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Full-length Article

Social cohesion and loneliness are associated with the antibody response to COVID-19 vaccination

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ABSTRACT

Background: Recent research has suggested that psychosocial factors influence the antibody response to vaccine, including SARS-CoV-2 (COVID-19) vaccines. Here we investigated whether social cohesion and loneliness were predictive of antibody response to a single dose of a COVID-19 vaccine. We also tested if the association between social cohesion and antibody response was mediated by feelings of loneliness.
Methods: Participants ($N = 676$) COVID-19 antibody data were extracted from March 2021 wave of the Understanding Society COVID-19 study from the UK. Relevant socio-demographics, health and lifestyle, loneliness, social cohesion indices were also used in a series of hierarchical linear regression to test our main hypotheses.
Results: After controlling for covariates (e.g., age and chronic health conditions), lower social cohesion was associated with a lower antibody response. Further, the association between social cohesion and poorer antibody responses was mediated by loneliness; those reporting lower social cohesion also reported higher loneliness, which in turn was associated with lower antibody response.
Conclusion: This study confirms that feelings of 'being in it together' relate to the strength of the antibody response to COVID-19 vaccination, emphasising the importance of the social cohesion agenda during the pandemic.

1. Introduction

To date, the SARS-Co-V2 pandemic has already led to well over 5-million deaths and 275 million infections (Li et al., 2021). Since the identification of SARS-CoV-2 genomic sequence early in 2020, there are now several successful candidate vaccines (e.g., AstraZeneca, Moderna, Janssen & BioNTech/Pfizer), although some are more efficacious than others (e.g., BioNTech/Pfizer is ~ 95% vs AstraZeneca ~ 62%) (Creech et al., 2021). While it is obvious that vaccine efficacy is highly dependent on vaccine-related factors (e.g., protein subunit, viral vector, mRNA), number of doses, and the interval between doses (Creech et al., 2021), the psychosocial and behavioural characteristics of vaccine recipients also matter (Madison et al., 2021). In fact, there is a well-established literature on the influence of psychosocial factors on immunity (Irwin, 2008; Segerstrom & Miller, 2004) and more specifically the antibody response to vaccination (Burns et al., 2003; Burns and Gallagher, 2010; Pedersen et al., 2009; Phillips, 2011; Whittaker, 2018). Although factors such as social cohesion and 'being in it together' have been shown to be relevant to vaccine uptake (Muldoon et al., 2021) these factors also potentially have an important influence on the COVID-19 vaccine antibody response. This analysis addresses this important question.

A sense of social cohesion is one psychosocial factor that has been prominent during the pandemic (Berrocal et al., 2021; Guterres, 2020). Social cohesion is the degree of social connectedness and solidarity among different community groups within a society, including levels of trust and connectedness between individuals and across community groups (Fonseca et al., 2019; Ludin et al., 2019). Higher social cohesion and trust in others has been associated with better health outcomes including depression and cardiovascular disease (Chuang et al., 2013; Feng et al., 2016; Miller et al., 2020; Williams et al., 2020). During the initial lockdowns, we had 'clap for carers' in the UK, Italians sang on the balconies while Dubliners played bingo on them; displays such as these served to build a sense of community connection and civic participation, creating feelings of 'us all being in this together'. The importance of social cohesion for recovery from the pandemic has also been noted,

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with the United Nations commissioning a rapid review of social cohesion and community resilience to help guide COVID-19 recovery roadmaps (Jewett et al., 2021). Moreover, communities that invested in integration programmes were found to have higher levels of social cohesion in the midst of the COVID-19 pandemic (Lalot et al., 2021). Despite this, while high social cohesion is frequently evident during a crisis, UK researchers have found declines over time from pre-pandemic to during the pandemic. For example, the number of people who felt that they could trust other people in their neighbourhood fell from nearly 70% in 2011/12 to 56% in 2020 (Borkowska & Laurence, 2021).

Trust in neighbours and broader government are central for social cohesion and adherence and engagement with public health messages (Muldoon et al., 2021). For example, during the COVID-19 crisis governments, institutions and scientists were essential to developing public trust and engagement with public health measures such as transparency around health risks, vaccine side effects as well as counteracting pseudoscientific beliefs. In some countries, the low level of government transparency, poor science communication, as well as favouritism and inconsistency in the application of lockdown rules across social groups led to a breakdown of trust (Gratz et al., 2021). In the UK, public trust was severely undermined when government officials were not punished for breaking lockdown creating a 'one rule for them and another rule for us' scenario (Fancourt et al., 2020). A similar decline in trust in government sources was observed in the United States, which has been often linked to conservative political affiliation (McLamore et al., 2022), and right wing leaning media (Latkin et al., 2020). Moreover, this waning public trust in governments has been associated with vaccine hesitancy (Muldoon et al., 2021). Others have noted that low social cohesion can be viewed as a socially relevant stressor (Fonseca et al., 2019) with implications for health (Jewett et al., 2021). Elsewhere the concepts of social psychoneuroimmunology and social immunology have been proposed as a way of understanding how these social factors get inside the body (Muscatell, 2021; Shattuck, 2021). Potential pathways linking social cohesion to adaptive immunity, that is, the COVID-19 vaccine response, are likely to include activation and release of inflammatory cytokines (e.g. IFN-γ = interferon γ) which are released by effector T-cells during the antigen-dependent activation stages of antibody production (Gaudino & Kumar, 2019; Vazquez et al., 2015). Moreover, perturbations in social environments (e.g. involve social conflict, isolation, devaluation, rejection and exclusion) have been found to activate neural–immune reactivity, which when sustained, can increase inflammatory cytokines and therefore an individuals' risk for viral infections and other immune-related disorders (Leschak & Eisenberger, 2019; Shattuck, 2021; Slavich, 2020).

In fact, two recent theoretical papers have argued that psychosocial and behavioural factors are likely to have implications for the efficacy of COVID-19 vaccine antibody response (Madison et al., 2021; Vedhara, 2020). For example, research has found that factors such as stress have a negative effect on antibody response to several vaccine types (Glaser et al., 1992; Miller et al., 2004; Moynihan et al., 2004; Vedhara et al., 1999). The negative effect of stress, reducing optimal antibody response, has been recently found in men exposed to the human papilloma virus (Wu et al., 2017). Other research has also confirmed that stress was associated with a lower antibody response to both thymus-dependent and thymus-independent vaccines (Gallagher et al., 2009a, 2009b; Gallagher et al., 2008a; Phillips et al., 2005). Young adults reporting a higher number of negative life events had lower antibody responses to a hepatitis A vaccine, (thymus-dependent) while parents caring for children with developmental disabilities had lower antibody responses to an influenza (thymus-dependent) and pneumococcal vaccine (thymus-independent). In contrast, social support had a positive effect, whereby higher levels of social support were associated with a higher antibody titre following vaccination (Gallagher et al., 2008b; Glaser et al., 1992; Phillips et al., 2005). This small but positive effect for social support on antibody response has been confirmed in a recent meta-analysis (Uchino et al., 2020). Taken together, these studies confirm that psychosocial experiences influence antibody responses to vaccination and given that, poor social cohesion is a socially relevant stressor it is a likely candidate to explore in this current context.

The UK lockdown seemed to have reduced social cohesion (Borkowska & Laurence, 2021) and left others feeling lonely (Gallagher et al., 2021; Gallagher & Wetherell, 2020). In fact, loneliness has been to the fore during the current pandemic (Pai & Vella, 2021). Government lockdowns and restrictions on social activities and mobility are some of the main reasons why loneliness has become a serious concern for health during the current crisis (Tomaz et al., 2021). On the one hand, isolating had health protective effects (e.g., slowing down virus replication rates); but on the other, the unintended consequences of this social isolation was its negative effects on mental health across multiple cohorts and vulnerable groups (Gallagher et al., 2021; Gallagher & Wetherell, 2020; Hu & Gutman, 2021; Polenick et al., 2021). Others have argued that the effects of loneliness experienced during the pandemic may also have pathophysiological effects such as negatively affecting the immune system (D'Acquisto & Hamilton, 2020) including antibody responses (Madison et al., 2021). Moreover, the effect of loneliness on immune and endocrine outcomes, pathways underlying the antibody response, are well established (Cacioppo et al., 2015; Smith et al., 2020). Importantly, one previous study showed that loneliness was associated with a lower antibody titre to an influenza vaccine (Pressman et al., 2005). Given the recent health concerns regarding loneliness, it is plausible that greater feelings of loneliness experienced during the pandemic will negatively affect the COVID-19 vaccine response.

We examined the antibody response to a single COVID-19 vaccine shot. Those who got a second vaccination or who were exposed to the virus previously would have a secondary response and there may be different psychosocial and immunological factors at play there (Burns and Gallagher, 2010). This analysis of the response to a single shot therefore is an indicator of a primary immune response, which allows us to investigate the response mounted to a novel antigen, i.e. SARS-Co-V2. Based on the evidence above, we hypothesise that higher levels of loneliness and lower social cohesion will be associated with a poorer antibody response to the COVID-19 vaccination. Moreover, lower social cohesion will be being predictive of a higher risk of loneliness (Yu et al., 2021), therefore we also hypothesise that the association between social cohesion and COVID-19 antibody response will be mediated by feelings of loneliness.

2. Methods

2.1. Study design and participants

An observational study design was employed by using two waves (January 2021 and March 2021) of the *Understanding Society* UK Household Longitudinal Study (UKHLS) COVID-19 study (Understanding Society, 2020–21). This COVID-19 arm of the main study captures the changing impact of the pandemic on the welfare of UK individuals, families and wider communities. In March 2021, participants (N = 12,680) who completed the first lockdown survey (April 2020) were invited via to take part in a COVID-19 serology study. Of those, 6,600 provided a blood sample for detection of COVID-19 antibodies in response to natural infection or vaccination; here we focus on the vaccination only. We extracted health behaviour data from the January survey data. After weighting the sample to control for selection bias, we were left with a sample of 4,184. Of this sample, 3,452 reported not receiving a vaccine, with 695 participants reporting receiving a first COVID-19 vaccine and no prior infection via testing and 19 were removed for not reaching the antibody threshold (see section 2.2.3 below). Thus, the final sample for the primary antibody response outcome was $N = 676$. If a vaccine is given after a primary infection then a secondary antibody response occurs leading to a more robust immune response (see (Jalkanen et al., 2021) hence this analysis focusing on the primary response excluded those with prior infection. There were no details on vaccine type in the dataset. Based on power (0.80) for a mediation model, 368 was the minimum sample size required (Fritz & Mackinnon, 2007). All participants (see Results section for further details) gave informed consent and ethical approval was obtained by the University of Essex, UK from NHS Health Research Authority, London – City & East Research Ethics Committee, reference: 21/HRA/0644.

2.2. Measures

2.2.1. Social cohesion

As in recent studies (Borkowska & Laurence, 2021) with this dataset, social cohesion was assessed using five item which were Neighbourhood Social Cohesion scale used in the Project on Human Development in Chicago Neighborhoods (PHDCN, 2007). These were 'I regularly stop and talk with people in my neighbourhood', 'People around here are willing to help their neighbours', 'People in this neighbourhood can be trusted', 'I think of myself as similar to the people that live in this neighbourhood' and the reverse-scored 'People in this neighbourhood generally don't get along with each other' with each measured on a 5-point Likert scale (1-strongly agree to 5-strongly disagree). In this case, a higher score represent lower levels of social cohesion. A total scale was computed as the sum of scores of the five items (Cronbach's alpha = 0.84).

2.2.2. Loneliness

Loneliness in the Understanding Society study was assessed by a single item: "In the last 4 weeks, how often did you feel lonely?" with three responses, 1 = Hardly ever or never; 2 = Sometimes; 3 = Often. Previous research has found these single item measures to be appropriate for assessment for loneliness (Ong et al., 2016) and to be predictive of COVID-19 related health outcomes (Gallagher & Wetherell, 2020) as well as the response to other vaccinations (Pressman et al., 2005).

2.2.3. Blood sampling and antibody analysis

Participants were sent a labelled home COVID-19 testing kit (via Royal), an information sheet and a link to a YouTube video on how to collect the blood sample (0.5 ml) via a finger prick into collection tubes. They were instructed to take the blood sample as soon as possible, i.e. within a few days. Samples were then returned to the testing laboratory, Thriva, (https://thriva.co/) for analysis. The kit tested for the presence of COVID-19 specific IgG spike protein which is associated with neutralising levels, i.e. viral clearance (Pang et al., 2021). Overall, a value of 0.8 U/ml was needed for a positive response to the vaccination and 19 people (2.7%) did not achieve this status. In our analyses, we use the continuous antibody score, and even also use neutralising level cut-off levels. Even though cut-off levels of neutralising levels of antibodies have yet been unequivocally defined, one study that has identified neutralization level for COVID-19 antibodies, against several vaccine candidates which was $\geq$ 54 international unit/ml (Khoury et al., 2021). Moreover, this cut-off has also been employed in similar studies across several variant types (Cantoni et al., 2022). Thus, this cut-off was used to create a neutralizing cohort and non-neutralizing cohort.

2.3. Covariates

In line with other vaccine studies and theoretical papers (Burns and Gallagher, 2010; Gallagher et al., 2009b; Madison et al., 2021; Pang et al., 2021), we consider the influence of socio-demographic characteristics such as: age, gender (men/women), ethnicity (White British, White Irish, Indian, Pakistani/Bangladeshi, Black, and Other ethnic group which were dichotomised into White and BAME), and annual household income on vaccine response. Moreover, we also checked if the level of vaccine protection varied by health condition (yes/no), as well as health behaviours including smoking (yes/no), portions of fruit/veg intake per day; alcohol intake frequency in past month, 1 = never, 2 = once, 3 = 2–4 times total, 4 = 2–3 times a week, 5 = 4–6 times a week and 6 = daily. The number of days walking for 30 min or more per week was also included.

2.4. Data reduction and analysis

Our analysis was conducted using version 27 of the Statistical Package for the Social Sciences (SPSS; IBM). Given longitudinal weights for the UKHLS COVID-19 survey are not currently produced, we were only able to correctly adjust for unequal selection probabilities and panel attrition using cross-sectional weights; see (Kaminska and Lynn, 2019) for weighting details. Following this, those not reaching the 0.8 antibody units detection threshold (see above) were removed. Given the skew of the data, antibody titres were subjected to $\log_{10}$ transformation. There were no outliers observed for social cohesion or loneliness. Initial analyses focused on descriptive statistics, correlations and tests of differences, i.e. including *t*-tests for interval data and chi -squared for nominal, across the socio-demographic, health and lifestyle variables and the continuous antibody response. Hierarchical linear regressions were then conducted to determine if our main predictor variables (social cohesion and loneliness) were associated with antibody response status independent of covariates. In these models, co-variates (age and health conditions) were entered in Step 1, followed by each predictor variable separately at Step 2; ΔR^2 was used as a measure of effect size. This was followed by bootstrapped (5000 samples) mediation analyses (PROCESS model 4 (Hayes, 2013). Next, we conducted logistic regressions using the same covariates to examine the prediction of 50% neutralizing antibody levels (coded as 0) or non-neutralizing antibody levels (coded as 1); covariates were entered in Step 1, with social cohesion or loneliness in Step 2. Odds Ratios (OR) were the measure of effect size.

3. Results

3.1. Participant and questionnaire data

The mean (*SD*) age was 61.55 (19.23) and range 20–92, with the majority (60.4%) of the sample being women and White (93%). Over 67% reported living with their partners, and annual income ranged from £0.00 to £500,000 with a mean £20,714.13 and a median (£4,163.58). In terms of health and lifestyle, 66.9% reported having a chronic health condition, 6.2% reported being a smoker, while the majority 20.2 % reported having an alcoholic drink 2–3 times per week over the last month with 6.6% drinking daily. Further, 4.94 (2.11) was the mean number of days participants reporting walking for 30-min or more over the week (range 0–7 days) and the portions of fruit and vegetables per day were 3.14 (0.92), ranged from 1 to 4 portions, and 3.31 (0.82), with a range of 1–4, respectively. The mode for loneliness was 1 with a mean (*SD*) of 1.41 (0.58), range 1–3, and the mean (*SD*) social cohesion score was 11.08 (3.21), with a range of 5–23.

3.2. Vaccination response

The mean (SD) antibody titre was 199.87 U/ml (86.55) with a geometric mean of 150.65 U/ml (60.45). Based on our neutralizing antibody protection cut-off scores, 578 participants were in neutralizing category and 98 in the non-neutralizing category.

3.3. Correlations between socio-demographics, health and lifestyle factors and antibody response (Log_{10})

As can be seen in Table 1, age and having a health condition were the only two socio-demographic and health-related variables associated with antibody response following vaccination. There were no gender differences. Age was negatively associated antibody response (Pearson's), and those who reported having a chronic health condition had lower antibody responses (M = 2.15, SD = 0.47) vs (M = 2.29, SD =

Table 1
Correlations across socio-demographics, health and lifestyle factors and Log_{10} antibody response.

Variable	Mean	1	2	3	4	5	6	7	8	9	10	11	12
1. Age		–											
2. Gender		−0.18**	–										
3. Living with partner		−0.05	0.14**	–									
4. Ethnicity		−0.06	−0.11**	0.11**	–								
5. Health Condition		0.37**	−0.11**	−0.03	−0.04	–							
6. Gross income		0.02	−0.07	0.02	−0.01	0.00	–						
7. Smoker		0.17**	−0.18**	−0.08*	−0.03	0.08*	0.02	–					
8. Alcohol in past month		−0.06	0.01	0.19**	0.14**	0.10*	0.08*	−0.08*	–				
9. Vegetables per day		0.03	−0.01	−0.09*	0.19	−0.08	−0.02	−0.06	−0.07	–			
10. Fruit per day		0.10**	0.09*	−0.01	−0.03	−0.10*	0.01	−0.02	−0.06	0.27**	–		
11. 7-days walking		0.18**	0.01	−0.05	−0.03	0.06	−0.02	0.07	−0.03	0.06	0.00	–	
12. Log_{10} Antibody response		−0.26**	−0.06	0.06	0.02	−0.17**	0.01	−0.01	0.00	0.05	0.00	0.07	–

* = $p < .05$; ** = $p < .001$.

Table 2
Hierarchical linear regression with social cohesion and loneliness, predicting antibody response to a single dose of a COVID-19 vaccine.

Variables	β	t	*p*	ΔR^2
Model 1 Step 1				
Age	−0.20	−5.04	**0.001**	
Health condition	−0.10	−2.37	**0.01**	
Step 2				
Loneliness	−0.07	−1.78	0.07	0.004
Model 2 Step 1				
Age	−0.20	−5.05	**0.001**	
Health condition	−0.09	−2.30	**0.02**	
Step 2				
Social Cohesion	−0.10	−2.55	**0.01**	0.009

0.29), $t(616) = 3.76$, $p < .001$; thus, these were included as covariates in regression analyses.

3.4. Associations between loneliness, social cohesion and antibody response (Log_{10})

In hierarchical linear regressions, after controlling for covariates (see Table 2), loneliness did not significantly predict antibody response ($p = .07$). However, social cohesion was negatively associated with antibody response such that those who reported less social cohesion (higher scores) had a lower antibody titre to the vaccine; $\beta = -0.10$, $t = -2.55$, $p = .01$, $\Delta R^2 = 0.009$. In sensitivity analysis, we examined individual social cohesion scale items and found that a lower level of agreement with the statements 'I regularly stop and talk with people in my neighbourhood' $\beta = -0.10$, $t = -2.62$, $p = .009$, $\Delta R^2 = 0.011$; 'People around here are willing to help their neighbours', $\beta = -0.11$, $t = -2.92$, $p = .004$, $\Delta R^2 = 0.012$ and 'People in this neighbourhood can be trusted', $\beta = -0.08$, $t = -2.20$, $p = .028$, $\Delta R^2 = 0.007$ were predictive of a poorer antibody response. 'People in this neighbourhood generally don't get along with each other' did not significant predict antibody response ($p = .09$).

3.5. Mediation analysis

Here, in this analysis, we again controlled for age and chronic health conditions, and on entering loneliness as a potential mediator our initial direct association between social cohesion and antibody response became non-significant (See Fig. 1). However, as can be seen in Fig. 1, and as expected, the 95% bias corrected CI based on 10,000 bootstrap samples indicated that the indirect effect was entirely below zero, providing evidence for mediation, i.e., a significant indirect effect. Participants who reported less social cohesion also reported higher levels of loneliness and this was predictive of a lower antibody response to a single shot of the COVID-19 vaccine. Given the cross-sectional nature of the data we also ran the alternative model, i.e. loneliness predicting antibody response via social cohesion but this pathway was not significant, ($ab = -0.0038$) entirely below zero [−0.0111, 0.0015].

3.6. Predictors of non-neutralising COVID-19 antibody status

In logistic regression, after controlling for covariates (e.g., age, and health conditions) in Step 1, and loneliness in Step 2, loneliness was not

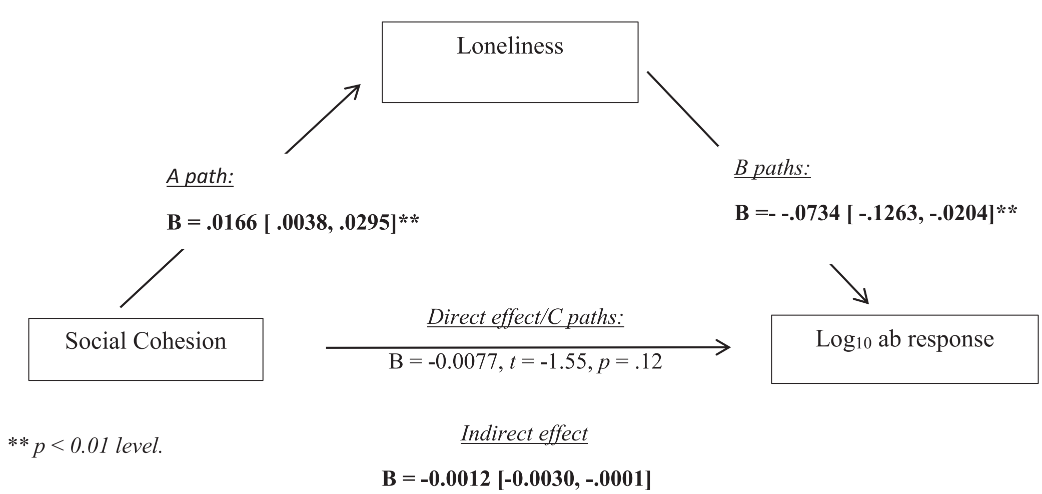

Fig. 1. Adjusted (age and health conditions) mediation path diagram: Direct effects of Social Cohesion on log_{10} Antibody and Indirect effects via feelings of loneliness. Significant effects are highlighted in bold text.

predictive of non-neutralising antibody status, p =.25 and social cohesion did not quite reach statistical significance, OR = 1.06 (95% confidence interval (95% CI), 0.99–1.14), p =.08. In analysis of the individual social cohesion scale items, the only item that proved predictive of non-neutralising antibody titre was a lower level of agreement with the statement 'People in this neighbourhood can be trusted'; OR = 1.38 (95% confidence interval (95% CI), 1.02–1.86)), p =.03. However, this association did not withstand adjustment for multiple testing. We followed this analysis up by repeating the mediation model above and it was not significant.

4. Discussion

To our knowledge, this is the first demonstration of an association between psychosocial factors and the antibody response to COVID-19 vaccination. In this population-based study, we found that participants who reported less social cohesion had a lower antibody titre to a single shot of the vaccine. Moreover, of the social cohesion items, those who had lower levels of agreement with statements like 'talking' or 'helping' their neighbours and level of 'trust in their neighbours' had a poorer antibody response. Research has found that this decline in social cohesion and trust to be a likely consequence of lack of transparency, poor communication and public adherence to health advice and measures, as well as inconsistent application of lockdown rules (Fancourt et al., 2020; Gratz et al., 2021). In addition, while higher feelings of loneliness was not independently correlated with antibody response, the association between social cohesion and antibody response was mediated by feelings of loneliness. People who reported less social cohesion also reported higher levels of loneliness, and this in turn was associated with a lower antibody response to vaccination. As such, developing a sense of social cohesion among the public is worthy of investment as it is likely to have a substantive impact on vaccine efficacy.

Our finding for a direct association between loneliness and antibody response, while not significant was in the expected direction, broadly in line with existing studies on loneliness and antibody response (Pressman et al., 2005). Moreover, loneliness was also a key pathway linking social cohesion to antibody response. Those who reported lower social cohesion reported higher feelings of loneliness and, in turn, they had a lower antibody response to the vaccine. While no study has examined the effect of social cohesion on antibody response previously, our findings do align with the social safety theory and other research demonstrating the negative effects of social stressors such as low social cohesion on immunity (Muscatell, 2021; Slavich, 2020) and with data showing low perceived social support relating to poorer antibody responses to vaccination (Gallagher et al., 2008ab; Phillips et al., 2005). Moreover, in terms of biological pathways, some argue that disruption of social bonds during the pandemic is likely to lead to social instability and hormonal and immunological effects which will influence the body's ability to fight infections (Mattos dos Santos, 2020). With trust in one's neighbours declining during the pandemic (Borkowska & Laurence, 2021), it is hardly surprising that it was this item that was one of the strongest social cohesion predictors of both low antibody titre and non-neutralising antibody levels. In terms of biological pathways, dysregulation of Hypothalamus-Pituitary (HPA) and the Sympathetic-adrenal medullary (SAM) axes as well as the cytokine milieu are some of the identified mechanisms behind these associations (Burns and Gallagher, 2010). However, from an evolutionary perspective, some researchers argue that while cooperative contact with others has been fundamental for human survival, during a pathogenic threat, social trust lessens and to some extent constitutes a motivated pathway for pathogen avoidance due to less social contact (Aarøe et al., 2016). If this is the case, our findings represent a true paradox. On the one hand, lower level of neighbourhood trust may be protective against viral infection due to the behavioural avoidance; however, paired with beliefs of mistrust it may negatively affect the antibody response to vaccination.

The clinical implications of this work are also clear. As the pandemic continues and with the emergence of other strains of the virus these vaccines have become a crucial tool in the fight against the virus. However, we have shown that beyond well-established predictive factors such as age and existing health conditions, psychosocial characteristics do matter (Madison et al., 2021; Vedhara, 2020). Low social cohesion was a key factor for predicting poorer antibody response. It is worth noting that a recent systematic review has found that antibody response to a variety of vaccinations are reactive to psychosocial interventions (Vedhara et al., 2019). Thus, while the COVID-19 pandemic has tested the strength of social cohesion, its importance as a health protective and social intervention target is underscored by the United Nations commission a rapid review of social cohesion research to aid with the development of a roadmap for COVID-19 recovery (Jewett et al., 2021). For example, recent research framework has found that strategies geared toward putting the public first and improving transparency, such as development of protocols and procedures and consistency of accurate information, also helped to build credibility and trust (Wilson et al., 2017); a framework that has proposed for building public during COVID-19(Henderson et al., 2020). Thus, efforts to improve social cohesion therefore should become a political priority because they also support improved antibody response and contribute to the overall vaccination and pandemic effort.

The present study, while it has several strengths (e.g., large sample size, a population-based study, excluding those with prior infection, and accounting for health behaviours) it also has a number of limitations. First, we only examined the primary antibody response to the vaccine; thus, our findings can only generalize to that cohort and not those who have had a secondary response because of prior exposure or having a second vaccine shot. It is worth noting that psychosocial factors can influence both responses (Burns and Gallagher, 2010) and our study does have implications for single shot COVID-19 vaccines. Second, there was no information on the type of COVID-19 vaccine the participants had, nor how long since they had received it, both of which may influence antibody titres (Burns and Gallagher, 2010). Although the Pfizer vaccine was administered in the UK during that period, the Oxford/AstraZeneca vaccine was the main vaccine given at this time and while we refer to antibody production, psychosocial factors might also influence antibody maintenance/decay, as has been found previously (Gallagher et al., 2009b). Despite this, the threshold level of neutralizing antibodies used in this study were from several vaccine types and this level protected against symptomatic infection (Khoury et al., 2021); and given that the majority of the sample were of similar age, they are likely to have received the vaccine around the same time through the coordination of the vaccination programme in the UK. Future research could examine the influence of vaccine type and impact of psychosocial factors on secondary antibody response and/or antibody maintenance. Further, while we were interested in those given a single shot of the vaccine and excluded those who had the virus itself, it is plausible that some of our cohort were asymptomatic, in that case, this would suggest that a secondary response would be affected. Third, the small effect sizes for the Log_{10} antibody titre may be viewed as not clinically meaningful; however, it is worth nothing that the 38% risk of being in non-neutralizing group because of low social cohesion does have clinical implications. Fourth, our measures of social cohesion and loneliness were not validated psychometric scales so there may be measurement error with these constructs. Although our Cronbach alpha level was high for the social cohesion measure and single item measures are not uncommon in population based studies (Bowling, 2005). Similarly, we used income as a proxy for SES measures but studies looking at the effects of SES and health have found it is the strongest index for predicting health (Darin-Mattsson et al., 2017). Fifth, social cohesion has been found to be lower in BAME and lower SES groups (Borkowska & Laurence, 2021), and while these were not associated with antibody response, we checked if they were correlated with social cohesion; in this analysis no correlations were observed for ethnicity (p =.71) or income (p =.49). It is also worth acknowledging that this measure may not capture an individual's perception of their actual community, which could be different geographical community, i.e., gay or religious community. Similarly, while previous studies (Borkowska & Laurence, 2021) have found declines in cohesion during the pandemic, we cannot claim causality due to the cross-sectional nature of the study. Finally, while we controlled for age and health conditions, and accounted for other socio-demographics there are other important factors such as body mass index, sleep, depression, stress, and personality that may be influencing antibody response.

In summary, recent research has suggested that the antibody response to the COVID-19 vaccine could be influenced by psychosocial factors (Madison et al., 2021). The present study has confirmed this to be the case. In a population-based study from the UK, we found, for the first time, that people who reported lower social cohesion had poorer antibody response to a single shot of the vaccine and this was also associated with non-neutralizing antibody protections levels. In addition, the association between social cohesion and antibody response was mediated by feelings of loneliness such that those who reported lower social cohesion were also lonelier and this in turn was associated with a poorer antibody response. Our findings have clear clinical implications, as the COVID-19 crisis is still ongoing and vaccines are still being administered globally. We show that the efficacy of vaccine responsiveness is influenced by the recipient's psychosocial experiences; experiences that are amendable to intervention which may act as behavioral vaccine adjuvants.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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