Stigma and Health

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BRIEF REPORT

Understanding the Psychological, Relational, Sociocultural, and Demographic Predictors of Loneliness Using Explainable Machine Learning

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Loneliness—an important indicator of social health—is increasingly recognized to derive from factors operating at multiple levels. However, simultaneously examining the role of factors at multiple levels implies using large samples and testing multiple factors at the same time, which traditional statistical methods cannot accommodate. We used machine learning techniques to address this problem. We identify the most important out of 32 correlates of loneliness frequency in a large sample of people ages 16+ years, residing all over the world, who took part in the British Broadcasting Corporation Loneliness Experiment. Factors spanned individual, relational, sociocultural, and demographical areas. The most statistically important associate of loneliness was daily experiences with prejudice (or stigma), followed by couple satisfaction, neuroticism (emotional stability), personal self-esteem, average hours spent alone daily, extraversion, social capital, and relational mobility. Interaction effects were also evident, showing that experiences with prejudice were most negatively associated with loneliness when individuals spent a lot of time alone and the least when individuals were emotionally stable, had high personal self-esteem, or had high levels of couple satisfaction. This research highlights what factors need to be considered when developing effective interventions to mitigate loneliness.

Clinical Impact Statement

This research points out the relative importance of multiple correlates of loneliness for people over 16 years old, residing all over the world. Some of the factors that emerged as most important are already often considered when developing interventions (e.g., low self-esteem), but others are less so (e.g., experiences with social stigma and poor couple satisfaction). These need to be considered by those developing interventions to prevent or address loneliness.

Keywords: loneliness, machine learning, daily prejudice

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Yiming Qin played a lead role in formal analysis, software, and visualization and an equal role in conceptualization, methodology, and writing–review and editing. Christina Victor played an equal role in conceptualization, funding acquisition, and writing–review and editing. Pamela Qualter played a lead role in data curation and project administration and an equal role in conceptualization, methodology, supervision, and writing–review and editing. Manuela Barreto played a lead role in supervision and writing–original draft and an equal role in conceptualization, funding acquisition, investigation, methodology, and writing–review and editing.

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Loneliness—the feeling that one's social relationships are not as we would like them to be (Perlman & Peplau, 1981)—has significant negative consequences for individuals (Griffin et al., 2020; Park et al., 2020) and societies (Kung et al., 2021; Mihalopoulos et al., 2020) to the extent that it has been declared a public health priority in some countries (Holt-Lunstad et al., 2017) and worldwide (World Health Organization, 2023). Despite attempts to reduce loneliness—an indicator of social health—there is little evidence of success (Eccles & Qualter, 2021; Mann et al., 2017; Quan et al., 2020). One potential reason for the modest effectiveness of existing interventions is that research seldom takes into account factors operating at multiple levels and their relative impact on loneliness. Indeed, research seldom tests the relative role of multiple predictors at the same time, partly because examining the effects of a large number of predictors and their interactions requires large samples and complex statistical techniques. Machine learning (ML) is one such technique, and it has been recently used to examine social and psychological correlates of loneliness in samples of adults living in the United Kingdom (Altschul et al., 2021; Ejlskov et al., 2018).

Ejlskov et al. (2018) used ML to examine the combination and relative importance of 42 potential predictors of loneliness in a sample with 2,453 participants aged 68+ from a British birth cohort study (the Medical Research Council National Survey of Health and Development). The variables examined were personality characteristics, affective states, demographic characteristics, social relations, and health. The variables that emerged as the most important associates of loneliness in this sample were (in this order): positive well-being, personal mastery, having the spouse as the closest confidant, being extroverted, and having informal social interactions.

In turn, Altschul et al. (2021) conducted exploratory and confirmatory analyses of psychological and sociodemographic associates of loneliness with four independent samples of older British people (45+). They examined the predictive role of personality variables, general cognitive function, subjective health, and sociodemographic variables. Neuroticism and extraversion were associated with loneliness among participants aged 45–69 years, and neuroticism, subjective health, and social circumstances (e.g., living alone) were associated with loneliness among those aged 70–79.

The Current Article

We complement existing work by using machine learning (ML) to identify the relative role of a series of potential loneliness predictors in a data set of over 40,000 individuals, ages 16–99 years, living across 237 countries, islands, and territories. These data were collected as part of a collaboration between the authors and the BBC and include a range of variables that span multiple levels of analysis, being therefore very well suited for our goals. We extend the work by Altschul et al. (2021) and Ejlskov et al. (2018) in the following ways: (a) We include participants from a wider age range; (b) we explore a more culturally diverse sample to generalize results beyond the United Kingdom; (c) we examine a wider range of potential predictors that span individual, relational, sociocultural, and demographic factors; and (d) we use an explainable ML technique that quantifies the dependencies between loneliness and the variables most related to it (i.e., interactions) while marginalizing the values of all other variables.

Regarding *individual* factors, we included both personality and well-being indicators. A large portion of psychological research on the predictors of loneliness has focused on individual difference factors, especially the Big Five personality characteristics (Buecker et al., 2020, 2021). This research has found associations between personality variables and loneliness, particularly for neuroticism (positive) and extraversion (negative)—a finding replicated by Altschul et al. (2021) and (partially) by Ejlskov et al. (2018). Although health status is more commonly seen as an outcome of loneliness, it can also predict loneliness by decreasing a person's opportunities to engage with others (Dahlberg et al., 2022). Subjective health status was identified by Altschul et al. (2021) as one of the most important associates of loneliness in their sample. We add to this an indicator of mental well-being, that is, personal self-esteem, because research has shown that personal self-esteem is a key predictor of relationship quality (Murray et al., 2002) and strongly related to loneliness (Du et al., 2019).

As to *relational* factors, both the quantity and the quality of social interactions are important determinants of loneliness (Victor et al., 2000). The quantity of social interactions (or *relational isolation*; Weiss, 1973) is often indexed by asking participants how often they meet other people, whether they live alone, or how much time they spend alone (Hawkley et al., 2005). In addition, individuals' attitudes toward living alone (including whether this is a choice) and even the extent to which they see loneliness as a positive or negative experience can predict how prevalent loneliness is in their lives (Wang et al., 2013).

Although indicators of the quantity of social interactions are relatively straightforward and often included in research, indicators of the quality of a person's social interactions are often left out (possibly in part due to concerns about their overlap with measures of loneliness) or limited to interpersonal relationship quality. For example, Altschul et al. (2021) did not include relationship quality in their predictors, while Ejlskov et al. (2018) asked participants to indicate the level of emotional support they received from the person they felt closest to and negative aspects of this relationship. Although this seems important, loneliness can also be predicted by the quality of daily interaction experiences with others with whom one does not necessarily have a close relationship (Cacioppo & Cacioppo, 2012). For example, there is evidence that daily interpersonal experiences with prejudice and discrimination (or social stigma) are important determinants of loneliness (Lee & Bierman, 2019; Priest et al., 2017) and that positive and trusting relationships with one's neighbors (corresponding to high social capital) can protect against loneliness (Matthews et al., 2019). Therefore, we indexed relationship quality through couple satisfaction, daily experiences with prejudice, and neighborhood social capital.

Sociocultural differences in individualism–collectivism (Hofstede, 1991; Triandis, 1995)—reflecting the extent to which a given society values loose versus tightly knit networks—can also impact loneliness, although evidence is mixed regarding the direction of this effect. Another cultural variable that might be relevant in this context but has only been examined among adolescents (Jefferson, Barreto, Jones, et al., 2023) is power distance (Hofstede, 1991), consisting of the extent to which a social environment promotes the existence of hierarchical differences between people or whether it strives for more egalitarian relationships. Finally, researchers have examined the impact of relational mobility—the extent to which social relationships in each network or society tend to be primarily chosen

or ascribed (Yuki & Schug, 2020)—on various aspects of social networks, but the impact of this variable on loneliness is yet to be examined.

Research has also shown that certain *demographic* characteristics are associated with loneliness. This research has examined effects of age, gender, educational level, and socioeconomic or employment status (Buecker et al., 2020). Less frequently, researchers have demonstrated that some demographic characteristics associated with social roles (such as being a carer or a parent of young children) or with socially stigmatized characteristics (homelessness, minority sexual orientation, migrant status) can make people vulnerable to loneliness. Contrary to what is commonly assumed, loneliness is not most prevalent in older people, with studies that include samples with a wide age range showing that young people 16–25 report the highest levels of loneliness (Barreto et al., 2021; Office for National Statistics, 2018). Effects of gender are inconsistent, with a meta-analysis showing that, overall, these are small and generally negligible (Maes et al., 2019), though research using ML techniques has found interactions between gender and living alone, so that men living alone were the loneliest group (Altschul et al., 2021). In addition, socially stigmatized groups experience more loneliness than nonstigmatized groups (see also Barreto et al., 2023). For example, both young (Madsen et al., 2016) and older (Victor et al., 2012) migrants report more loneliness than those without a migration experience; individuals with a mental illness report more loneliness than those without a mental illness (Lauder et al., 2004); and sexual minority individuals report more loneliness than heterosexuals (Doyle & Molix, 2016). High levels of loneliness have also been reported by individuals with low socioeconomic status (Morgan et al., 2019), homeless youth (Kidd, 2007), individuals with a disability (Tough et al., 2017), and unemployed individuals (Kleftaras & Vasilou, 2016). To account for such possible loneliness discrepancies, we examined the role of a range of demographic characteristics and identities measured in the British Broadcasting Corporation (BBC) Loneliness Experiment.

Studies focusing on a small number of potential predictors at the time are important, but they do not allow for the simultaneous examination of factors operating at multiple levels and their interactions to shed light on the relative importance of each factor. They also involve substantial subjectivity in deciding what variables and interaction terms to include in the analyses and in what order, as well as the risk of multicollinearity. However, advanced machine learning techniques, which capture patterns from data, can handle those challenges a lot better. While there will always be some degree of subjectivity involved in the selection of variables on which to collect data, this technique identifies the interactions that are most useful to examine from the data itself. Given the lack of consensus in the prior studies that have used this method, the wider age and cultural diversity in our sample, and the different indicators, we did not raise specific hypotheses about the relative importance of potential predictors of loneliness in this study, which remained exploratory.

Method

We used cross-sectional data from the BBC Loneliness Experiment. Data were collected in 2018 from participants aged 16–99 years living in one of 237 countries, islands, and territories (Barreto et al., 2021). The study was a collaboration between the researchers and the BBC Radio, who advertised the study on Radio 4 and on the BBC World Service. The study was also covered in a range of other news media. Participants were therefore self-selected volunteers who accessed the study online. The questionnaire was available only in English, and the sample was recruited over a month without aiming for a predetermined sample size. We used data from all participants who had data in the measures of interest, resulting in a sample size of 40,080. Of these, approximately 83% resided in the United Kingdom (see Supplemental Table S1, for a specification of numbers of participants per country). The characteristics of the sample can be seen in Table 1.

Loneliness was measured with four items from the UCLA Loneliness Scale (Russell, 1996): Do you feel a lack of companionship? Do you feel left out? Do you feel isolated from others? and Do you feel in tune with people around you? (reverse-coded). Each item was rated on the frequency with which it was true for the participant (from 0 = *never* to 5 = *always*; internal reliability: Cronbach's $\alpha = .84$).

Although this study did not collect data for all possible potential predictors of loneliness (e.g., measures of cognitive biases were not included), it did include a range of important psychological, relational, sociocultural, and demographic variables. We measured personality using the 10-item scale by Gosling et al. (2003), which includes all the Big Five dimensions (Agreeableness, Openness to Experience, Conscientiousness, Emotional Stability, and Extroversion/Introversion). This scale includes two items to measure each dimension and has adequate internal reliability with Pearson correlations ranging from .48 for "Openness to Experience" to .71 for "Emotional Stability." Well-being was measured with one indicator of psychological well-being (personal self-esteem, measured with four items from Rosenberg's, 1965, scale, e.g., "On the whole, I am satisfied with myself," $\alpha = .91$) and one item measuring subjective health ("Would you say that, in general, your health is," from 1 = *poor* to 5 = *excellent*).

Quantity of social contact was indexed in several ways. First, participants indicated if they lived alone, and if so, how long (in months); participants who said they did not live alone were asked, "How many people (excluding yourself) live in your household?" (open answer); all participants were asked, "How much time do you spend alone?" (from 1 = *never* to 4 = *always*), and "on average, how many hours do you spend alone in 1 day?" We also asked if participants had chosen to live alone ("Did you choose to live alone?"), whether they enjoyed spending time alone ("how much do you enjoy spending time alone?"), and how they evaluated their loneliness experiences ("Is the experience of loneliness positive for you?" with options no, sometimes, yes). The latter question was not shown to participants who indicated never feeling lonely (see Switsers et al., 2023, for a characterization of those who indicate that their loneliness experiences are sometimes positive).

Regarding the quality of social contact, couple satisfaction was measured with the four-item version of the Couples Satisfaction Index (Funk & Rogge, 2007). This measure was only presented to participants who indicated being in a relationship. An example item is "How rewarding is your relationship with your partner?" (from 1 = *not at all* to 7 = *completely*; $\alpha = .94$). Participants' daily experiences with prejudice and discrimination were assessed with the five-item version of the Everyday Discrimination Scale by Sternthal et al. (2011). Participants were asked to indicate how often each of the five items happened to them. A sample item is "You are treated with less courtesy or respect than other people"

Table 1
Descriptive Statistics for All Variables Included in the Analyses

Variable	*N* (%)	*M* (*SD*)
Loneliness frequency (UCLA mean)		
Scale 1–5		2.66 (1.13)
Gender		
Male	12,811 (32%)	
Female	27,269 (68%)	
Age		
16–24	2,899 (7.2%)	
25–34	5,230 (13.0%)	
35–44	6,170 (15.4%)	
45–54	9,139 (22.8%)	
55–64	9,786 (24.4%)	
65–74	5,782 (14.4%)	
75+	1,074 (2.7%)	
Employment status		
Employed	37,757 (94.2%)	
Unemployed	2,253 (5.6%)	
Years of education		
<10 year	1,422 (3.5%)	
11–14 years	7,197 (17.9%)	
>15 years	31,461 (78.5%)	
Income		
Poorly	6,669 (16.6%)	
Fairly well	19,910 (49.7%)	
Very well	13,501 (33.7%)	
Subjective socioeconomic status		
Scale (1–10)		6.12 (1.81)
Choice to live alone		
Alone and choose alone	24,338 (60.7%)	
Alone but choose not to	6,804 (17.0%)	
Not alone and choose not to	8,938 (22.3%)	
Length living alone (years)		
Open number		4.56 (11.12)
Number of people in household		
Open number		1.23 (1.40)
Marital status		
Single	11,644 (29.0%)	
In a relationship but not living together	2,295 (5.7%)	
Married or cohabiting	16,463 (41%)	
Divorced or separated	7,409 (18.5)	
Widowed	2,269 (5.7%)	
Sexual orientation		
Exclusively heterosexual	30,849 (76.9%)	
Predominantly heterosexual	5,051 (12.6%)	
Equal	933 (2.3%)	
Predominantly homosexual	730 (1.8%)	
Exclusively homosexual	1,434 (3.5%)	
Asexual	1,083 (2.7%)	
Dependants		
Have dependants	28,465 (71.0%)	
No dependant	11,615 (29.0%)	
Length as carer (years)		
Open number		0.09 (0.40)
Age of the youngest child (months)		
Open number		136.41(176.15)
Number of children		
Open number		1.04 (1.33)
Couple satisfaction		
Scale (4–32)		16.56 (5.43)
Loneliness positive		
Scale (1–3)		1.47 (0.56)
No = 1; Sometimes = 2; Yes = 3		
Hours spent alone		
Open number		11.63 (7.20)

(*table continues*)

Table 1 (*continued*)

Variable	*N* (%)	*M* (*SD*)
Enjoyment time alone		
Scale (1–5)		3.39(0.97)
Not at all = 1; Very much = 5		
Personality		
Extraversion		
Scale (1–7)		3.71 (1.49)
Agreeableness		
Scale (1–7)		4.79 (1.25)
Conscientiousness		
Scale (1–7)		5.29 (1.21)
Emotional stability		
Scale (1–7)		4.51 (1.45)
Openness to Experience		
Scale (1–7)		5.06 (1.23)
Subjective health		
Scale (1–5)		3.41 (1.02)
Daily experiences with prejudice		
Scale (1–7)		2.36 (0.97)
Self esteem		
Scale (4–32)		17.25 (3.13)
Social capital		
Scale (1–5)		3.00 (0.73)
Relational mobility		
Scale (1–7)		3.97 (0.85)
Migration status		
Residence in same country as birth	27,809 (69.4%)	
Residence in different country as birth	12,271 (30.6%)	
Individualism		
Hofstede index (1–100)		83.80 (14.92)
Power distance		
Hofstede index (1–100)		38.43 (10.75)
Country of residence[a]		
United Kingdom		83% (*N* = 33304)

[a] See Supplemental Materials for detailed information about how many participants participated from each country, island, or territory. UCLA = University of California, Los Angeles.

(from 1 = *never* to 7 = *every day*; α = .79). Social capital was measured with the seven-item scale by Martin et al. (2004), with items such as "People around my local neighborhood are willing to help their neighbors" (from 1 = *strongly disagree* to 5 = *strongly agree*; α = .82).

To operationalize collectivism and power distance, participants indicated their country of residence, which was coded using Hofstede's (1991) indices, with zero corresponding to collectivism or low power distance and 100 corresponding to individualism and high power distance. Our participants resided in countries that spanned the full range of these two dimensions. We also measured relational mobility with the 12-item scale by Thomson et al. (2018). Participants were asked to reflect on the people in their immediate society and to indicate to what extent they agreed with each item. An example item is "They are able to choose, according to their own preferences, the people whom they interact with in their daily life" (1 = *strongly disagree* to 6 = *strongly agree*; α = .90).

Demographic information provided gender (male, female, other, prefer not to say); age; marital status (single, in a relationship but not living together, married or cohabiting, separated or divorced, widowed); country of residence; country of birth; employment status (retired, in part or full time work, part or full time student, unemployed); education level (years of education completed); income ("how well do you feel that your needs are met by the financial resources you have?" very well, fairly well, poorly); subjective socioeconomic status (SES, MacArthur scale, Adler et al., 1994; from 1 = *bottom rung* and 10 = *top rung*); carer (yes/no); if participants indicated being a carer, they also indicated how long they had been a carer; dependents (yes/no); number of children and age of the youngest child (both only for those with children); and sexual orientation (from 1 = *exclusively heterosexual* to 6 = *exclusively homosexual*, with 7 = asexual). Migrant status was computed using birthplace and place of residence by categorizing participants as living in the country of their birth (one) or not (zero).

Ethical approval was obtained for this study prior to data collection from the University Research Ethics Committee at the University of Manchester.

Analytical Strategy

The analyses reported in this article were not preregistered. We used machine learning (ML), which involves the searching for generalizable patterns to make precise predictions from a data set. ML contrasts with traditional statistics that focus on inferring relationships between variables from a sample. ML models provide four advantages compared to traditional statistical methods (Kyriazos et al., 2021): (a) No assumptions about the distribution of the dependent and independent variables need to be made, (b) ML uses

training data to recognize patterns in the training data and make predictions to be tested in test data, (c) it manages missing data effectively, and (d) it can handle large data sets efficiently. To identify the most important factors related to loneliness, we used random forest analysis, which is based on the results of an ensemble of regression trees to predict the response values. Random forests can effectively model complex nonlinear relationships between input features (i.e., predictors) and the target variable through the collection of decision trees. Each tree makes decisions based on thresholds in features, splitting the input space into piecewise-constant segments. For example, if the decision tree determines that "6 hr alone per day" is an important point at which loneliness changes, then this becomes a threshold. This piecewise approximation allows random forests to adapt to data with multiple interaction effects and high-dimensional feature spaces without the need for explicit feature transformation, making them powerful for capturing nonlinearity in regression tasks. In this study, we use random forest to analyze the relationship between loneliness frequency and the other variables.

The standard practice of allocating 80% of the data for the training set and the remaining 20% for the test set (Joseph, 2022) was adopted. During the model training process, hyperparameters were selected by minimizing the mean squared error. Predictions on the test set were made using these optimal hyperparameters. The importance of each feature was computed by averaging the reduction in mean squared error attributed to each feature across all trees, representing the relative importance or contribution of each feature to the prediction model.

In a second stage of the analyses, partial dependence plots (PDPs) were employed to assess how the most important variables influence the prediction of loneliness when all other variables in the model are held fixed. The PDP algorithm was proposed by Friedman (2001) for investigating the relationships among input variables and the output prediction. The advantage of the PDP compared to that of the conventional regression on the scatter plots is that PDPs allow us to visualize how relatively small changes in the predictor (between participants) are associated with changes in the outcome variable (also between participants) while at the same time excluding the effects of other confounding variables through a marginalized distribution (a detailed explanation of the PDP can be found in Qin et al., 2022). This method allows for the individual effects of each predictor on the outcome (loneliness) to be examined in detail and in isolation of other potential predictors.

We employed both 1-D and 2-D PDPs. A 1-D PDP visualizes the relationship between a single feature and the outcome (loneliness frequency) by plotting the prediction against different values of the feature while other features are held constant. For the 1-D PDPs, we selected as the x variable only the variables that explained at least 5% of variance in loneliness frequency, and all other variables were held at their respective mean values. In addition, we employed 2-D PDPs to show the interaction between two features and how they jointly influence the prediction of loneliness frequency. For the 2-D PDPs, we included as predictors the variable that emerged as the most important predictor in interaction with the remaining most important predictors (those who explained at least 5% of variance). The complete research materials, data sets, and data analysis scripts can be found at https://osf.io/9mvbk/?view_only=6497e5306e9e47bdbe270a7f82fd1d71.

Results

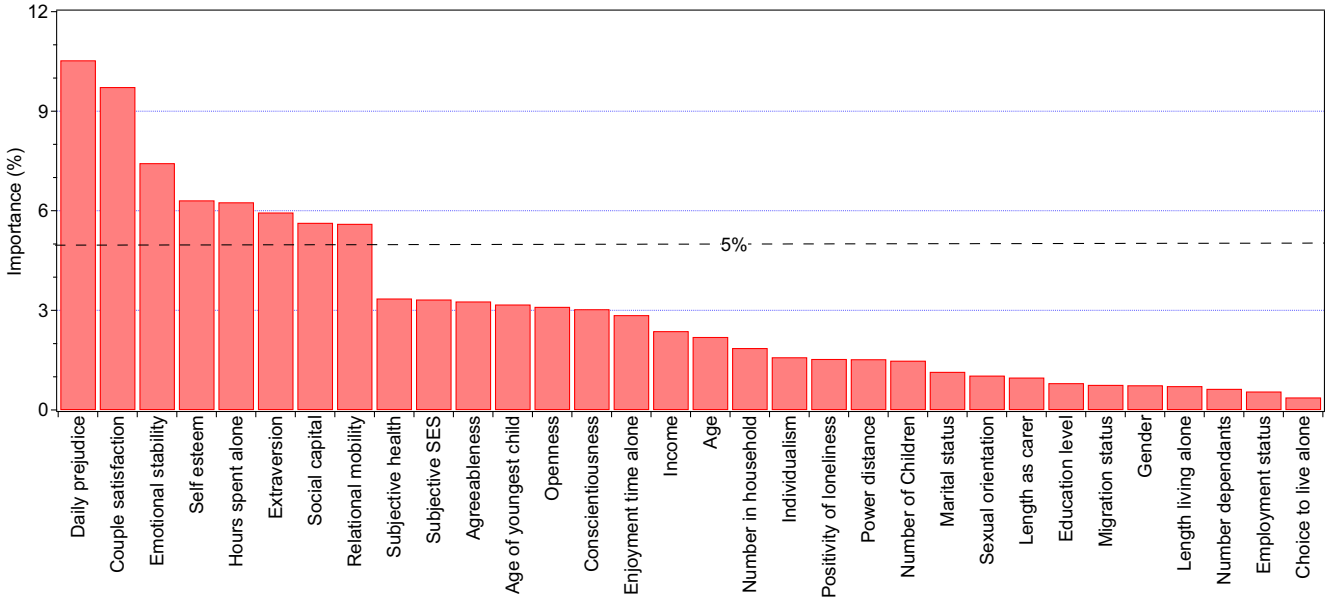
Loneliness frequency was widely spread across the scale (from 1 to 5), with a mean of 2.66 and a standard deviation of 1.13 (see Table 1 and Supplemental Figure S1). The correlation coefficients (R^2) prediction for loneliness frequency in the training set and the test set were 0.93 and 0.48, respectively. The random forest model exhibited a high degree of accuracy on the training set, accounting for 93% of the variation in loneliness frequency, which suggests a strong alignment with the training data. On the test set, the model explained 48% of the variation, indicating a moderate predictive performance on unseen data. It is worth noting that it is normal for the training set to have a much higher degree of accuracy because the model is specifically tuned to this data, whereas the test set is tested in unseen data (James et al., 2013). This suggests that while there is room for improvement in the model performance, it has a considerable amount of predictive power when applied beyond the data it was trained on. Both values were above the value reported by Ejlskov et al. (2018), which was 32% accuracy, suggesting that the variables included in this study add predictive power to those examined in prior research.

Figure 1 shows the important identifiers of loneliness frequency in random forests. The variable importance measure was scaled so that the sum of all feature importance scores becomes 100%, providing the relative importance of a variable among all input variables. Higher values of importance indicate that those features have a stronger association with loneliness. The wide spread of the important identifiers indicates that loneliness was associated with several variables. Among the 32 variables included in the analyses, daily experiences with prejudice and discrimination, couple satisfaction, emotional stability (also called neuroticism), self-esteem, hours spent alone daily, extraversion, social capital, and relational mobility were identified as the most important variables, each accounting for more than 5% of variance in loneliness. This means that each one of these variables individually contributed substantially to the differences observed in loneliness levels across the study sample, making them particularly important for understanding loneliness. As can be seen in Figure 1, the next strongest associate explained 3% or less variance in loneliness.

To further explore the relationship between loneliness frequency and these eight most important predictors, we estimated the partial dependence of loneliness frequency with respect to *changes* (between participants) in experiences with these predictors using 1-D PDPs (see Figure 2). The changes in the specific input variable (i.e., each of the eight predictors that explained at least 5% of variance in loneliness frequency) in relation to loneliness frequency were estimated while considering the variability of the rest of the variables through marginal effects. In this way, we could inspect the expected loneliness frequency as a function of the input features of interest. The partial dependence of loneliness frequency with experiences with prejudice indicates that there was a relationship between the frequency of loneliness and these experiences, but this relationship was not constant across all levels of prejudice. Between participant differences between low (Level 1) and moderate (Level 2) experiences with prejudice were only associated with a slight increase in loneliness, whereas the difference in loneliness between participants who experienced moderate (Level 2) and high (Level 4) levels of prejudice was pronounced. This implies that the impact of discrimination on

Figure 1

Importance of Identifiers of Loneliness Frequency in Random Forests Prediction



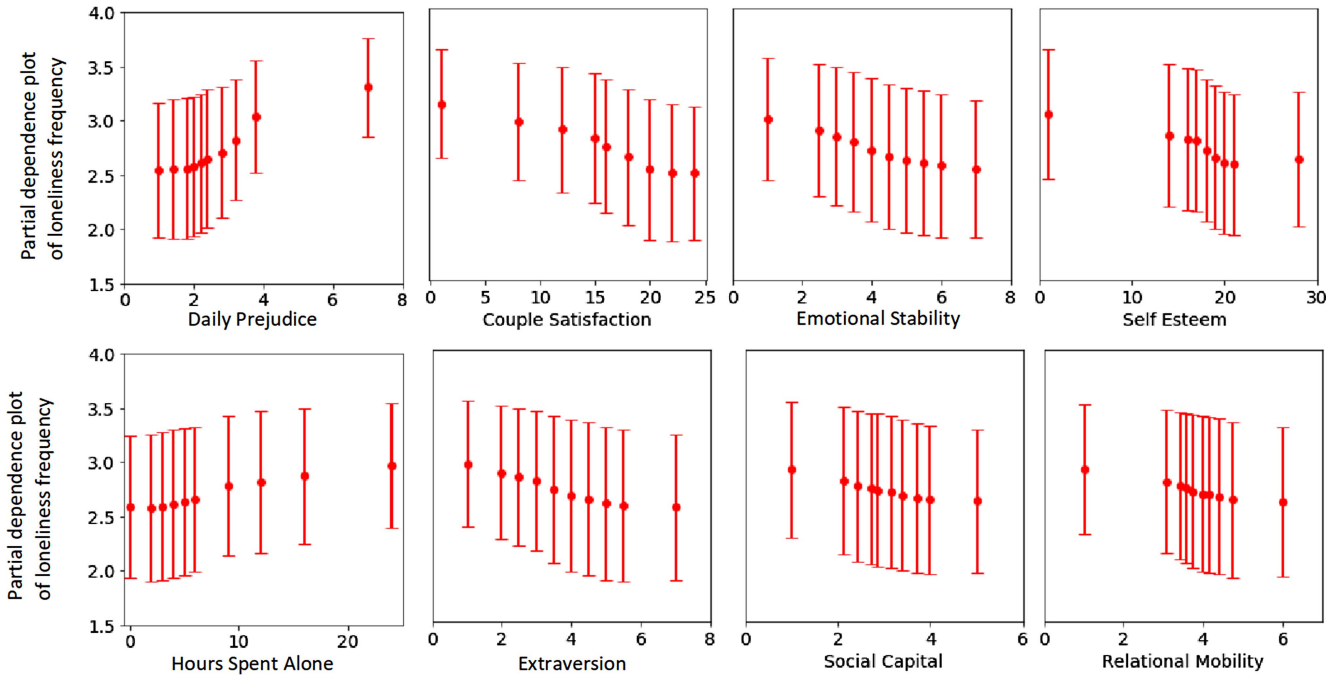
Note. SES = socioeconomic status. See the online article for the color version of this figure.

loneliness became significantly stronger as experiences with prejudice crossed a certain threshold. Beyond that point, increases in experiences with prejudice were associated with more substantial increases in feelings of loneliness.

In terms of the relationships between loneliness frequency and couple satisfaction, the results indicate a clear link between couple satisfaction and the frequency of loneliness. Specifically, up to a couple satisfaction score of 20, the more participants were satisfied

Figure 2

One-Dimension Partial Dependence Plots of Loneliness Frequency With Respect to the Eight Most Important Features



Note. The *y*-axis is the partial dependence of expected loneliness frequency as a function of the input features of interest. The solid dots represent the average estimation, and the error bars represent the standard deviation. See the online article for the color version of this figure.

with their relationship, the less lonely they reported feeling (with loneliness averages ranging from 3 at low levels of couple satisfaction to 2.5 at high levels of couple satisfaction). Once couple satisfaction exceeded a score of 20, the frequency of loneliness stabilized and did not decrease further, suggesting that beyond this point, increases in couple satisfaction (between participants) did not have a significant impact on loneliness frequency.

The relationship between loneliness frequency and emotional stability was characterized by a negative correlation, where more emotional stability was associated with less loneliness frequency. This association was more pronounced when emotional stability scores were between 2 and 5.

Self-esteem was negatively associated with loneliness, particularly when self-esteem scores were within the range of 15–20. We also observed an extreme value when self-esteem was at zero, indicating that participants with this very low level of self-esteem reported considerably high levels of loneliness frequency. This means that at the lowest possible level of self-esteem, the frequency of loneliness was notably higher compared to at other levels of self-esteem, underscoring a strong inverse relationship between self-esteem and loneliness.

We also observed that participants expressed more frequency of loneliness when they spent a high number of hours a day alone. This increase became more pronounced for participants who spent more than 7 hr a day alone, and even more so for those who spent more than 20 hr a day alone. Therefore, while there was a general trend for more loneliness with increased alone time, it is especially noticeable at higher thresholds of time spent alone.

The 1-D PDP plot also shows that loneliness frequency gradually decreased when extraversion increased. This suggests that more extroverted individuals generally reported feeling lonely less often than their less extroverted counterparts. Similar to the effect of extraversion, an increase in social capital also corresponded to a decrease in the frequency of loneliness. This suggests that individuals who had more social resources at their disposal were less likely to experience loneliness, emphasizing the importance of social connections and community involvement in mitigating feelings of isolation. Likewise, with relational mobility, as relational mobility increased, the frequency of loneliness tended to decrease. This indicates that in environments where individuals have more opportunities and feel more at ease to establish and change social connections, they were generally less likely to report feelings of loneliness. This underscores the value of being in a dynamic social environment that supports and encourages the formation of new social ties.

Given that experiences with prejudice and discrimination were identified as the most critical factor for predicting loneliness, as illustrated in Figure 1, we further examined how prejudice interacts with other factors to predict loneliness. To investigate this, we generated 2-D PDPs. A 2-D PDP depicts in detail the interaction between (changes in) two variables and their combined effect on a response variable, with other variables held constant at their average values. It displays this interaction on a grid where the axes represent the predictors and the surface color indicates the outcome (here, loneliness frequency). The plot uses colors to represent different levels of the outcome loneliness across two dimensions: One axis for prejudice and the other for the second variable of interest. By interpreting the colors, we can discern how between participant differences in levels of experienced prejudice and this second variable together influence the frequency of loneliness, with the color intensity typically indicating higher or lower values of the outcome. The lighter color in Figure 3 indicates a higher value of loneliness frequency.

Figure 3 suggests that the association between prejudice experiences and loneliness was influenced by several other factors, including emotional stability, couple satisfaction, hours spent alone, and personal self-esteem. First, emotional stability appears to buffer the association between loneliness and prejudice; people who had higher emotional stability experienced a lower frequency of loneliness even when they faced similar levels of prejudice compared to those with lower emotional stability. Second, the relationship between couple satisfaction and loneliness in the context of prejudice was more complex. When couple satisfaction was low to medium, it did not significantly interfere with the association between loneliness and prejudice experiences. However, at higher levels of couple satisfaction, there is a notable decrease in loneliness frequency, even with the same experiences of prejudice. This indicates that high couple satisfaction can mitigate the negative association between experiences with prejudice and loneliness. Third, hours spent alone interacted strongly with prejudice experiences. Regardless of the level of prejudice faced, the more time participants spent alone, the higher their frequency of loneliness. This might be taken to suggest that spending time alone can amplify the loneliness that experiences with prejudice can cause. Last, personal self-esteem also played a protective role. Individuals with higher self-esteem experienced less loneliness at equal levels of prejudice experiences than those with lower self-esteem. This suggests that higher self-esteem might be able to reduce the negative impact of prejudice on loneliness frequency. These interactions imply that emotional stability, couple satisfaction, time spent alone, and self-esteem were significant moderators of the relationship between prejudice experiences and loneliness, either weakening or strengthening the association between prejudice experiences and how frequently individuals feel lonely.

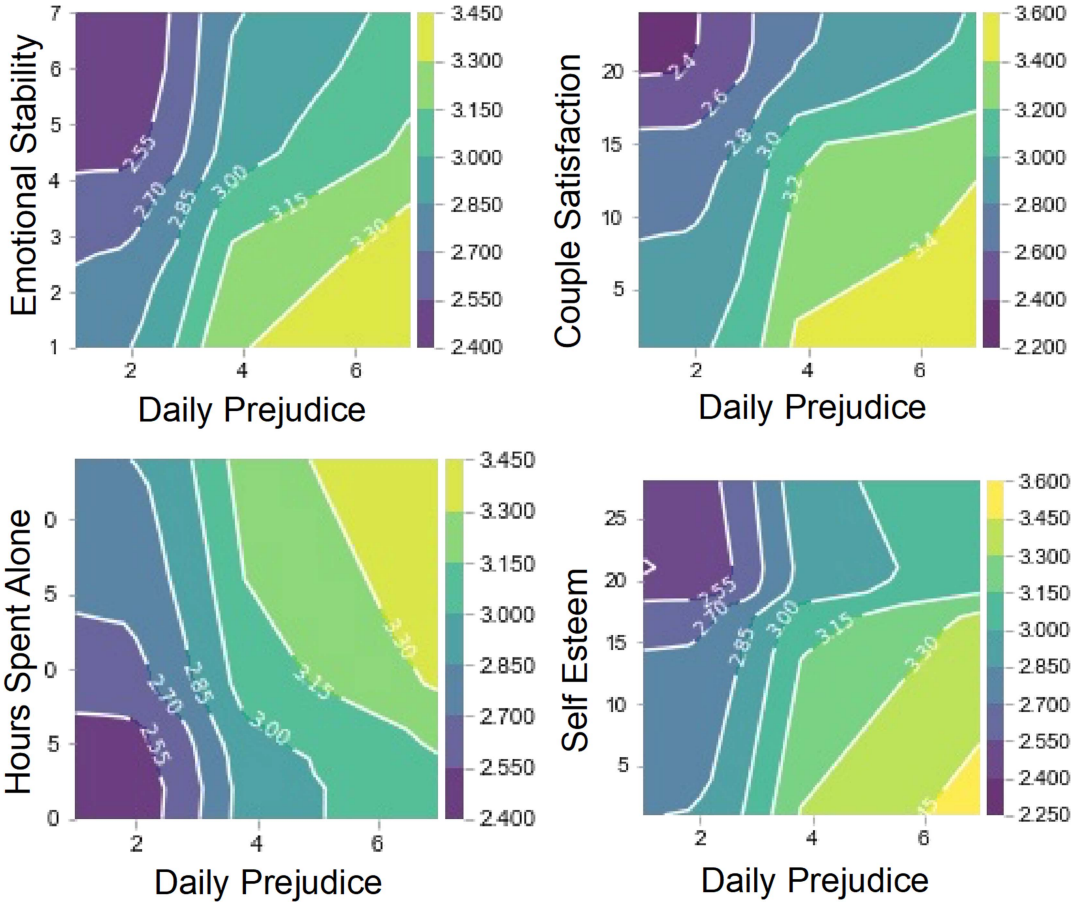
Exploratory analyses (described in the Supplemental Materials) additionally show that the association of loneliness with prejudice, couple satisfaction, emotional stability, and extroversion is similar for all age groups.

Discussion

We used advanced ML to explore the relative importance of 32 individual, relational, sociocultural, and demographic factors as correlates of loneliness frequency among those who participated in the BBC Loneliness Experiment. While examination of the correlates of loneliness is not new, the identification of the unique and most important associations of loneliness among those aged over 16 years using ML is novel. By expanding the age range of previous ML samples (Altschul et al., 2021; Ejlskov et al., 2018) to adolescence (from 16 years) and young adulthood, we were able to explore important correlates of loneliness across ontogeny. We also examined a more culturally diverse sample than in previous ML work and focused on individual factors, relational, sociocultural, and demographic factors. Our findings support existing ML research on loneliness and earlier work in the field that used traditional statistical methods, showing there to be important associates of loneliness, but our random forest ML provides more precision compared to those earlier studies that used regression analyses and advanced the previous work using ML.

Figure 3

Two-Dimensional Partial Dependence Plots of Loneliness Frequency and the Interactions of Daily Prejudice With Emotional Stability, Couple Satisfaction, Hours Spent Alone, and Self-Esteem



Note. Colored contour bands represent ranges of loneliness frequency prediction. The light color represents high loneliness frequency, and the dark color represents low loneliness frequency. The exact loneliness frequency values in each contour band are also listed in the figure. See the online article for the color version of this figure.

We found that the main correlates of loneliness among those aged 16 and 99 years were, in order of importance: Everyday experiences with prejudice, couple satisfaction, emotional stability (neuroticism), average hours spent alone per day, low self-esteem, extraversion, social capital, and relational mobility. This highlights the need to examine multiple factors simultaneously and provides information that can be used to inform the development of interventions, thus expanding both our understanding of loneliness and the potential avenues for support.

The most important associate of loneliness for people who participated in the BBC Loneliness Experiment was daily experiences with prejudice and discrimination, suggesting that loneliness often results from processes of social marginalization and devaluation (see also Barreto et al., 2023; Barreto et al., 2024). Importantly, it was not the demographic membership of groups that are often marginalized (such as migrants) that predicted loneliness but daily experiences with prejudice. This suggests that loneliness often emerges from processes of exclusion rather than being inherent to how members of these groups function socially. These findings suggest that the most needed interventions to reduce loneliness might be those focused on making social environments more inclusive (see also Jefferson, Barreto, Jones, et al., 2023; Jefferson, Barreto, Verity, & Qualter, 2023). Enhancing our understanding of the link between prejudice experiences and loneliness requires greater research attention to understand the precise direction of causality (e.g., through experimental methods) and how specific types of discrimination are related to loneliness. Recent work has taken some steps in this direction by showing that the manipulated salience of racist experiences increases loneliness among racial minorities, compared to when these experiences are not salient (Doyle & Barreto, 2024).

Across several studies using traditional statistical methods, couple satisfaction was a powerful factor protecting individuals from reporting loneliness (Luhmann & Hawkley, 2016). We support that finding using more sophisticated ML. Recent prospective work has shown that loneliness can also predict couple satisfaction (Mund & Johnson, 2021). Our finding that this variable emerged as one of the most important associates of loneliness further underlines the

relevance of further exploring this bidirectional relationship, keeping in mind that a biodirectional relationship is one where both directions of causality are important.

A recent meta-analytic study (Buecker et al., 2021) showed that emotional stability was the strongest correlate of loneliness among the Big Five personality traits. Our findings align well with that work, but the mechanisms linking emotional stability and loneliness still need to be examined. In addition to having a genetic component (Mund et al., 2020), there is evidence that this variable is related to a heightened reactivity to social stressors (Zautra et al., 2005), but also that individuals low in emotional stability are more sensitive to social rejection cues (Denissen & Penke, 2008), both of which are linked directly to increases in loneliness (Qualter et al., 2015). It is also possible that emotional stability is affected by lifelong experiences such as childhood adversity or repeated experiences with prejudice. Direct examination of the mechanisms linking neuroticism and loneliness is needed. Similarly, we found that extroversion was one of the most important associates of loneliness and that its effect was similar for all age groups and for men and women.

While aloneness is not the same as loneliness, we found the number of hours a person spent alone on an average day were an important associate of loneliness when all others were controlled for, particularly when people were spending quite a lot of time alone (more than 20 hr). Indeed, spending time alone can be very valuable and often deliberately sought, but spending a lot of time alone on a daily basis, such as when people live alone and far from their social networks, can be detrimental to well-being (Weinstein et al., 2021). This finding lends complexity to the commonly expressed idea that aloneness and loneliness are distinct and suggests that more research is needed to better understand the relationship between these variables, how much time alone is detrimental, and how people might be able to monitor their alone time to avoid loneliness.

Low self-esteem also emerged as an important correlate of loneliness when all other variables were kept constant, which is consistent with a wide range of studies linking self-esteem to relational behavior and relationship quality (e.g., Murray et al., 2002). Although the relationship between self-esteem and loneliness is likely to be bidirectional, low self-esteem can perpetuate loneliness by increasing hypervigilance and biasing interpretations of others' behaviors as rejecting, leading to defensive behaviors and motivating withdrawal (Qualter et al., 2015). Importantly, self-esteem can be lowered by a variety of life experiences, such as bullying and other forms of victimization, which points toward areas of intervention to reduce experiences that lower self-esteem.

Importantly, our analytical technique and sample size allowed us to examine interactions between variables. While computing interactions between all possible variables would be unfeasible, we examined interactions between the variable that emerged as most important (experiences with prejudice) and the remaining variables that explained at least 5% of variance. The results indicate that experiences with prejudice are most negatively associated with loneliness when individuals spend a lot of time alone and the least when individuals are emotionally stable, have high personal self-esteem, or have high levels of couple satisfaction. It seems reasonable that if people have few social experiences, those they have need to be positive, justifying why experiences with prejudice are particularly problematic when people spent a lot of time alone. How self-esteem protects from the emotional toll of prejudice and discrimination had been established in a series of experimental studies, but this had not yet been done in connection to loneliness (Cihangir et al., 2010). In turn, while couple satisfaction has been shown to be detrimentally affected by experiences with prejudice (e.g., Doyle & Molix, 2014), its role as a moderator of the impact of these experiences on loneliness had not yet been demonstrated. The role of emotional stability as a moderator of the impact of prejudice has, to our knowledge, not been documented before. Importantly, experiences with prejudice had a similar association with loneliness frequency for all age groups and for men and women. Supplementary analyses also showed that couple satisfaction, emotional stability, and extroversion were similarly associated with loneliness at all ages and for men and women.

It is important to acknowledge that even though our machine learning approach provides high levels of precision and nuance, these findings are ultimately based on correlational data and that further research is needed to examine these associations prospectively and experimentally to clarify causal relationships. Our analytical strategy also does not take into account the nested nature of the data. That said, the analytical techniques we employed complement prior research by identifying particularly important associations when multiple others are controlled for, as well as enabling the more detailed examination of how between participant differences in a predictor are associated with differences in loneliness. In this way, our findings point to several factors that are already targets for intervention, many having been shown to be moderately successful at reducing loneliness (Lasgaard et al., 2022), but add by highlighting which of these might require most attention, as well as by drawing attention to some factors that are not yet receiving enough attention in loneliness interventions (e.g., experiences with prejudice). In addition, the robustness of the ML and the inclusion of a wider range of ages and cultures than in prior research offer precision and superior evidence. We acknowledge, however, that our sample is not representative of any population, a problem that our analytical strategy does not correct for and which limits the generalizability of the results, but we counter this by including considerable diversity within the sample. Moreover, the inclusion of a measure of everyday discrimination (which was not included in prior research using ML) and the fact that it was the strongest correlate of loneliness by far offers new ideas for intervention that would work well alongside more traditional intervention strategies focused on relational and individual changes.

Conclusions

Our findings show that the key correlates of loneliness, when others are kept constant, are sociocultural (discrimination), relational (couple satisfaction, hours spent alone), and individual (neuroticism, personal self-esteem). As such, interventions need to focus on multiple factors, both to address the multiple factors affecting the loneliness of each individual and to cater for different individuals and, crucially, address marginalization. Indeed, the typical focus on individual and relational strategies without addressing structural factors will do little to mitigate loneliness and the adverse effects that it has on health and well-being, creating further inequalities for already marginalized groups.

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