC. 2019. Heritability of education rises with intergenerational mobility. Proceedings of the National Academy of Science 116: 25386–25388.

Erzurumluoglu AM, et al. 2020. Meta-analysis of up to 622,409 individuals identifies 40 novel smoking behaviour associated genetic loci. Molecular Psychiatry 25: 2392–2409.

Fornwagner H, Hauser OP. 2020. Do Parents Invest Into Voluntary Climate Action when Their Children are Watching? Evidence from a Lab-in-the-field Experiment. Research Platform Empirical and Experimental Economics, University of Innsbruck.

Ge T, Holmes AJ, Buckner RL, Smoller JW, Sabuncu MR. 2017. Heritability analysis with repeat measurements and its application to resting-state functional connectivity. Proceedings of the National Academy of Sciences 114: 5521–5526.

Gordon HS. 1954. The economic theory of a common-property resource: The fishery. Pages 178–203 in Gopalakrishnan C, ed. Classic Papers in Natural Resource Economics. Macmillan.

Gifford R. 2011. The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. American Psychologist 66: 290.

Gifford R, Nilsson A. 2014. Personal and social factors that influence pro-environmental concern and behaviour: A review. International Journal of Psychology 49: 141–157.

Hardin G. 1968. The tragedy of the commons. Science 162: 1243–1248.

Harden KP, Koellinger PD. 2020. Using genetics for social science. Nature Human Behaviour 4: 567–576.

Horwitz AV, Videon TM, Schmitz MF, Davis D. 2003. Rethinking twins and environments: Possible social sources for assumed genetic influences in twin research. Journal of Health and Social Behavior 44: 111–129.

Kim HN, Roh SJ, Sung YA, Chung HW, Lee JY, Cho J, Shin H, Kim HL. 2013. Genome-wide association study of the five-factor model of personality in young Korean women. Journal of Human Genetics 58: 667–674.

Lades LK, Laffan K, Weber TO. 2021. Do economic preferences predict pro-environmental behaviour? Ecological Economics 183: 106977.

Lehmann L. 2007. The evolution of trans-generational altruism: Kin selection meets niche construction. Journal of Evolutionary Biology 20: 181–189.

Lorenzoni I, Nicholson-Cole S, Whitmarsh L. 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. Global Environmental Change 17: 445–459.

Markowitz EM, Shariff AF. 2012. Climate change and moral judgement. Nature Climate Change 2: 243–247.

Milfont TL, Duckitt J. 2010. The environmental attitudes inventory: A valid and reliable measure to assess the structure of environmental attitudes. Journal of Environmental Psychology 30: 80–94.

Neale MC, Cardon LR. 2013. Methodology for Genetic Studies of Twins and Families. Springer Science and Business Media.

Neale MC, Hunter MD, Pritikin JN, Zahery M, Brick TR, Kirkpatrick RM, Estabrook R, Bates TC, Maes HH, Boker SM. 2016. OpenMx 2.0: Extended structural equation and statistical modeling. Psychometrika 81: 535–549.

Nisbet EK, Zelenski JM, Murphy SA. 2009. The nature relatedness scale: Linking individuals' connection with nature to environmental concern and behavior. Environment and Behavior 41: 715–740.

Oh RR, Fielding KS, Nghiem LT, Chang CC, Carrasco LR, Fuller RA. 2021. Connection to nature is predicted by family values, social norms and personal experiences of nature. Global Ecology and Conservation 28: e01632.

Palomo-Vélez G, Buczny J, Van Vugt M. 2020. Encouraging pro-environmental behaviors through children-based appeals: A kin selection perspective. Sustainability 12: 748.

Pavalache-Ilie M, Cazan AM. 2018. Personality correlates of pro-environmental attitudes. International Journal of Environmental Health Research 28: 71–78.

Plomin R, Deary IJ. 2015. Genetics and intelligence differences: Five special findings. Molecular Psychiatry 20: 98–108.

Polderman TJ, Benyamin B, de Leeuw CA, Sullivan PF, van Bochoven A, Visscher PM, Posthuma D. 2015. Meta-analysis of the heritability of human traits based on fifty years of twin studies. Nature Genetics 47: 702–709.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.

Reuter M, Frenzel C, Walter NT, Markett S, Montag C. 2011. Investigating the genetic basis of altruism: The role of the COMT Val158Met polymorphism. Social Cognitive and Affective Neuroscience 6: 662–668.

Revelle W. 2014. Psych: Procedures for Psychological, Psychometric, and Personality Research. Northwestern University.

Rhead R, Elliot M, Upham P. 2015. Assessing the structure of UK environmental concern and its association with pro-environmental behaviour. Journal of Environmental Psychology 43: 175–183.

Rutter M, Silberg J. 2002. Gene-environment interplay in relation to emotional and behavioral disturbance. Annual Review Psychology 53: 463–490.

Scruggs L, Benegal S. 2012. Declining public concern about climate change: Can we blame the great recession? Global Environmental change 22: 505–515.

Suzuki S, Akiyama E. 2005. Reputation and the evolution of cooperation in sizable groups. Proceedings of the Royal Society B 272: 1373–1377.

Taylor J, Roehrig AD, Soden Hensler B, Connor CM, Schatschneider C. 2010. Teacher quality moderates the genetic effects on early reading. Science 328: 512–514.

Teisl MF, O'Brien K. 2003. Who cares and who acts? Outdoor recreationists exhibit different levels of environmental concern and behavior. Environment and Behavior 35: 506–522.

Urpelainen J, Van de Graaf T. 2018. United States non-cooperation and the Paris agreement. Climate Policy 18: 839–851.

Verdi S, et al. 2019. TwinsUK: The UK Adult Twin Registry update. Twin Research and Human Genetics 22: 523–529.

Verhulst B, Prom-Wormley E, Keller M, Medland S, Neale MC. 2019. Type I error rates and parameter bias in multivariate behavioral genetic models. Behavior Genetics 49: 99–111.

Visscher PM, Hill WG, Wray NR. 2008. Heritability in the genomics era: Concepts and misconceptions. Nature Review Genetics 9: 255–266.

Vukasović T, Bratko D. 2015. Heritability of personality: A meta-analysis of behavior genetic studies. Psychological Bulletin 141: 769–785.

Weber EU. 2017. Breaking cognitive barriers to a sustainable future. Nature Human Behaviour 1: 1–2.

Wilson EO. 1984. Biophilia. Harvard University Press.

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