Understanding Opposition to Human Gene Editing: A Role for Pathogen Disgust Sensitivity?

Abstract

Recent advances in gene editing technology promise much for medical advances and human well-being. However, in parallel domains there have been objections to such biotechnologies being used. Moreover, the psychological factors that govern the willingness to use gene editing technology have been underexplored to date. In this registered report, we sought to test whether pathogen disgust sensitivity is linked with opposition to gene editing. N=347 UK-based, adult participants were recruited to this study. Gene editing attitudes reflected two largely distinct latent factors concerning i) enhancing human traits, and ii) treating medical disorders. In contrast to prediction, pathogen disgust sensitivity was related to greater support for gene editing in both of these domains. This result suggests that gene editing, at least in the current study, is not viewed as pathogenic, or that the perceived benefits of gene editing outweigh any perceived pathogen risk.

Keywords: gene editing; pathogen disgust sensitivity; GM crops; cultured meat; vaccinations

Introduction

Genetic technology is advancing rapidly. For example, it is now possible to accurately and reliably edit DNA using techniques such as CRISPR-Cas9 (Oude Blenke et al., 2016). Such advances are likely to have substantial implications for human society. Some researchers have even suggested that in the near future we will be able to eradicate major disorders/diseases, such as Huntington's disease (Feng et al., 2018).

However, these technological advances can only be implemented if humans are willing to see them applied. And many promising advances – such as genetically-modified (GM) crops and nuclear energy – have not been as widely implemented as some would have hoped because of psychological (rather than technological) factors (Scott et al., 2016). In other words, psychology is often the bottleneck through which new technology is adopted or discarded. This observation powerfully highlights the need to better understand the psychological concerns toward emerging gene editing technology in order to predict how it will be received by the public and incorporated into society.

Perhaps unsurprisingly, surveys have shown that people differ quite notably in their perceptions and/or attitudes toward gene editing (Calnan et al., 2005; Hendriks et al., 2018; McCaughey et al., 2019; Xiang et al., 2015). For example, recent work found that 59% of respondents agreed with "*genetic editing of cells in children or adults to cure a life threatening disease*", with 31% responding with 'neutral' or 'don't know', and 10% reporting they disagreed with its use. The variability was more pronounced still on the issue of "*genetic editing of cells in embryos to alter any non-disease characteristic*": here 27% reported agreeing with its use, 30% reported being 'neutral' or 'don't know', and 43% reported they disagreed with its use(McCaughey et al., 2016).

Variability in response to gene editing issues aside, little research to date has sought to characterise the psychological factors that might account for these differences in opinion.

The current study sought to address this gap in the literature with a special focus on pathogen disgust sensitivity.

The case for pathogen disgust sensitivity

Why pathogen disgust sensitivity? The argument builds from the theory that disgust sensitivity stems from the adaptive need for humans (and many other species) to avoid contact with toxins and/or pathogens (Schaller & Park, 2011). Work in this vein has established that pathogen disgust sensitivity is both relatively automatic and inflexible – e.g. knowledge that a dog-poo shaped chocolate is harmless does not make the morsel readily edible (Rozin et al., 1986.). Moreover, there appears to a sensitivity bias such that a disgust response is commonly deployed even without direct exposure to a disease vector. For example, and of special relevance to the current study, disgust responses have been shown to emerge following exposure to entities that are seen as unnatural, such as cultured meat (Siegrist et al., 2018), genetically modified animals (Pivetti, 2007), or trypophobia inducing objects (Imaizumi et al., 2016), rather than exclusively pathogen threats. The rationale here is that pathogen disgust sensitivity favours false alarms as the implications of making a false positive are markedly less than the implications of a false negative with regard to maintaining bodily integrity.

Several recent studies have bolstered this perspective in closely related domains. For example, individuals who score higher on pathogen disgust sensitivity have been reported to show lower levels of support for GM foods (Clifford & Wendell, 2016; Scott et al., 2016). Another study observed that individuals who scored higher on the purity measure from the Moral Foundation Questionnaire (which contains a number of items assessing disgust-proneness) were less likely to show support for stem cell research (Koleva et al., 2012). And genetically modified crops are routinely referred to as “Frankenstein food”, illustrating that concerns over unnatural manipulation and mutation in this domain are omnipresent in the

public's mind (Tenbült et al., 2005). This observation also draws parallels with the usage of the term 'designer baby'- indicating something artificial and unnatural, which as suggested previously, has been shown to elicit disgust responses (Scott et al., 2016). In sum, then, there is good reason to hypothesise a link between higher levels of pathogen disgust sensitivity and opposition to the use of gene editing.

Additional psychological factors?

While there is a clear case for expecting pathogen disgust sensitivity to (at least partially) underpin attitudes toward gene editing, it is also clear that a variety of other variables likely play a role. These include resistance to change, on the grounds that gene editing represents a fundamental shift in how we practice medicine (among other things) and so is likely to be opposed by those who are sensitive to change; trait neuroticism, on the grounds that those who are more prone to negative affect may be especially likely to anticipate deleterious, unanticipated consequences of gene editing; risk taking, on the grounds that those who can tolerate and/or value risky environments/decisions will be more inclined to support gene editing despite the potential for it doing harm; and trust in scientists, on the grounds that gene editing at its core represents a scientific breakthrough and thus perceptions concerning the motives and trustworthiness of scientists will be a relevant factor in determining support/opposition to the technology.

Additionally, age, educational attainment, knowledge of gene editing, and sex have been shown to predict gene editing attitudes in previous studies (Calnan et al., 2005; Gaskell et al., 2017; McCaughey et al., 2019; Weisberg et al., 2017) and so warrant inclusion here both as predictors in their own right, as well as to rule out potential confounding of our hypothesised psychological links to gene editing attitudes (e.g. women are more disgust-sensitive (Tybur et al., 2011) and more likely to oppose gene editing (Weisberg et al., 2017)).

As well as being candidate predictors, a number of variables are plausible mediators of the putative link between pathogen disgust sensitivity and gene editing attitudes. In particular, higher levels of religiosity and political conservatism have been reported to be positively associated with pathogen disgust sensitivity (Inbar et al., 2009; Terrizzi et al., 2013) as well as opposition to gene editing(Critchley et al., 2019; Weisberg et al., 2017). We posit religiosity and political conservatism as mediators in line with work suggesting that ostensibly non-political individual differences constructs, such as pathogen disgust sensitivity, are commonly argued to be antecedent to politics/religion (Lewis, 2018; Roets & Van Hiel, 2011; Wink et al., 2007). In turn, one's political and religious views are commonly argued to give rise to specific policy positions (Jost et al., 2009).

The current study

With the above in mind, we sought to examine a number of hypotheses:

H1) Pathogen disgust sensitivity will be positively associated with opposition to gene editing.

H2) Pathogen disgust sensitivity will be positively associated with opposition to the use of broader biotechnology: i.e. vaccinations, GM foods, and cultured meat.

H3) Opposition to gene editing will be positively associated with political conservatism, religiosity, neuroticism, and resistance to change, as well as negatively associated with subjective knowledge of gene editing, objective knowledge of gene editing, risk taking, and trust in scientists.

H4) The positive association between pathogen disgust sensitivity and opposition to gene editing will be independent of age, sex, educational attainment, resistance to change, subjective knowledge of gene editing, objective knowledge of gene editing, risk taking, trust in scientists, and neuroticism.

H5) The association between pathogen disgust sensitivity and opposition to gene editing will be mediated by i) political conservatism and ii) religiosity.

H6) The positive association between pathogen disgust sensitivity and opposition to vaccinations, GM foods, and cultured meat will be independent of age, sex, educational attainment, resistance to change, subjective knowledge of gene editing, objective knowledge of gene editing, risk taking, trust in scientists, and neuroticism.

H7) The association between pathogen disgust sensitivity and opposition to vaccinations, GM foods, and cultured meat will be mediated by i) political conservatism, and ii) religiosity.

Methods

Participants

The study sample consisted of 347 participants (96 Male, 249 Female, 2 Other). Their mean age was 36.88 years (SD = 12.87). Participants were recruited from Prolific Academic, a web-based recruitment service where members of the public can complete surveys/experiments for payment. Prolific Academic provides high quality data on a far broader subset of the population that would be represented in an undergraduate or opportunity sample. Participants were recruited from residents of the United Kingdom and were a minimum of 18 years old.

Our sample size was guided by a set of power analyses (using G*Power3) considering the required N to detect a modest effect in our core tests; that is, the correlational and linear regression analyses (see Steps 2 and 3 below). The median effect size in the social/personality literature (Gignac & Szodorai, 2016), as well as typical effect sizes in recent work on pathogen disgust sensitivity and political conservatism (Tybur et al., 2015) is approximately r=.15. To achieve 80% power to detect i) an r of ≥.15, and ii) an

increase in R^2 of ≥.02 at alpha of .05 (two-tailed) indicated a need for N of 346 and 344, respectively. With this mind, we sought to collect at least 346 usable participant datasets (see exclusion criteria below).

Exclusion Criteria. Participants that failed to fully complete each section of the questionnaire, failed the attention check, or showed evidence of spurious responding (i.e. completing the survey in a time less than 2.5 standard deviations of the mean completion time), were excluded from the analyses. Recruitment was planned to stop once 346 participants had met these criteria[1].

Measures

Gene Editing Attitudes. Participants were provided with a brief introduction to gene editing technology (modified from recent related work in the field (Weisberg et al., 2017)): "Recently, scientists have figured out a way to edit genes. This technology means they might be able to correct disease-causing genes. It may also mean they are able to add genes that are protective against future health problems. It also means they may be able to improve genes to enhance normal traits".

Participants were then asked to indicate their view on 15 items (see the Appendix) concerning gene editing spanning treating mental and physical illness and enhancing mental and physical capabilities and lifespan in human adults and embryos, and in non-human animals. Example items included: "How likely would you be to support the use of gene editing in adults for the treatment of a mental disorder like depression or anxiety?"; "How likely would you be to support the use of gene editing in embryos for the following enhancements? [physical strength]". These items used a 4-point scale, with responses options being: 1 - 'Highly unlikely', 2 - 'Unlikely', 3 'Likely', 4 - 'Highly likely'. Scale

[1] We ended up collecting N=347 because we over-recruited in anticipation of those participants who would fail the exclusion criteria.

scores were constructed following the exploratory factor analyses, as detailed more fully below, with higher scores indicated greater opposition to gene editing.

Biotechnology Attitudes. A brief description of cultured meats, genetically modified (GM) crops (derived from Wilks & Phillips, 2017), and vaccinations was given and then participants were asked to report on whether they eat meat or are vegetarian/vegan, followed by 5 questions concerning the use of genetically modified crops, cultured meat, and vaccinations: "How willing would you be to eat cultured meat compared to soy substitutes?"; "How willing would you be to eat cultured meat compared to traditionally farmed meat?"; "How willing would you be to eat genetically modified crops compared to traditionally farmed crops?"; "How likely would you be to have a vaccination?"; "How likely would you be to have your child vaccinated?". These items used a 4-point scale, with responses options being: 1 - 'Highly unlikely', 2 - 'Unlikely', 3 'Likely', 4 - 'Highly likely'. The two cultured meat items and the two vaccination items were combined into mean scores. Responses were reverse-coded such that higher scores reflected higher levels of opposition to the respective biotechnology.

Three Domain Disgust Scale (Tybur et al., 2009). This 21-item measure assesses disgust sensitivity in three domains – pathogen disgust, sexual disgust, and moral disgust. For the purposes of the current study, only the pathogen disgust items were included. Responses to all items were given on a 7-point Likert scale, with responses ranging from 0 - 'Not at all disgusting' to 6 - 'extremely disgusting'. Scale scores were constructed as the sum of the item responses. Higher scores indicated higher levels of pathogen disgust sensitivity.

Disgust Scale- Revised: In order to control for the possibility of response sets that may occur by using pathogen disgust sensitivity alone (as the TDDS is scored in one direction), participants were also measured on core disgust, which is a sub-scale of the

broader Disgust Scale-Revised (Olatunji et al., 2007). Core disgust is a 12-item measure and was been selected due to its high correlation in previous work with the pathogen disgust sensitivity measure in the TDDS. Note, because of a coding error only the first six of the core disgust items were included in this survey (the six true-false items in the scale), alongside six items from the other two sub-scales (these items were not analysed here and so are not discussed further). Scale scores were constructed as the sum of the item responses. Reverse scoring was used so that higher scores indicated higher levels of core disgust sensitivity.

Neuroticism. Neuroticism was measured using the 12-item scale from the Big Five inventory-2 (BFI-2) (Soto & John, 2017). Responses to all items were given on a 7-point Likert scale, reverse-coding where necessary, with responses ranging from 1 - 'Strongly disagree' to 7 - 'Strongly agree'. Scale scores were constructed as the mean of the item responses. Higher scores indicated higher levels of neuroticism.

Risk taking. Risk taking was measured using the 6-item Recreational Risk Taking sub-scale from the Domain-Specific Risk-Taking (DOSPERT) scale (Blais & Weber, 2006). Responses to all items were given on a 7-point Likert scale, with responses ranging from 1 - 'Extremely unlikely to 7 - 'Extremely likely'. Scale scores were constructed as the mean of the item responses. Higher scores indicated higher levels of risk taking.

Political ideology. Political ideology was measured using the mean of two items – one each for social and economic political ideology: "On [economic/social] issues, where overall would you consider your views to be on the left-right spectrum?". Responses to both items were given on a 7-point Likert scale, with responses ranging from 1 - 'Very much on the left' to 7 - 'Very much on the right'. Higher scores indicated higher levels of political conservatism/right-leaning politics.

Religiosity. Religiosity was measured using the mean score of three items used in previous work (Lewis & Bates, 2013): "How religious are you?"; "How important is religion in your life?"; "How important is it for you – or would it be if you had children now – to send your children for religious or spiritual services or instruction?". Responses to all items were given on a 4-point scale, with responses ranging from 1 - 'Not at all' to 4 - 'Very'. Higher scores indicated higher levels of religiosity.

Trust in scientists. Trust in scientists was measured using the mean of four items, taken from the Trust in Science and Scientists scale (Nadelson et al., 2014): "I trust that the work of scientists make life better for people", "We should trust the work of scientists", "We cannot trust scientists to consider ideas that contradict their own", "Scientific theories are trustworthy". Responses to these items were given on a 7-point Likert scale, reverse-coding where necessary, with responses ranging from 1 - 'Strongly disagree' to 5 - 'Strongly agree'. Higher scores indicated higher levels of trust in scientists.

Genetics knowledge. Objective genetics knowledge was measured with 5 items taken from previous research (Fitzgerald-Butt et al., 2016). Example items included "A person with an altered (mutated) gene may be completely healthy"; "A person has thousands of genes" (see Appendix 1 for a full list). These items are responded to as either 'true' or 'false'. The percentage of correct answers was used for analysis. Higher scores indicated higher levels of genetics knowledge. Note, due to a coding error a measure of subjective knowledge of genetics was not included in the study survey and so analyses regarding this variable are not reported below.

Resistance to change (Oreg, 2003). Resistance to change was measured with the 17-item Resistance to Change scale. Example items include: "I generally consider changes to be a negative thing"; "Often, I feel a bit uncomfortable even about changes that may potentially improve my life". Responses to all items were given on a 7-point Likert scale,

with responses ranging from 1 - ‘Strongly disagree’ to 7 - ‘Strongly agree’. Scale scores were constructed as the mean of the item responses. Higher scores indicated higher levels of resistance to change.

Demographics. Participants were asked to indicate their religious affiliation, educational attainment, age, sex (Males = 1, Females = 2), and ethnicity.

Attention check. We included an item towards the end of the survey that stated: “Some participants don’t always read the instructions carefully. Just to check you are paying attention please select the ‘other’ option and type ‘hi there’”. Those who did not correctly complete this attention check were excluded from the analyses.

Analysis Plan

Our analysis plan was pre-registered and accepted by the editor prior to data collection. We detailed the following steps:

Step 1) We will first perform a parallel analysis on the gene editing items in order to establish their underlying factor structure. If a single factor is identified, we will use principal component analysis to determine how the items load on the first component. A mean score will be created from all items that load >.40. If two or more factors are identified, we will perform an exploratory factor analysis (principle axis factoring with Promax rotation) and create mean scores corresponding to each factor based on the items that load >.40 (and do not load >.40 on any other factor).

Step 2) We will next perform correlational analyses (using a Pearson product-moment correlation) to test for zero-order associations between pathogen disgust sensitivity, core disgust sensitivity, gene editing attitudes, objective and subjective level of knowledge, political ideology, neuroticism, resistance to change, religiosity, risk taking, trust in scientists, and the broader biotechnology attitudes, as specified in our hypotheses (H1, H2, H3).

Step 3) We will then perform a linear multiple regression analysis to test whether pathogen disgust sensitivity is an independent predictor of our gene-editing dependent variables when considering potential confounding variables (H4). To this end, we will enter age, sex, objective and subjective level of knowledge, educational attainment, resistance to change, risk taking, trust in scientists, neuroticism, and pathogen disgust sensitivity as predictors into the model in a single step.

Step 4) Should pathogen disgust sensitivity be an independent predictor of gene-editing attitudes in Step 3 we will examine whether this association is mediated (using a path modelling approach implemented in the R package 'lavaan' (Rosseel, 2012)) by political ideology and religiosity (H5).

Step 5) Step 3 & 4 will be repeated for each of the vaccination, GM foods and cultured meat dependent variables (H6 & H7).

Step 6) To examine if the pathogen disgust responses are susceptible to response sets, Steps 3 & 4 will then be repeated, using the core disgust sensitivity measure as a sensitivity check.

Results

Descriptive statistics for study variables are detailed in Table 1. Participants' level of genetics knowledge was high, with a median score of 5 out of 5 correct answers. They were not especially religious (M=1.45, SD= .73) and were slightly left-leaning in their political ideology (M= 3.36, SD= 1.35).

Table 1. Descriptive statistics of study variables.

Variable	Mean	SD	Median
GE-treatment	1.86	0.68	
GE-enhancement	2.85	0.72	
Religiosity	1.45	0.73	

Age	36.88	12.87	
Political ideology	3.36	1.35	
Resistance to change	4.15	0.81	
Risk taking	5.07	1.55	
Neuroticism	4.07	1.14	
Trust in scientists	5.22	0.99	
Vaccination opposition	1.36	0.62	
Cultured meat opposition	2.83	0.89	
GM crops opposition	2.69	0.89	
Pathogen disgust sensitivity	4.73	1.00	
Core disgust sensitivity	1.66	0.24	
Genetic knowledge			5 (100%)
Ethnicity			White British
Religious affiliation			Agnostic
Educational attainment			Undergraduate degree

Parallel and exploratory factor analyses

A parallel analysis indicated that the 15 gene editing items were best characterised by two underlying latent factors. As such we then submitted these items to an exploratory factor analysis (promax rotation) specifying the retention of two factors. Factor loadings from this analysis are detailed in Table 1. Factor 1 was labelled 'enhancement' due to the consistent loading on items concerning the use of gene editing to enhance human performance/ability. Factor 2 was labelled 'treatment' due to the consistent loading on items concerning the use of gene editing to treat human disease.

To operationalize these factors for further analyses we created scales from the mean score of the 5 treatment items and the 8 enhancement items, respectively. We refer to these scales herein as GE-treatment and GE-enhancement, with higher scores on these measures corresponding to higher levels of opposition to gene editing in these domains. Cronbach's alpha for the GE-enhancement and GE-treatment scales were excellent: α=.92 and α=.84, respectively. Participants were favourable towards gene editing for treatment (M=1.86,

SD=0.68) but not enhancement (M=2.85, SD=0.72). GE-treatment and GE-enhancement showed a significant positive correlation (r=.50. p<.001).

Hypothesis 1 – Pathogen disgust sensitivity will be positively associated with opposition to gene editing.

Contrary to prediction, pathogen disgust sensitivity showed a significant *negative* correlation with both opposition to GE-treatment (r=-.20, p<.001) and opposition to GE-enhancement (r=-.18, p<.001).

Hypothesis 2 – Pathogen disgust sensitivity will be positively associated with opposition to the use of broader biotechnology.

In line with prediction, we saw a significant positive relationship between pathogen disgust sensitivity and opposition to cultured meat (r=.12, p=.032) and GM crops (r=.15, p=.006), although no statistically significant association was seen between pathogen disgust sensitivity and opposition to vaccinations.

Table 2. Factor loading results for the gene editing items.

Item	**Factor 1**	**Factor 2**
Strength enhancement – adults	.81	
Cognitive enhancement – adults	.80	
Lifespan enhancement – adults	.56	
Attractiveness enhancement – adults	.89	
Strength enhancement – embryos	.92	
Cognitive enhancement – embryos	.86	
Lifespan enhancement – embryos	.60	
Attractiveness enhancement – embryos	.96	
Treatment of mental disorders – adults		.73
Treatment of physical disorders – adults		.96
Treatment of mental disorders – embryos		.73
Treatment of physical disorders – embryos		.95
Increasing diseases resistance – animals		.69
Increasing food production - animals		

Population control - animals	

Note. Factor loadings <.40 have been suppressed.

Hypothesis 3 – Opposition to gene editing will be positively associated with political conservatism, religiosity, neuroticism, and resistance to change, as well as negatively associated with subjective knowledge of gene editing, objective knowledge of gene editing, risk taking, and trust in scientists.

Opposition to GE-treatment, in line with predictions, was positively associated with religiosity (r=.14, p=.008) and negatively associated with trust in scientists (r=-.29, p<.001). There was also a positive association with educational attainment (r=.17, p=.002), opposition to cultured meat (r=.27, p<.001), and opposition to GM crops (r=.14, p=.035), which we did not predict a priori. In contrast to predictions, we did not observe a statistically significant association between opposition to GE-treatment and the following variables: political conservatism, neuroticism, resistance to change, objective knowledge of gene editing, and risk taking.

Opposition to GE-enhancement, against prediction, did not show a statistically significant association with any of the following variables: political conservatism, religiosity, neuroticism, resistance to change, objective knowledge of gene editing, risk taking, and trust in scientists. There were, however, positive associations observed with age (r=.11, p=.047), educational attainment (r=.17, p=.002), sex (r=.13, p<.001), and opposition to cultured meat (r=.19, p<.001), which we did not predict a priori.

Hypothesis 4 – The positive association between pathogen disgust sensitivity and opposition to gene editing will be independent of age, sex, educational attainment, resistance to change,

subjective knowledge of gene editing, objective knowledge of gene editing, risk taking, trust in scientists, and neuroticism.

Although the initial correlational findings went in the opposite direction to prediction, due to the significant observed associations we next sought to establish if pathogen disgust sensitivity continued to predict support for GE-enhancement and GE-treatment when a range of plausible confounders were modelled. To this end we used linear multiple regression and included either GE-enhancement or GE-treatment as our dependent variable, and pathogen disgust sensitivity, age, sex, educational attainment, resistance to change, genetics knowledge, risk taking, trust in scientists, and neuroticism as our independent variables.

GE-enhancement model: Age, sex, educational attainment, and pathogen disgust sensitivity were each independent, significant predictors of opposition to GE-enhancement. The adjusted R^2 of the model for enhancement was 0.10. Those who were older (β=.16, p=.006), more educated (β=.18, p<.001), female (β=.16, p=.003), and less sensitive to pathogen disgust (β=-.17, p=.002) were more likely to oppose gene editing for enhancement. See full model results in Table 4.

Table 3. Inter-correlations for study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.Age																
2. Sex	-.04															
3. Educational attainment	-.09	-.02														
4. Resistance to change	**-.11**	-.04	-.07													
5. Risk aversion	**.26**	**.13**	-.07	**.23**												
6. Political ideology	**.18**	-.03	**-.23**	.00	.04											
7. Neuroticism	**-.23**	**.13**	-.09	**.39**	.06	**-.12**										
8. Religiosity	-.02	.01	**.12**	.04	-.04	**.12**	-.09									
9.Trust in scientists	**-.16**	-.07	.10	.00	-.01	**-.13**	-.04	**-.21**								
10. Genetic knowledge	-.07	.02	.04	-.04	.02	-.02	.01	-.06	.02							
11.Vaccination opposition	.07	-.02	**-.26**	-.07	.05	.09	.00	.08	**-.31**	**-.15**						
12. Cultured meat opposition	.10	**.22**	.02	**.11**	**.14**	.05	.10	**.11**	**-.25**	-.03	**.18**					
13. GM crop opposition	.05	.10	-.07	.04	.06	.09	.04	.09	**-.30**	-.07	**.21**	**.58**				
14. Opposition to GE-treatment	.04	.02	**.17**	.08	-.03	-.07	.05	**.14**	**-.29**	.00	.08	**.27**	**.14**			
15. Opposition to GE-enhancement	**.11**	**.13**	**.17**	.01	-.04	-.05	.08	.05	-.09	.06	-.10	**.19**	.06	**.50**		
16. Core disgust sensitivity	.08	**.19**	**-.13**	**.15**	**.28**	**.15**	**.12**	.05	.04	-.09	.10	**.23**	**.15**	**-.11**	-.10	
17. Pathogen disgust sensitivity	-.03	.09	**-.12**	**.17**	**.23**	.09	.09	.04	.08	-.07	.05	**.12**	**.15**	**-.20**	**-.18**	**.47**

Note. Bold indicates p<.05; 1=Male, 2=Female.

Table 4. Regression model results with opposition to GE-enhancement and GE-treatment as dependent variable.

	GE-enhancement		**GE-treatment**	
Variable	β	p	β	p
Age	**.16**	.006	.02	.774
Sex	**.16**	.003	.03	.520
Knowledge	.06	.271	-.00	.937
Educational attainment	**.18**	<.001	**.19**	<.001
Resistance to change	.05	.368	**.13**	.027
Risk taking	-.06	.265	-.01	.826
Trust in science	-.06	.267	**-.29**	<.001
Neuroticism	.11	.069	.02	.689
Pathogen disgust sensitivity	**-.17**	.002	**-.18**	.001
F	**5.166** (p<.001)		**7.518** (p<.001)	
R^2/Adjusted R^2	0.12/0.10		0.17/0.15	

Note. Bold indicates p<.05; 1=Male, 2=Female.

GE-treatment model: Educational attainment, resistance to change, trust in science, and pathogen disgust sensitivity were independent, significant predictors of GE-treatment. The adjusted R^2 of the model for enhancement was 0.15. Those who were more resistant to change (β=.13, p=.027), more educated (β=.19, p<.001), less trusting in science (β=-.29, p <.001), and lower in pathogen disgust sensitivity (β=-.18, p=.001) were more likely to oppose gene editing for treatment. See full model results in Table 4.

Hypothesis 5 – The association between pathogen disgust sensitivity and opposition to gene editing will be mediated by i) political conservatism and ii) religiosity.

Although the predicted association between gene editing opposition and pathogen disgust sensitivity was significantly positive (for both GE-treatment and GE-enhancement) rather than negative, we still examined whether these associations

were mediated by political ideology or religiosity. To this end we fitted two models: with political ideology and religiosity mediating the path from pathogen disgust sensitivity to either GE-treatment or GE-enhancement.

In the models with pathogen disgust sensitivity, the direct effect in all models was significant (all β>-.18, all p<.0), but there was no evidence for mediation in any of the models (all indirect pathways were p>.104, apart from religiosity predicting opposition to GE-treatment model, (β = .16, p= .010)).

Hypothesis 6 – The positive association between pathogen disgust sensitivity and opposition to vaccinations, GM foods, and cultured meat will be independent of age, sex, educational attainment, resistance to change, subjective knowledge of gene editing, objective knowledge of gene editing, risk taking, trust in scientists, and neuroticism.

We next sought to establish if pathogen disgust sensitivity continued to predict opposition to GM crops and cultured meats when a range of plausible confounders were modelled. To this end we used linear multiple regression and included either GM crops or cultured meat as our dependent variable, and pathogen disgust sensitivity, age, sex, educational attainment, resistance to change, genetics knowledge, risk taking, trust in scientists, and neuroticism as our independent variables.

GM crops model: Trust in science and pathogen disgust sensitivity were independent, significant predictors of GM crops. The adjusted R^2 of the model was 0.10. Those who were less trusting in science (β=-.30, p <.001) and higher in pathogen disgust sensitivity (β=.16, p=.003) were more likely to oppose GM crops. See full model results in Table 5.

Cultured meat model: Sex and trust in science were independent, significant predictors of cultured meat. The adjusted R^2 of the model was 0.13. Those who were female (β=.19, p<.001) and less trusting in science (β=-.24, p <.001) were more likely to oppose cultured meat. Pathogen disgust sensitivity showed a non-significant positive association (β=.10, p=.072). See full model results in Table 5.

Although we did not observe zero order correlations between pathogen disgust sensitivity and opposition to vaccinations, we carried out the regression analyses in line with our pre-registration, details of which may be found in the supplementary materials. In short, we did not find an association between pathogen disgust sensitivity and vaccination opposition in this analysis.

Table 5. Regression model results with opposition to GM crops and cultured meat as dependent variables

	GM crops		**Cultured meat**	
Variable	β	p	β	p
Age	.01	.833	.08	.167
Sex	.06	.272	**.19**	<.001
Knowledge	-.06	.269	-.02	.675
Education	-.01	.804	.08	.108
Resistance to change	.01	.878	.09	.125
Risk taking	-.00	.937	.05	.335
Trust in science	**-.30**	<.001	**-.24**	<.001
Neuroticism	.00	.937	.04	.490
Pathogen disgust sensitivity	**.16**	.003	.10	.072
F	**5.35** (p<.001)		**6.43** (p<.001)	
R^2/Adjusted R^2	0.13/0.10		0.15/0.13	

Note. Bold indicates p<.05; 1=Male, 2=Female.

Hypothesis 7 – The association between pathogen disgust sensitivity and opposition to vaccinations, GM crops, and cultured meats will be mediated by i) political conservatism and ii) religiosity.

To test this hypothesis we fitted a model with pathogen disgust as a predictor of GM crop opposition, mediated by religiosity political ideology. While the direct path was significant (β=.14, p = .017), there was no evidence of mediation (indirect pathways were p>.054).

Although there was no significant independent effect of pathogen disgust sensitivity on either opposition to vaccinations or cultured meat after regression analyses, in line with our pre-registration we carried out mediation analysis. These results are reported in the supplementary materials. In short, these tests found no evidence for mediation in any of the models.

Sensitivity Checks

In a series of sensitivity checks (as noted in our pre-registered analysis plan) we next examined whether our results were robust to replacing pathogen disgust sensitivity for a closely related measure: core disgust sensitivity. In aggregate these results were well-aligned with those reported above for pathogen disgust sensitivity.

As with pathogen disgust sensitivity, opposition to GE-treatment showed a significant negative correlation with core disgust sensitivity (r=-.11, p=.039). Opposition to GE-enhancement did not show a significant correlation with core disgust sensitivity, although the association was in the same direction as seen for pathogen disgust sensitivity (r=-.10, p=.062).

When controlling for the potential confounders noted above we saw a reversal of this pattern: GE-treatment was no longer significant (β=-.10, p=.072), whereas GE-enhancement was significant (β=-.12, p=.039) (see Table 6). Of note, the point

estimates were virtually unchanged across the two analyses and so interpretations regarding nominal significance (or lack thereof) should be made with caution. And as with pathogen disgust sensitivity, we observed no evidence for mediation by political ideology or religiosity (all indirect pathways were $p>.391$).

We saw a significant positive relationship between core disgust sensitivity and opposition to cultured meat ($r=.23$, $p<.001$) and GM crops ($r=.15$, $p=.010$) (although no statistically significant association was seen with opposition to vaccinations). These significant associations were robust to the inclusion of the potential confounders noted above (see Table 7). However, and as with pathogen disgust sensitivity, we observed no statistically significant evidence for mediation by political ideology or religiosity (all indirect pathways were $p>.268$).

Table 6. Regression model results with opposition to GE-enhancement and GE-treatment as dependent variables (and including core disgust sensitivity as an independent variable).

	GE-enhancement		**GE-treatment**	
Variable	β	p	β	p
Age	**.17**	.002	.03	.543
Sex	**.16**	.003	.04	.500
Knowledge	.06	.267	-.00	.992
Education	**.19**	<.001	**.20**	<.001
Resistance to change	.04	.454	**.12**	.045
Risk taking	-.08	.193	-.03	.600
Trust in science	-.06	.222	**-.30**	<.001
Neuroticism	.11	.058	.03	.634
Core disgust sensitivity	**-.12**	.039	-.10	.072
F	**4.46** (p<.001)		**6.40** (p<.001)	
R^2/Adjusted R^2	0.11/0.08		0.15/0.12	

Note. Bold indicates p<.05; 1=Male, 2=Female.

Table 7. Regression model results with opposition to GM crops and cultured meat as dependent variables (and including core disgust sensitivity as an independent variable).

	GM crops		**Cultured meat**	
Variable	β	p	β	p
Age	-.01	.906	.06	.261
Sex	.05	.384	**.17**	.001
Knowledge	-.05	.290	-.01	.837
Education	-.02	.767	.09	.749
Resistance to change	.01	.806	.08	.140
Risk taking	-.01	.898	.03	.556
Trust in science	**-.30**	<.001	**-.25**	<.001
Neuroticism	.00	.952	.03	.624
Core disgust sensitivity	**.14**	.009	**.19**	<.001
F	**5.08** (p<.001)		**7.64** (p<.001)	
R^2/Adjusted R^2	0.12/0.10		0.17/0.15	

Note. Bold indicates p<.05; 1=Male, 2=Female.

Discussion

The central goal of this study was to examine whether pathogen disgust sensitivity predicted opposition to gene editing. In contrast to this prediction, pathogen disgust sensitivity was *negatively* correlated with two observed aspects of opposition to gene editing: enhancement and treatment (these aspects are discussed in more detail below). In other words, individuals who self-rated as being higher on pathogen disgust sensitivity were *more* likely to support gene editing for enhancing human traits and for treating disease.

These associations were relatively modest in magnitude; however, they remained statistically significant when controlling for a selection of plausible confounding variables, including age, sex, risk taking, resistance to change, trust in science, educational attainment, genetics knowledge, and neuroticism. Of further note, and contrary to prediction, the relationships between pathogen disgust sensitivity and gene editing attitudes were not mediated by either political ideology or religiosity. In fact, and perhaps surprisingly, gene editing attitudes were unrelated to political ideology.

Pathogen disgust sensitivity was positively correlated with opposition to GM crops and cultured meat, although no statistically significant association was observed with opposition to vaccinations. Similarly, we did not observe a significant link between gene editing attitudes and opposition to vaccinations. However, we did observe a significant positive relationship between opposition to gene editing and opposition to cultured meat and GM crops. These findings partially replicate recent work reporting positive associations between disgust sensitivity and biotechnology

attitudes (Sanyal et al., 2019; Scott et al., 2016; Siegrist et al., 2018) . Of note, then, pathogen disgust appears to play a different role depending on the technology: relating to support for gene editing, but to opposition in the case of other biotechnology issues.

Given that our central prediction – that pathogen disgust sensitivity would be related to opposition to gene editing, what might account for the opposite finding? One possibility is that our participants did not view gene editing as an invasive, pathogenic procedure; but rather a relatively benign technique that simply treats or enhances human disease or 'weaknesses' with no danger to the individual. As such, it's conceivable that pathogen disgust sensitivity in turn predicted support for gene editing treatment and enhancement in order to treat illness and 'imperfection'. Indeed, recent work has noted that disgust sensitivity predicts health purity-related behaviours, such as a preference for organic food over GM foods, and support for regulation of smoking and illegal drugs (Clifford & Wendell, 2016), as well as disliking the overweight (Lieberman et al., 2012), and an increased likelihood of being anorexic (Aharoni & Hertz, 2012). This suggestion could be tested in future research by examining the effect of message framing in relation to gene editing. For example, the negative relationship observed here may be attenuated, or even reversed, if risks such as off-target genetic mutations following gene editing treatments are explicitly highlighted.

As noted above, attitudes toward gene editing reflected two broadly distinct – albeit moderately correlated – latent factors concerning treatment and enhancement. This finding had been hinted at in recent work (Gaskell et al., 2017; Robillard et al., 2014; Xiang et al., 2015); but prior to the current study had not been formally

established. As such, these results indicate that future research into gene editing attitudes should consider using distinct scales with regard to these issues, as well as seeking to further understand and establish the latent architecture of attitudes in this domain. For example, it is yet to be established if the factor structure observed here generalises across cultures/countries. In addition, these results indicate that adult, embryo, and animal gene editing attitudes are largely fungible concepts (at least within the categories of treatment and enhancement); although further work is recommended to more definitively confirm this suggestion.

Some weaknesses of the current study are noteworthy. Firstly, the sample consisted solely of adult participants from the United Kingdom. However, attitudes toward gene editing may differ by country, as is the case for GM crops (Brosig & Bavorova, 2019), thus limiting the generalisability of our findings. A similar concern is reflected in the observation that our sample was very knowledgeable about genetics (scoring a median five out of five on our knowledge measure) and so our findings may not generalise to less well-educated/knowledgeable populations who may hold different opinions about genetics/gene editing. Secondly, we used a cross-sectional study design, which limits our ability to infer causation. In order to build on the current findings future work might wish to use an experimental design: for example, inducing participant disgust in the laboratory and assessing if this in turn increases willingness to use gene editing technology.

In summary, the current study highlighted two key findings. Pathogen disgust sensitivity predicts attitudes towards gene editing (albeit in the opposite manner to that predicted): those who are more sensitive to pathogen disgust are more likely to support gene editing both for treating disease and for enhancing human traits.

Moreover, these associations were independent of a range of potential confounding variables, including age, sex, risk taking, resistance to change, trust in science, education, genetic knowledge and neuroticism. Secondly, individual differences in gene editing attitudes are underpinned by two related, but largely distinct, latent factors reflecting sentiment regarding gene editing being used for enhancement and for treatment. These findings provide a platform for future research into the psychometric structure and antecedents of gene editing attitudes and suggest that experimental methods (e.g. message framing, disgust induction) and cross-cultural work, among other approaches, are now required to make further headway on this important basic and applied science issue.

Appendix 1

A complete list of the gene editing items used in the study:

Adults:
1) How likely would you be to support the use of gene editing in adults to increase a person's resistance to a mental disorder such as depression or anxiety?
2) How likely would you be to support the use of gene editing in adults to increase a person's resistance to a physical disorder such as heart disease or cancer?
3-6) How likely would you be to support the use of gene editing in adults for the following enhancements?

- Physical strength
- Cognitive ability/Intelligence
- Lifespan
- Attractiveness/looks

Embryos:
7) How likely would you be to support the use of gene editing in an embryo to increase resistance to a mental disorder like depression or anxiety?
8) How likely would you be to support the use of gene editing in an embryo to increase resistance to a physical disorder like heart disease or cancer?
9-12) How likely would you be to support the use of gene editing in embryos for the following enhancements?

- Physical strength
- Cognitive ability/Intelligence
- Lifespan
- Attractiveness/looks

Animals:
13) How likely would you be to support the use of gene editing in animals to increase their resistance to disease?
14) How likely would you be to support the use of gene editing in animals to increase food production?
15) How likely would you be to support the use of gene editing in animals to control their population?

Genetics objective knowledge items:

1) A person with an altered (mutated) gene may be completely healthy. (True)
2) Altered (mutated) genes can cause disease. (True)
3) A gene is a piece of DNA. (True)
4) The child of a person with an inherited disease will always have the same disease. (False)
5) A person has thousands of genes. (True)

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