



# **An Examination of Attitudes Towards Biotechnology**

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**Submitted in partial fulfilment of the requirements for the degree of Doctor of  
Philosophy in the Department of Psychology**

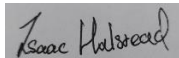
**Royal Holloway, University of London**

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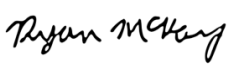
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Within this partly co-authored work, I declare that the following contributions are entirely my own work.

### **Chapter 1: Introduction**

This is entirely my own work.

### **Chapter 2: Methodology**

This is entirely my own work.

### **Chapter 3: Understanding Opposition to Human Gene Editing: A Role for Pathogen Disgust Sensitivity?**

I designed the study, wrote the preregistration, collected the data, analysed the data, and drafted the full manuscript with the support of my supervisor at the time.

### **Chapter 4: Opposition to Novel Biotechnologies: Testing An Omission Bias Account**

I designed the study, wrote the preregistration, collected the data, analysed the data, and drafted the full manuscript with the support of my supervisor and collaborator.

### **Chapter 5: The Role of Social Dominance Orientation in Attitudes Towards Animal Centred Gene Editing**

I found the dataset, analysed the data, and drafted the full manuscript with the support of my supervisor.

### **Chapter 6: Heterogeneous Attitudinal Profiles Towards Gene Editing: Evidence From Latent Class Analysis**

I found the dataset, analysed the data, and drafted the full manuscript with the support of my supervisor and collaborator.

### **Chapter 7: COVID-19 and seasonal flu vaccination hesitancy: Links to personality and general intelligence in a large, UK cohort**

I found the dataset, analysed the data, and drafted the full manuscript with the support of my supervisor and collaborator.

### **Chapter 8: Discussion**

This is entirely my own work.

*For Toby*

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I would not be in the position I am today without the support and guidance of Ryan and Gary. They have made me a better scientist and challenged me to improve with every manuscript. I hope that I can continue to apply their lessons and ways of thinking in the years to come. You are the scientists I aspire to be.

Thanks must also go to my loved ones. Most of you do not know what I do, but are pleased and proud that I am doing it, and for that I am grateful. Your cheerleading, your checking in, and your understanding when I am quiet mean the world to me.

What small amount of thanks remaining should go to that scared, depressed teenager with a U in his psychology AS level. He could not have begun to imagine where he would be 14 years later, but he persisted until he could. You can rest now.

## Abstract

Biotechnology has the potential to greatly improve the quality of life for many. However, there are sizeable proportions of the population that oppose its use. If the public are to benefit from the quality-of-life improvements biotechnology provides, we must understand this opposition. The research regarding attitudes towards biotechnology has often investigated demographic predictors of broad attitude trends, with only tentative steps to examine psychological constructs. This thesis takes advantage of this gap in the literature to investigate the role of psychological predictors in biotechnology attitudes, with a special focus on the previously neglected area of gene editing.

In Chapter 3, I examined the role of several psychological constructs in attitudes towards a broad range of biotechnologies, but with a focus on gene editing. I found that pathogen disgust sensitivity robustly predicted greater *support* for gene editing but corresponded with greater *opposition* to other biotechnology applications.

In Chapter 4, I expanded previous research into the role of omission bias in vaccines to two novel areas: gene editing and nanotechnology decision making. I found tentative evidence for the role of this construct in decision making across all three biotechnologies. I also discuss how different paradigms lead to different conclusions about the existence of omission bias.

In Chapter 5, I explored the role of socio-political and worldview variables in attitudes towards animal centred gene editing. I found evidence of Social Dominance Orientation (SDO), Chemical Avoidance and Environmental Concern scores predicting attitudes towards the use of gene editing to control pest populations.

In Chapter 6, I investigated gene editing attitudes in a deeper and more nuanced way by utilising a Latent Class Analysis (LCA) approach. This method provided novel insights into the way gene editing attitudes cohere within an individual and found evidence for 10

heterogeneous classes of gene editing attitudes and the demographic predictors that play a role in membership of these classes.

In Chapter 7, I turned my attention to the COVID-19 pandemic and sought to understand the public's attitudes towards this biotechnological challenge. This was done by examining attitudes towards COVID-19 vaccination. I found evidence for the role of Big 5 personality traits and general intelligence as independent predictors of COVID-19 vaccination hesitancy.

In sum, this thesis expands the existing biotechnology attitudes research, while providing novel insights into previously unexplored psychological constructs and under-researched biotechnology applications. These findings build upon the limited previous literature, but also provide a range of new avenues upon which future biotechnology attitude research may be developed.

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# Chapter 1: Introduction

## 1.1 What are Biotechnologies?

The term biotechnology can refer to a wide variety of different technologies. As this thesis refers to these technologies often, it is important to provide an explanation for the main technologies that I investigated in this thesis.

### *Gene editing*

Gene editing in the context of this thesis refers to the use of the technology CRISPR-Cas9. This latest iteration of gene editing technology has brought renewed interest in the area – due to its superior precision and cost effectiveness compared to previous gene editing tools (Fernández et al., 2017; Mohamed Saleem, 2014). The process of gene editing consists of using a set of ‘shears’ (the Cas9 protein) that are guided to a selected genetic sequence (using a guide RNA), which then creates a break in the strand of DNA. This can render genes inactive (silenced) or provide a gap in which new genetic sequences can be introduced. The most promising applications of this technology are for illnesses that are the result of a single gene, such as Huntington’s disease (Vachey & Déglon, 2018) or Cystic fibrosis (Maule et al., 2020).

The ability to treat genetic diseases has clear implications for improving an individual’s quality of life, but it could also prevent future generations from inheriting the disease, depending on the nature of the gene edit. Gene editing can be used to edit the somatic cells of an individual, leading to modifications that do not persist in their offspring (Committee on Human Gene Editing: Scientific et al., 2017). However, it can also be used to edit the germline of an individual, which leads the edit to be retained in future generations (Schleiden et al., 2020). Gene editing may also be used in the future to enhance health related traits, such as disease resistance (Tebas et al., 2014). The possibility of enhancement has also been raised for non-health related traits, such as increasing intelligence (Cwik, 2019).

### ***Nanotechnology***

Nanotechnology is concerned with the manipulation of matter smaller than 100 nanometres in size (McNeil, 2005). In the context of this thesis, I am primarily concerned with the medical applications of nanotechnology. Nanoparticles have the potential to introduce medicines into the body, and to precisely deliver cancer treatments to the affected area (Misra et al., 2010). Nanoparticles could also be introduced into the bloodstream to help treat internal bleeding or increase cell repair (Perán et al., 2013). As with the case of gene editing, nanotechnology may also be used to enhance – such as being able to use nanoscale machines to improve cognitive function (Berger et al., 2011).

### ***Vaccines***

Vaccination involves a substance being introduced into the body to stimulate the production of antibodies to increase immunity (Clem, 2011). The type of vaccine can vary significantly, for example, they can involve the use of an attenuated (weakened) form of the target disease (such as the MMR vaccine) (Belshe et al., 2007), which creates an immune response that protects against future cases of the disease. Another kind of vaccine are RNA vaccines that target cells and stimulate the production of antibodies (such as the Pfizer and Moderna COVID-19 vaccines) (A. B. Vogel et al., 2018).

### ***Cultured meat***

Cultured meat refers to the cultivation of animal cells to produce edible meat (Stephens et al., 2019). The process of creating cultured meat involves taking muscle cells from a live animal, which are suspended in a growth medium that allows them to replicate. Cultured meat allows the traditional agricultural methods of meat production to be circumvented. While this technology is promising as a cruelty free and environmentally friendly alternative to conventional meat products, it is currently very costly and time consuming to produce (Stephens et al., 2018).

### ***GM foods***

Genetically modified foods refer to foods that have been genetically modified by introducing genetic sequences from other species. This differs from gene editing, which is concerned with editing pre-existing genetic sequences. Genetic modification can be used in both plants and animals and can be used to introduce genes from species that are similar or dissimilar from the target species (Shew et al., 2018). For example, Golden rice is a genetically modified crop which has high levels of beta-carotene, which is used to produce vitamin A (Kettenburg et al., 2018). This was produced by introducing genes from Daffodils and a strain of soil bacterium, which increases the production of beta-carotene in Golden rice (Kettenburg et al., 2018).

### **1.2 The Growing Importance of Biotechnology**

As these technologies advance in their cost effectiveness and precision, it is becoming increasingly likely that advanced technologies such as gene editing, or medicine aided by nanotechnology, will be accessible to the general population. With this possibility, it is important to understand what factors influence an individual's attitudes towards these diverse biotechnology applications, to avoid a psychological bottleneck wherein their use is held back by an aversion to the technology rather than the technological limitations. This could lead to people being denied access to technologies that may dramatically improve their quality of life.

An example of this bottleneck is in the discourse surrounding vaccinations, where a previously widely accepted biotechnology has declined in usage due to psychological factors rather than practical limitations. In the wake of negative news coverage and the controversy created by Andrew Wakefield, who suggested that the measles, mumps, and rubella vaccination can cause autism, vaccination uptake declined (Calvert et al., 2013; Godlee et al., 2011; Leask et al., 2010). Despite the subsequent revelation that Wakefield fabricated his data, the impact

on trust between parents and physicians is still being felt (Allan & Harden, 2014; Leask et al., 2010). This increase in opposition towards vaccination has led to an increase in the spread of preventable diseases (Hussain et al., 2018). This has become such a significant issue, the World Health Organisation lists vaccine hesitancy as a threat to global health (The World Health Organization, 2019b).

Gene editing may soon be subject to a similar public reaction, due to a recent controversy within the field. He Jiankui is a Chinese researcher that gene edited a set of twins – initially with the intention to increase their resistance to HIV (Le Page, 2018). However, this was done without sufficient ethical or technical oversight. He Jiankui and his team also failed in their attempt to increase HIV resistance – the twins were only partially edited, with some of their genes not showing the desired edit (known as mosaicism). Their gene selection was also flawed, as there is evidence that the CCR5 gene that they edited is associated with vulnerability to a flu that is common in their region of China (Falcon et al., 2015). Furthermore, the CCR5 gene has been found to be associated with cognitive ability (Zhou et al., 2016), and by silencing it they may have inadvertently enhanced the twins – which raises further ethical issues regarding the acceptability of genetic enhancement. While the full backlash of this controversy remains to be seen, it risks creating a narrative of ‘rogue scientists’ that do not consider the ethical implications of their practices (X. Zhang et al., 2021) – which may harm the adoption of gene editing technology by the general population. This case powerfully highlights the need to understand emerging biotechnology attitudes and what psychological factors underlie them.

### **1.3 Current Perceptions of Biotechnology Applications**

In the following section, I will summarise the current attitudes and appraisals towards the biotechnologies encompassed by this thesis: gene editing, nanotechnology, vaccines, cultured meat, and GM foods. I have given more focus to gene editing literature, as it represents



a more significant part of my project. Attitudes toward gene editing also represents a more novel area, due to the lack of literature in comparison to vaccination or genetic modification attitude research.

### *Gene editing attitudes*

Firstly, there appear to be generally favourable attitudes towards gene editing for the treatment of disease. McCaughey et al. (2016) examined the responses of 12,000 participants drawn predominantly from Europe, North America, China, Japan, Egypt, South Africa, and Australia. They found that 60% of participants supported gene editing for health purposes (e.g. the treatment of disease). Similarly, in a Dutch sample (N=1013), participants generally favoured the use of gene editing, with 66% of participants supporting its use for health purposes (Hendriks et al., 2018). However, there have been exceptions to these favourable attitudes. Xiang et al. (2015) examined a sample (N= 579) of medical students and postgraduates in China. They found 39% supported the use of gene editing in the treatment of disease.

While there is an overall positive sentiment towards the use of gene editing, it is often framed in terms of use in adults for the treatment of disease. Gene editing can also be used prenatally - research conducted by Gaskell et al. (2017) on a sample (N= 11,716) from 10 European countries and the USA found gene editing opposition increased when using questions that concerned prenatal gene edits. Similarly, Hendriks et al. (2018) found that when embryos were the target of gene editing to treat neuromuscular disease, support dropped from 85.2% for use in adults to 65.9% for use in embryos.

In contrast to this, other research has found a less pronounced difference in public attitudes for gene editing babies compared to adults. Work by Uchiyama et al. (2018) (N= 11,925) found that applications concerning gene editing in babies were only slightly less supported (52.6%) compared to applications that made no mention of them (53.7%). Furthermore, McCaughey et al. (2016) found the difference between attitudes towards prenatal

and postnatal editing was minimal, with 63% of participants approving of gene editing to treat prenatally, compared to 59% approval in the case of editing children and adults. Whether this is a reflection of genuine attitudes or a lack of awareness of the technology and its implications is questionable. While some of the studies did examine the level of pre-existing awareness of gene editing (Hendriks et al., 2018; Uchiyama et al., 2018), these studies did not inform participants of the details of each form of gene editing. This may have led to participants considering just the obvious benefits of treating or preventing diseases, without considering the moral or practical consequences of choosing to edit embryos.

Another key division in the gene editing attitude literature is whether the edit is for treatment or enhancement purposes. Studies have consistently shown greater levels of opposition to enhancement compared to treatment (Delhove et al., 2020). Xiang et al. (2015) found that participants were divided in their attitudes (50% supporting and 50% opposing) towards improving memory or increasing lifespan, compared to 60% support for treatment of serious health issues. McCaughey et al.'s (2016; 2019) work repeated this division in enhancement attitudes, with participants split 50% and 50% in support and opposition. Finally, Gaskell et al (2017), found their participants opposed both adult and prenatal enhancement.

Among these enhancements, there is nuance in what participants consider acceptable. A recent American MTurk study found increasing lifespan received the highest level of support (40%), followed by enhancements to intelligence (39%), physical strength and fitness (37%), physical appearance (25%) and production of superhuman characteristics (20%) (Robillard et al., 2014). When similar traits were examined within a Chinese sample, the level of support was lower; improving memory received 15% support and increasing lifespan was supported by 20% of participants (Xiang et al., 2015). Finally, in a Dutch sample, increasing intelligence only received 16% support and HIV resistance 30% (Hendriks et al., 2018).

### *Nanotechnology attitudes*

Medical nanotechnology attitudes have not been comprehensively explored. Many researchers have examined attitudes towards other generalised uses of nanotechnology – such as its use in foods, cosmetics, or clothing. However, few have provided participants with examples concerning medical nanotechnology. This fails to account for important distinctions between medical nanotechnology and its other applications – for example, the concerns of nanotechnology in clothing are likely to be markedly different from the concerns surrounding using nanotechnology in the human body.

In the few studies that examine nanotechnology's use in medicine, there are generally optimistic appraisals of the health risks and benefits. Scheufele and Lewenstein (2005) found in their sample ( $N = 704$ ) that 74% believed that nanotechnology would lead to new ways to treat illnesses. This pattern of optimism is also found in work by Siegrist et al. (2007), who found that their participants ( $N = 421$ ) perceived the use of nanobots, or the treatment of cancer with nano capsules, to be less risky to health than its use in food packaging, sunscreen, or mobile phones. Cobb and Macourbrie (2004) also found in their sample ( $N = 1536$ ), that 57% of participants listed improvements in disease treatment and detection as the most important benefit of nanotechnology. Joubert et al. (2020) found that in their sample ( $N = 1076$ ), 70% agreed that nanotechnology has positive effects on health.

A similar divide exists in medical nanotechnology research as in gene editing, where the beliefs regarding the risks and benefits of the technology become more pessimistic when participants are responding to the topic of enhancement. Cobb and Macoubrie (2004) found that only 11% of their sample thought physical and mental enhancement was the most important benefit of nanotechnology. In Scheufele and Lewenstein's (2005) sample, 62% of participants thought that nanotechnology would be used to improve human abilities, compared to 74% that believed it would be used to treat illness. Finally, Hays et al. (2013) found that

34% of their sample (N = 849) believed that the overall risks and benefits of human enhancement were equal, and 29% believed the benefits outweighed the risks.

### ***Vaccination attitudes***

In a cross-cultural sample (N = 5323, split between 24 countries), 54% of participants expressed anti-vaccination sentiments (e.g. concerns over the effectiveness and side effects) (Hornsey et al., 2018). Despite this, other research has found vaccination attitudes to be very positive, with 88% of a US sample (N= 3627) believing that the benefits outweighed the risks (Funk et al., 2017). Overall, actual vaccination uptake is low. For example, in a review of HPV vaccine uptake across 15 countries (N = 840,838), only 41.5% of the sample were vaccinated. However, vaccine uptake rates can be quite variable. Vaccination uptake is sensitive to world events, such as when negative news regarding vaccination is reported. Vaccine uptake has been observed to decrease in the wake of controversies (Hansen & Schmidtlaicher, 2021; Verger et al., 2015), as well in response to the spread of misinformation (Kanozia & Arya, 2021). In a longitudinal study by Hansen et al (2020), 95% of their baseline Danish sample (N = 328,799) in 2012 received the HPV vaccination. In later samples the uptake dipped to 83% between 2013 and 2015 after negative news coverage, then further to 50% between 2015 and 2017, after the negative news coverage increased, and only returned to baseline uptake in 2018 and 2019, after an information campaign to counter the negative news coverage. Recent studies have also found vaccination uptake to vary significantly by country, for example in a recent review of COVID-19 vaccination rates, Sallam (2021) found that vaccine hesitancy was as high as 76.4% in Kuwait, and as low as 16.5% in China and Italy.

### ***Cultured meat attitudes***

In a review of the literature that concerns willingness to consume cultured meat, Bryant and Barnett (2018) identified only three studies that directly examined this sentiment. The first of these studies used an online sample (N = 673) and found that 65.3% of their participants

would be willing to try cultured meat, but only 31.5% would be willing to use cultured meat as a replacement for traditionally farmed meat. In a French and mixed nationality sample (N= 865, N= 817, respectively), acceptance was even lower, with 5.3% of the French sample and 11.1% of the mixed nationality sample willing to eat cultured meat (Hocquette et al., 2015). Finally, Slade (2018) found in their online sample (N = 533) that 11% would choose cultured meat over conventional meat sources. Since this initial review, the amount of research concerning cultured meat attitudes has dramatically increased, but show limited evidence of improvement (Bryant & Barnett, 2020). For example, Weinrich et al., (2020) found in a German sample (N= 713) that 31% of their sample would be willing to eat cultured meat instead of conventional meat. However, M. Zhang et al. (2020) found in a Chinese sample (N= 1004) that 45% of participants were at least somewhat supportive of cultured meat.

### ***GM foods attitudes***

GM food attitudes, as with vaccination attitudes, can vary significantly by country. Costa-Font and Gil (2009) found in their Greek, Italian and Spanish samples (N= 490, 454, and 502, respectively) that only 18%, 28%, and 42% of participants believed that GM foods should be encouraged, respectively. In a study (N= 266) that examined New Zealand attitudes, 10% of participants expressed an intention to purchase GM foods (Cook et al., 2002). In a Norwegian, US and Spanish sample (N= 660), 30.5%, 53%, and 21.2% , respectively, were at least somewhat willing to consume GM foods (Angulo & Gil Roig, 2007, see also Chern & Rickertsen, 2001). Finally, in US and Irish samples (N = 681 and 195, respectively) 47.7% and 72.8%, were likely to buy GM foods (Evenson & Santaniello, 2004).

## **1.4 What Underlies Biotechnology Attitudes?**

Now that the general attitudes regarding the main biotechnologies examined within this thesis have been outlined, I turn my attention to the predictors of these attitudes. Most of these

constructs underlie multiple biotechnologies simultaneously. Therefore, I will discuss each predictor separately, combining the findings for each biotechnology application, how they are associated with these constructs, outline candidate variables that could be explored and predict their relation to biotechnology attitudes.

### ***Perceived risks and benefits***

The relative perceived risk and benefits of each biotechnology application have been shown as consistent predictors of attitudes or adoption of a technology (Binder et al., 2012; Cobb & Macoubrie, 2004; Poortinga & Pidgeon, 2006; Siegrist, 2000, 2000; Siegrist et al., 2007). For example, in gene editing and nanotechnology applications, one of the strongest concerns that participants express is concern over the long-term health risks of the technology (Cobb & Macoubrie, 2004; Funk & Hefferon, 2018; Robillard et al., 2014; Xiang et al., 2015). In the vaccination literature, the perceived risk of vaccines has been found to be a key predictor of vaccination attitudes and uptake (Bond & Nolan, 2011; DiBonaventura & Chapman, 2008; Hornsey et al., 2018; Martin & Petrie, 2017). The way in which people consider the benefits a technology provides, and the risks associated with it may also account for some of the differences between biotechnological treatments or enhancements. In particular, why people are far less positive about enhancements using biotechnologies compared to using them for the treatment of illness.

In the case of gene editing for treatment purposes, participants typically consider the technology in the context of preventing life threatening illness. As one would expect this receives a high level of support, despite people's concerns about the long-term health risks (Delhove et al., 2020; Uchiyama et al., 2018; Weisberg et al., 2017). The level of support is lower when the treatment is for less serious illnesses or disorders, such as ADHD (Robillard et al., 2014; Xiang et al., 2015). This could be due to the reduced benefits to a person's quality of

life, while the level of risk stays constant – a person would risk generalised anaesthetic in surgery to remove a tumour but may be less inclined to do so for a deep cut.

The deficit in perceived benefits compared to risks is further exaggerated in genetic enhancement, where there is no need to ensure a person has an average quality of life, and the purpose of the gene editing is instead to improve beyond the average. This is supported by research that found enhancing a person's appearance was supported much less than enhancing a person's memory (Robillard et al., 2014) – the benefit of being better looking is considered less integral to a person's quality of life than cognitive ability. This possibility is also supported in other biotechnologies – the lack of support for GMO's has been partially attributed to their perceived lack of benefits, rather than their perceived risks (Gaskell et al., 2004).

### *Unnaturalness*

Other concerns about biotechnologies include the perception that they are unnatural. There are often narratives surrounding biotechnologies that suggest that developers of these technologies are 'playing god' (Dragojlovic & Einsiedel, 2013). There have been references to GMO's as ' Frankenfoods' (Hellsten, 2003) and children born of IVF as 'test tube' babies (Russell, 2010). Entities identified as unnatural are often associated with disgust responses (Clifford & Wendell, 2016; Sanyal et al., 2021). Furthermore, there is evidence biotechnologies elicit a disgust response in some individuals (Nabi, 1998; Sanyal et al., 2021; Siegrist et al., 2018). In particular, pathogen disgust – the disgust response to potential sources of contamination or illness (Tybur et al., 2009). Pathogen disgust appears to be a sensitive part of the behavioural immune system, as it can be triggered by entities that do not constitute direct pathogenic risks, such as objects that trigger tryptophobia (the fear of clusters of small holes) (Imaizumi et al., 2016).

Research into attitudes towards cultured meat has found that disgust was associated with stronger opposition to the technology (Siegrist et al., 2018). Similarly, heightened levels

of disgust have been found to predict greater opposition to GM crops (Scott et al., 2016). However, the extent of the link between disgust and biotechnologies has yet to be fully explored; novel technologies such as gene editing have not yet been studied in relation to disgust. As biotechnologies frequently involve the introduction of ‘foreign’ matter into the body, and are often perceived as unnatural, it would be logical that gene editing for example, may trigger a person’s pathogen disgust, increasing the probability of them opposing the technology.

### ***Scientific knowledge***

The reliability of scientific knowledge as a predictor of biotechnology attitudes has been subject to considerable debate. The knowledge deficit model suggests that the greater a person’s knowledge of science, the more likely they are to support technologies (Sturgis & Allum, 2004). However, this theory does not appear to hold up to scrutiny – when the relationship between knowledge and attitude are examined, some studies have found positive relationships, while others have found negative (Črne-Hladnik et al., 2012; Delhove et al., 2020; Marks, 2016; Simis et al., 2016). Other researchers have attempted to reconcile the inconsistencies in the direction of the relationship between knowledge and attitude, by suggesting that other factors (e.g. trust in science) determine the valence of an attitude, and knowledge influences the magnitude of the relationship (Brunk, 2006). Other researchers suggest that trust in science is a more consistent predictor of attitudes when compared with knowledge or education (Priest et al., 2003).

### ***Trust in science***

A greater level of trust in science is associated with a greater degree of support for biotechnology. It has been suggested to be one of the key factors for acceptance of genetic technology (Connor & Siegrist, 2010), nanotechnology (Siegrist, 2010), and gene therapy (Gottweis, 2002). It has also been suggested as a better predictor for understanding attitudes



towards technology than scientific knowledge (Connor & Siegrist, 2010), which has received much scrutiny – with the knowledge deficit model falling out of favour (Simis et al., 2016).

### ***Demographic variables***

There are also several demographic variables that are associated with biotechnology attitudes. Women are consistently more likely to oppose biotechnologies (Delhove et al., 2020) across a diverse range of applications, such as gene editing, vaccination, nanotechnology, cultured meat, and genetic modification (Critchley et al., 2019; Gaskell et al., 2017; Gilkey et al., 2014; Lee et al., 2017; Lin & Wang, 2020; Siegrist, 2010; Siegrist et al., 2018; Zarobkiewicz et al., 2017). The reason for this is unclear, but it has been suggested that women are more sensitive to the pathogen risks presented by these technologies, as women typically score higher on pathogen disgust sensitivity (Tybur et al., 2009).

Religiosity is also a commonly found predictor of attitudes towards biotechnology, with a higher level of religiosity corresponding to greater levels of opposition (Allum et al., 2017; Critchley et al., 2019; Dragojlovic & Einsiedel, 2013; Scheufele et al., 2017). This has been suggested to be related to concerns of scientists ‘playing god’ (Dragojlovic & Einsiedel, 2013). In addition to this explanation, religiosity and political ideology may be examined in relation to pathogen disgust, as those who score higher in pathogen disgust sensitivity are often found to be more conservative and religious (Fincher & Thornhill, 2012; Kempthorne & Terrizzi, 2021; Yu et al., 2021). Given that non-political individual differences have been suggested to be antecedents of political and religious belief (Lewis, 2018; Roets & Van Hiel, 2011; Wink et al., 2007), and that political and religious beliefs may inform specific policy decisions (Jost et al., 2009), political ideology and religiosity may mediate the relationship between pathogen disgust and biotechnology attitudes.

The role of age in attitudes towards biotechnology is unclear. In a review paper by Delhove et al. (2020) regarding gene editing attitudes, they found four studies reported older

participants were more likely to oppose the technology and four studies that found no relationship between age and attitudes. While younger people are more accepting of technology in general (e.g. IT based technologies) (Arning & Ziefle, 2009; McFarland, 2001), older participants may benefit more from the quality-of-life improvements that new biotechnologies represent – which may correspond with higher levels of support.

### ***Cognitive biases***

The role of cognitive biases, such as omission bias, in biotechnology decision making is also unclear. Omission bias refers to a widely-observed phenomenon whereby people are more sensitive to the negative outcomes of acting than to those of failing to act (Baron & Ritov, 2004; Ritov & Baron, 1990). Omission bias has been observed in a range of situations: e.g. medical care decisions (Aberegg et al., 2005), moral decision making (DeScioli et al., 2012), social interactions (Pittarello et al., 2016), and vaccination (Asch et al., 1994; Baron & Ritov, 2004; Brown et al., 2010; DiBonaventura & Chapman, 2008). Omission bias has been highlighted as one of the major cognitive barriers to vaccination uptake (Miton & Mercier, 2015).

A similar pattern to that found in vaccination decisions may generalise to decision making in gene editing or nanotechnology to prevent one's child from contracting an illness, as in these contexts a parent must weigh up the risk presented by the illness and the risk of side effects from the treatment. Thus, a parent may desire a risk premium (i.e. the risk from the side effects being lower than that presented by the illness) before they are willing to use gene editing or nanotechnology.

### ***Socio-political variables***

There are also a number of non-human applications for gene editing, that have been previously neglected. For example, gene editing (and specifically gene drive) involve modifying genes so that a desired gene (e.g., a gene creating sterile offspring) is passed on at a

rate higher than the typical 50% found in conventional reproduction, which can be applied to the control of pest populations (Kirk et al., 2019). This has important implications for the control of pest populations that carry diseases, such as mosquitoes, which have been identified as a significant threat to public health in many countries (The World Health Organization, 2019a)

Given that the target of this gene editing application is a non-human animal, support for gene editing in animals may be associated with different predictors. For example, Social Dominance Orientation (SDO) – the belief in a rigid social hierarchy, has been found to predict willingness to exploit animals (Dhont et al., 2014; Dhont & Hodson, 2014). However, to date, limited research has examined psychological predictors of attitudes towards animal centred gene editing (e.g. Critchley et al., 2019).

### ***Alternative approaches to examining biotechnology attitudes***

As the literature review above shows, researchers often examine either broad trends of biotechnology attitudes (e.g. Funk et al., 2020), or examine specific concerns surrounding a biotechnology as individual beliefs (e.g. Robillard et al., 2014; Xiang et al., 2015). However, these approaches fail to examine how beliefs or concerns may coalesce within an individual to form an overall attitude. For example, a person may believe that gene editing will create new methods to treat illness (a pragmatic and optimistic appraisal of the technology) but be strongly opposed to the technology based on moral concerns. Previous research neglects the possibility that an individual can hold these conflicting beliefs simultaneously. This requires an approach that can provide an insight into the different kinds of biotechnology attitude within an individual, and how these classes of attitude qualitatively differ from one another. An approach such as Latent Class Analysis (LCA), can identify different classes of supporters or opposers, what beliefs differentiate them, as well as identify the predictors of membership to these classes.

### ***Conclusion***

From my examination of the previous findings relating to biotechnology attitudes, gaps in the literature begin to appear. Primarily, there are very few examples of studies that have examined psychological predictors of attitudes towards biotechnologies. This is especially apparent in the gene editing literature, which often examines specific beliefs or concerns, but not what psychological factors underpin them. This lack of psychological predictor research for several biotechnologies becomes apparent when compared to the rapidly growing body of research that has arisen in the wake of the biotechnological challenges that are the COVID-19 pandemic and COVID-19 vaccination hesitancy.

### **1.5 The COVID-19 Pandemic**

The COVID-19 pandemic has presented an unprecedented level of disruption to the lives and livelihoods of many. The reactions to the pandemic across the sciences have varied, with epidemiologists and biologists applying their knowledge to combatting the direct threat to public health presented by COVID-19. The vaccines that have been developed are leading the fight against COVID-19 (The World Health Organization, 2021). Psychologists have had a less direct contribution to fighting back against the pandemic. Psychology researchers have examined the effects of the pandemic on mental health (Niedzwiedz et al., 2020; Pierce et al., 2020), the impact on lifestyle (Kushner Gadarian et al., 2020; Yıldırım & Güler, 2020; Zajenkowski, 2020), and compliance with health guidelines (Kushner Gadarian et al., 2020; Zajenkowski, 2020). Others have examined vaccination hesitancy (Lin & Wang, 2020; Murphy et al., 2021). The following section will review predictors of attitudes towards vaccination in the context of COVID-19.

#### ***Attitudes towards COVID-19 vaccines***

Hesitancy is a well-documented response to vaccination, which exists across a wide range of possible vaccinations, such as those for human papillomavirus (HPV) (Donadiki et al., 2014; Hansen et al., 2020; Marlow et al., 2007), measles, mumps, and rubella (MMR) (Abhyankar et al., 2008; Allan & Harden, 2014; Casiday et al., 2006) and influenza (Akan et al., 2010; Tebruegge et al., 2010; Wong & Sam, 2011). The existence of vaccine hesitancy has been identified as a major threat to public health by the World Health Organisation (2019b) and has been suggested to be the reason for a resurgence in preventable diseases (Hussain et al., 2018).

A range of factors, including age (Schwarzinger et al., 2021), sex (Murphy et al., 2021), cognitive biases (Baron & Ritov, 2004; DiBonaventura & Chapman, 2008), income (Feiring et al., 2015), and education (Bertoncello et al., 2020) have been linked to vaccine hesitancy. Specifically, women, younger people, those with lower levels of education and income, those who are more prone to cognitive biases, and political conservatives are all more likely to reject vaccines. However, as identified previously in this thesis, vaccination hesitancy can be variable – depending on the country, type of vaccination, and discourse surrounding the vaccine. This may mean that previously identified levels of hesitancy, and predictors of hesitancy may not generalise to COVID-19 vaccination.

Several studies have examined the role of Big 5 personality traits in vaccination hesitancy during the COVID-19 pandemic. Lin and Wang (2020) (US sample, N = 3276) found that high openness, agreeableness, conscientiousness, and low neuroticism were associated with a belief in the health benefits of vaccination. Murphy et al. (2021) found non-significant associations in their Irish sample (N = 1041) between all personality traits, barring high agreeableness being associated with a higher vaccination likelihood. In their UK sample (N=2025) they found high agreeableness and conscientiousness, and low neuroticism was associated with a higher vaccination likelihood, but openness was *non-significantly* associated.

Across these studies, extraversion was non-significantly associated with vaccination attitudes. Overall, the literature seems to show that agreeableness and conscientiousness are negatively associated with vaccine hesitancy, with tentative support for a role of openness and neuroticism.

Intelligence may also predict likelihood to vaccinate. Recent research has identified a relationship between cognitive reflection (the ability to choose a correct but cognitively demanding answer over an obvious but incorrect one (Frederick, 2005)), COVID-19 vaccination likelihood (Murphy et al., 2021) and susceptibility to COVID-19 misinformation (Pennycook et al., 2020a). Cognitive reflection scores are associated ( $r \approx .40$ ) with a range of numerical ability measures (a facet of general intelligence) (Sobkow et al., 2020). Furthermore, intelligence is also associated with educational attainment (Deary et al., 2005), which is associated with attitudes towards science (Drummond & Fischhoff, 2017) and vaccination attitudes (Bertoncello et al., 2020; Gilkey et al., 2014; Mora & Trapero-Bertran, 2018). Given these findings and the complex decision making involved in vaccination decisions, intelligence may also predict vaccination attitudes.

Intelligence and personality may also predict the reasons that individuals are choosing not to vaccinate. Intelligence predicts engaging in positive preventative health behaviours (Deary et al., 2010), as well as an individual's ability to understand and correctly estimate medical risks (Låg et al., 2013). Neuroticism and conscientiousness have also been found to predict engagement with positive health behaviours, and a greater awareness of one's own health (Bogg & Roberts, 2004; Chapman et al., 2010; Friedman et al., 1995; Gale et al., 2017). In the context of the current pandemic, taking the vaccine may represent a preventative health behaviour. Consequently, those who reject the vaccine and score higher on intelligence, conscientiousness and neuroticism measures may do so for reasons other than the side effect risk.

There is also a lack of research that has explored whether asymmetries exist between predictors of attitudes towards different vaccines. For example, the seasonal flu represents a more mundane threat compared to the current COVID-19 pandemic, which constitutes a significant global health threat, as well as personal and societal disruption. It is possible that the relationships found between predictor variables and COVID-19 vaccination attitudes may not generalise to attitudes regarding seasonal flu vaccination.

### **1.6 The Current Thesis**

This thesis seeks to address two core issues. Firstly, the lack of research into psychological predictors of biotechnology (in particular, gene editing) attitudes. Secondly, to understand what psychological constructs are associated with the public's response to the biotechnological challenge that is COVID-19.

**Chapter 3 (Study 1)** represents an exploration of the often-expressed concern that biotechnologies are unnatural. Based on the broad range of non-pathogenic or unnatural stimuli that can elicit disgust, I hypothesised that this concern indicates that gene editing attitudes may be associated with pathogen disgust sensitivity. This investigation of pathogen disgust sensitivity was conducted alongside an examination of several related biotechnologies, and a broad range of possible predictor variables, mediator variables, and potential confounds.

**Chapter 4 (Study 2)** examines whether decisions to use various biotechnologies are characterised by omission bias. This research was based on the previously reported presence of omission bias in vaccine decisions. I hypothesised that omission bias would be found in decision-making for vaccination, gene editing, and nanotechnology. This was done using a paradigm which rectifies the limitations of previous research into vaccination, as well as extending omission bias research into novel biotechnologies – gene editing and nanotechnology.

**Chapter 5 (Study 3)** examines the role of socio-political variables in gene editing attitudes. This was based on research that indicated that higher SDO scores were associated with a greater willingness to exploit animals. I hypothesised that higher SDO scores would be positively associated with support for animal centred gene editing. Additionally, I examined whether opposition to gene editing was associated with avoidance of entities considered artificial or synthetic. To this end, I hypothesised that higher Synthetic Aversion would be negatively associated with support for gene editing.

**Chapter 6 (Study 4)** expands upon the previous, broad examinations that dominate the gene editing attitude literature, using methods that provide greater depth. This entailed the use of Latent Class Analysis to classify different kinds of support and opposition and examining their qualitative differences. Due to the exploratory nature of the analysis, I made no predictions regarding the number of classes that would be extracted. I also analysed several demographic variables to examine how these groups significantly differ from one another.

**Chapter 7 (Study 5)** was conducted to investigate the classic issue of vaccination hesitancy in the novel context of the COVID-19 pandemic. I included a number of individual difference and cognitive measures to examine their associations with vaccine hesitancy. I predicted that intelligence, and scores on personality measures would be associated with vaccination hesitancy. This study also examined whether associations between predictors of COVID-19 vaccination hesitancy are generalisable to other vaccines, specifically seasonal flu. Finally, I examined whether different kinds of vaccine hesitancy were associated with a number of predictor variables.



## Chapter 2: Methodology

The main research goals of this thesis were to examine which psychological constructs underlie attitudes towards biotechnologies, with a focus on gene editing, and to identify predictors of attitudes that are associated with the current COVID-19 pandemic. The main approach that I adopted for this project was the use of cross-sectional methods, in order to examine a wide variety of predictor and outcome variables simultaneously. A cross-sectional approach also allows for statistical controlling of possible confounds and the examination of alternative explanations. This was typically done by examining previously unexplored constructs and a broad range of biotechnologies simultaneously (e.g. examining pathogen disgust sensitivity across GM crops, vaccination, gene editing, and cultured meats), while including variables that were conceptually associated with the predictor and outcome (e.g. controlling for the influence of openness in the relationship between intelligence and vaccination). When I wished to examine a particular biotechnology in greater depth, such as in Studies 4 and 5, I adopted statistical techniques that allowed me to tease apart differences between individual attitudes or concerns (i.e. latent class analysis, or multinomial logistic regression).

I have also adopted experimental methodologies where they are appropriate. For example, in Study 2, an experimental design was used, as this was the best approach to measure omission bias across a range of biotechnologies, while addressing methodological critiques in previous research (e.g. including basic and reversed conditions to account for the way risk was anchored).

Below I have detailed my research questions and the rationale for determining the size of the samples in Studies 1 and 2. I also detail my more consistently used variables (e.g. Big 5

personality measures) and statistical approaches that the reader may not be familiar with (e.g. latent class analysis).

## **2.1 Research Questions**

### ***Study 1 – Understanding Opposition to Human Gene Editing: A Role for Pathogen Disgust Sensitivity?***

This study was intended to address the lack of research examining psychological constructs underlying attitudes toward gene editing. I wanted to understand whether pathogen disgust sensitivity predicted attitudes towards gene editing, independently of confounding variables such as sex and neuroticism, and whether religiosity or political ideology mediated the relationship.

### ***Study 2 – Opposition to Novel Biotechnologies: Testing An Omission Bias Account***

This study was intended to extend existing omission bias research to novel biotechnology applications: gene editing and nanotechnology. I also sought to explore several cognitive and decision-making variables and how they are associated with biotechnology decision making. Specifically, I wanted to identify whether omission bias was present across biotechnology decision making, and whether cognitive reflection and decision-making style predicted inclination to express bias in a risk balancing task.

### ***Study 3 – The Role of Social Dominance Orientation in Attitudes towards Animal Centred Gene Editing***

This study was intended to explore how a broad range of psychological predictors are associated with attitudes towards animal centred gene editing for pest control. This was with the intention of providing initial evidence for the role of socio-political variables. Specifically, I wanted to explore whether SDO and Synthetic Aversion predicted willingness to use gene editing in pest control, while controlling for potential confounds.

***Study 4 – Heterogeneous Attitudinal Profiles Towards Gene Editing: Evidence From Latent Class Analysis***

This study used LCA to provide a deeper insight into the way that attitudes towards gene editing cohere in an individual. I wanted to explore whether attitudes towards gene editing formed heterogeneous classes and identify what demographic variables predicted membership to the classes that emerged.

***Study 5 – COVID-19 and seasonal flu vaccination hesitancy: Links to personality and general intelligence in a large, UK cohort***

In this study I investigated a biotechnological issue of pressing global importance: vaccine hesitancy in the context of the COVID-19 pandemic. The aim was to explore novel predictors of vaccine hesitancy, while seeking to reconcile some of the inconsistencies in the vaccination and personality trait literature. Specifically, I wanted to identify whether intelligence, and Big-5 personality traits were independent predictors of vaccine hesitancy across two types of vaccine, and whether intelligence and Big-5 personality traits would predict specific motivations for being vaccine hesitant.

## **2.2 Sample Information and Rationale**

***Study 1*** Study 1 used primary data, sourced from Prolific Academic. The sample size and composition (347 British participants aged 18+) were pre-registered before data collection as part of a registered report.

***Study 2*** used primary data, sourced from Prolific Academic (N= 613). This sample was pre-registered before data collection, 18+ years old and recruited from The United States.

*Study 3* used secondary data, sourced from New Zealand's Biological Heritage Data Repository (N= 5554). This sample was 18+ years old and recruited from New Zealand.

*Study 4* used secondary data, sourced from The Pew Research Center American Trends Panel (N= 4726). This sample was 18+ years old and recruited from The United States.

*Study 5* used secondary data, sourced from The Understanding Society longitudinal household panel survey (N=9667). This sample was 18+ years old and recruited from The United Kingdom.

Sample size for Study 1 was based upon the findings of Gignac and Szodorai (2016), which was a comprehensive examination of effect sizes in individual differences literature. They found that the median correlation effect sizes in the literature were between  $r = .15$  and  $r = .20$ , which informed the effect size decisions for all of Study 1's cross-sectional components. I chose to power my studies to detect an effect size of .15, with 80% power. The decision to use 80% power ( $\alpha = .05$ ) was partially based upon monetary limitations and the relative risk severity of a false negative compared to a false positive (Lakens, 2021).

Study 2's sample size for the experimental component was based on a single t-test against a constant (10%), to detect a Cohen's d of .3, with 80% power and an alpha of .05 (two-tailed). This gave us a recommended sample size of 90, which was then multiplied by six (to account for each condition), giving a total of 540 participants across all the groups. We then added approximately 15% to account for participants that may be removed due to exclusion criteria, giving us a final sample size of 618 (103 per condition). For the correlation portion of the study, our sample was powered to detect  $r = .2$  with 80% power (two-tailed) if the reverse/basic conditions were aggregated, or  $r = .3$  with 80% power (two-tailed) if the reverse/basic conditions were not aggregated.

### 2.3 Use of Online Participant Recruitment

All of the primary data collection for this thesis was carried out using online crowdsourcing platforms, in particular, Prolific (<https://prolific.co/>). This decision was based upon the relative ease with which participants can be sourced, and the predominantly survey-based nature of the work. Previous research has found that sourcing participants online through services such as Prolific and Amazon's Mechanical Turk (MTurk) provides data that is at least comparable to conventional methods (Casler et al., 2013; Necka et al., 2016), and in some studies exceed it (Hauser & Schwarz, 2016). The choice of Prolific over Amazon's MTurk was based upon, Prolific's sample being more naïve to behavioural tasks compared to Mturk (Peer et al., 2017) and issues surrounding the proliferation of bots in Mturk samples (Bai, 2018; Kennedy et al., 2020). The quality of data from Prolific in this thesis was high, with less than 5% across all samples being removed due to failing attention checks or spurious responding (such as answering the questions too quickly, or being dishonest about their location, as shown by IP address).

The use of online samples is also supported by research that examined their viability when compared to more traditional data collection methods. Work by Gosling et al. (2004) found in a large online sample (N= 361,703) that web users were diverse (but not necessarily representative), and their performance on measures (e.g. the Big 5 inventory) replicated across presentation formats and across web-based and traditional data collection methods.

The diversity of participants also increases when using services such as MTurk, as does the reliability, compared to traditional methods and alternative web based approaches (e.g. forum recruitment) (Buhrmester et al., 2011). The quality of participant sourcing platforms has been found to be at least on par with traditional approaches (Buhrmester et al., 2011; Casler et al., 2013). While performance can differ on commonly used tasks (e.g. Dictator games,

Prisoner dilemma, or Trolley problems), with participants becoming familiar with these measures and how to perform optimally on them (Chandler et al., 2014), the current thesis does not make use of commonly used tasks, which avoids the issue of non-naivete. When examining which online participant sourcing platform is preferable (i.e. Prolific Academic or MTurk), samples appear to be interchangeable regarding diversity, dropout rates, and attentiveness (Adams et al., 2020).

However, it should be acknowledged that there are limitations associated with the use of online platforms. For example, online samples are significantly less likely to be religious (Burnham et al., 2018; Levay et al., 2016; A. R. Lewis et al., 2015), and there are small demographic and online questionnaire experience differences depending on the time of day at which the survey is conducted (Casey et al., 2017). Despite our research questions not focussing on religious factors (barring their inclusion as covariates, and one instance of mediation), these examples still suggest the possibility that the use of online sampling may have biased our results. However, the magnitude of this bias is unable to be measured in my studies.

## **2.4 Key Variables**

The studies this thesis is composed of make use of a wide variety of predictor variables. This decision was primarily motivated by the current lack of work that explores psychological predictors, and the likelihood that attitudes towards a given biotechnology are unable to be explained by a small number of predictor variables. Including a range of psychological predictors allows future research to build upon these initial findings, and given the wide range of biotechnologies examined, allows areas of heterogeneity between biotechnology predictors to be identified. Secondly, for each key predictor, there are a number of other variables that may confound the key predictor's relationship with biotechnology attitudes. For example, SDO

and political ideology are closely related concepts, which may play independent roles in predicting biotechnology attitudes (i.e. SDO predicting support for animal-centred gene editing due to moral distancing from a group perceived as lower on a social hierarchy, versus politically motivated opposition due to the politicisation of a scientific issue). Therefore, a wide range of confounding variables, or variables that may provide an alternative explanation for biotechnology attitudes were included to support the robustness of the relationships we found.

The key predictor variables for each study are listed below:

Study	Key predictor variables
Understanding opposition to human gene editing: a role for pathogen disgust sensitivity? (Chapter 3)	Pathogen disgust sensitivity, political ideology, religiosity.
Opposition to novel biotechnologies: testing an omission bias account (Chapter 4)	Cognitive reflection, biotechnology attitudes, decision-making style
The role of social dominance orientation in attitudes towards animal centred gene editing (Chapter 5)	Social dominance orientation, Synthetic avoidance
Heterogeneous attitudinal profiles towards gene editing: evidence from latent class analysis (Chapter 6)	N/A (a wide range of demographic variables were included, but for exploratory purposes)
COVID-19 and seasonal flu vaccination hesitancy: links to personality and general intelligence in a large, UK cohort (Chapter 7)	General intelligence, Big 5 personality traits

Below are detailed the key variables for the studies in this thesis, as well as others that have been used in multiple studies.

### ***Biotechnology information***

In Study 1 and 2 participants were given information regarding biotechnologies, to ensure a baseline level of knowledge, before they proceeded with the study. In Study 1, gene editing is explained using the following vignette, adapted from previous research (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.*

This style of information presentation is retained in Study 2, with the description altered to account for some of the differences in the other biotechnologies, for example *Recently, scientists have figured out a way to use nanotechnology – which involves manipulating matter on the scale of atoms and molecules – in medicine. This technology means they might be able to perform microsurgeries or deliver medications to specific areas of the body to treat or prevent health problems. This technology could also be used to enhance normal traits.* This information was not given in the vaccination scenarios, as it is a less novel biotechnology, that participants would be familiar with.

In Study 3 there was no information given to participants that described what gene editing was. However, they were given information on Gene drive, which is an application of gene editing techniques and reads as follows: *In the future, gene drive could be developed to rid New Zealand of rats. Gene drive is where an animal's DNA is edited in the lab. These animals can only produce male offspring. The lab animals are then released into the environment and when they breed with wild animals, the number of females declines. With fewer females to breed with, the entire population size falls over time.*

In Study 4, participants were given the following information: *New developments in genetics and gene-editing techniques are making it possible to treat some diseases and conditions by modifying a person's genes. In the future, gene-editing techniques could be used for any newborn, by changing the DNA of the embryo before it is born, and giving that baby a much reduced risk of serious diseases and conditions over his or her lifetime. Any changes to a baby's genetic make-up could be passed on to future generations if they later have children, and over the long term this could change the genetic characteristics of the population.*



Study 5 (secondary data) did not include information to explain what the COVID-19 vaccination entailed.

## **Biotechnology attitudes**

### ***Defining a biotechnology attitude***

This thesis makes frequent use of the word *attitudes* and the majority of the outcome variables used in my studies rely upon measurement of attitudes. In an attempt to provide a consistent and transparent definition, upon which the choice of attitude measures can be understood, the following is the definition we used for an attitude, which was interpreted from work by Richardson et al. (2020), using gene editing as an example. An attitude is an evaluative tendency toward an entity (e.g. gene editing) and this tendency is composed of one's valenced beliefs about the entity (e.g., gene editing could lead to unintended side effects, or gene editing is immoral), one's affect associated with the entity (e.g., negative feelings associated with gene editing), and recollections of past behaviour/interaction with the entity (typically first-hand experience, but due to the novelty of gene editing, this could be something like reading a negative news story about it). These different types of contents compose the overarching structure of an attitude towards a given biotechnology.

### ***Gene editing attitudes***

In Study 1, gene editing attitudes were measured using 15 items that covered a range of different applications that gene editing may be used for, including treatment of mental and physical illness, and enhancement of mental and physical abilities. The inclusion of these items was intended to capture a wide range of gene editing applications, such as treatment or enhancement, as well as pre-natal and adult editing, so that we may examine differences in opposition between them. The target recipients of these gene edits were varied, including babies, adults, and animals. Participants were asked to indicate how likely they would be to

support gene editing, using a 4-point Likert scale, with responses ranging from 1, *Highly unlikely*; 2, *Unlikely*; 3, *Likely*; and 4, *Highly likely*.

Gene editing attitudes in Study 2 were measured using 5 items that we created, but which were based upon existing themes in gene editing research (Robillard et al., 2014; Xiang et al., 2015). These items were intended to tap into overall attitudes towards gene editing, rather than specific issues of treatment versus enhancement, or target of the gene edit, which have been shown to produce different patterns of support (Delhove et al., 2020). Participants responded using a 5-point Likert scale, with responses ranging from 1 *Strongly agree* to 5 *Strongly disagree*. Examples of these items include *I think gene editing is immoral*.

In Study 3 (secondary data analysis) attitudes towards gene editing as a pest control method were measured using a single item *There are a number of ways to control species which are considered to be pests. Please indicate your general attitude towards the pest control methods listed below*, with gene editing presented as one of the methods; *Approaches involving genetic editing that result in most offspring being male*. Responses were measured using a 5-point Likert scale, with responses ranging from 1 *Should never be used under any circumstances* to 5 *I have no concerns at all about this method*.

The secondary dataset used in Study 4 contained a range of gene editing variables. We selected a sub-set of these items for analysis. Our question selections reflected the following themes: 1) Levels of excitement about gene editing; 2) Levels of worry about gene editing; 3) Beliefs regarding gene editing crossing a natural boundary; 4) Concerns about the consequences if gene editing was adopted; 5) Whether using gene editing to give babies a reduced risk of disease is morally wrong; 6) Whether the use of gene editing to give a person average/above average health is an appropriate use of technology.

During this process we removed several items. Some were removed due to their ambiguity, and others were removed due to them potentially tapping into other issues, such as the use of embryos in gene editing research. This gave us 10 questions that tapped into a broad range of attitudes regarding gene editing as mentioned above, and were supported by existing research (Critchley et al., 2019; Robillard et al., 2014; Xiang et al., 2015).

### ***Vaccination attitudes***

In Study 1 we measured vaccine attitudes using 2 items; *How likely would you be to have a vaccination?* And *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*. These two items were reversed coded such that higher scores reflected higher levels of opposition to vaccination. The combined mean scores of these items were used for analysis. We elected to use only two items, as vaccination attitudes were not the focus of the study.

Vaccination attitudes in Study 2 were operationalised using a measure that we created based upon themes that arise in vaccination literature (Bond & Nolan, 2011; Hornsey et al., 2018; Marlow et al., 2007). I used a larger number of items in this study, compared to Study 1, as vaccination was one of the focal biotechnologies, and wanted to comprehensively capture the different aspects of vaccination attitudes (e.g. morality, trust or safety). This 5-item measure was scored on a 5-point Likert scale, with responses ranging from 1 *Strongly agree* to 5 *Strongly disagree*. An example of the items is *I trust those who administer vaccinations*. Items were reverse coded where necessary so that a higher score indicates more opposition to vaccines. The mean score of these items was used for analyses.

In Study 5 (secondary data), COVID-19 vaccination hesitancy was measured using a single item. Participants were asked to respond to the question *Imagine that a vaccine against*

*COVID-19 was available for anyone who wanted it. How likely or unlikely would you be to take the vaccine?* Responses were recorded using a 4-point Likert scale, ranging from 1 = *Very likely* to 4 = *Very unlikely*.

In Study 5, Seasonal flu vaccination hesitancy was measured using a single item, which was given to participants aged 50-65, who had not received the seasonal flu jab (n = 1433). Participants were asked to respond to the question *The Government has indicated that it may offer flu jabs to all those aged 50 – 64 in November and December. If this is offered to you, how likely are you to have a flu jab this autumn/winter?* Responses were recorded using a 4-point Likert scale, ranging from 1, *Very likely* to 4, *Very unlikely*.

### ***Nanotechnology attitudes***

Nanotechnology attitudes in Study 2 were measured using 5 items that we created, using a 5-point Likert scale, with responses ranging from 1 *Strongly agree* to 5 *Strongly disagree*. These items, while not explicitly drawn from the nanotechnology attitude literature, were intended to mirror the vaccination and gene editing attitudes questions in the study. Examples of these items include *I think nanotechnology is immoral*. Scores were reverse coded so that higher scores indicate opposition for the respective biotechnology.

### ***Cultured meat attitudes***

In Study 1, we measured attitudes towards cultured meats. This was done by adapting two items taken from previous literature (Wilks & Phillips, 2017): *How willing would you be to eat cultured meat compared to soy substitutes?* and *How willing would you be to eat cultured meat compared to traditionally farmed meat?* These items used a 4-point scale, with responses options being 1, *Highly unlikely*, 2, *Unlikely*, 3, *Likely*, 4, *Highly likely*. The mean of these two items were used for analysis purposes. Responses were reverse-coded such that higher scores reflected higher levels of opposition to cultured meat.

### ***GM crop attitudes***

In Study 1, we measured attitudes towards GM crops. Participants were asked “How willing would you be to eat genetically modified crops compared to traditionally farmed crops?”. This item used a 4-point scale, with responses options being: 1, *Highly unlikely*, 2, *Unlikely*, 3, *Likely*, 4, *Highly likely*. Responses were reverse-coded such that higher scores reflected higher levels of opposition to GM crops.

### ***Pathogen disgust sensitivity***

Pathogen disgust is the reaction one experiences when encountering excrement or rotten meat. It is thought to be a part of the ‘behavioural immune system’, which is a set of evolutionary responses intended to maintain one’s health (i.e. a negative reaction to rotten meat prevents a person eating it and becoming ill) (Tybur et al., 2009). Pathogen disgust sensitivity has also been found to be associated with several domains, such as religiosity (Wagemans et al., 2018), political ideology (Inbar et al., 2009) and gender (Tybur et al., 2009), with those who are more religious, conservative, or female being more sensitive to pathogens.

People appear to prefer a false positive to a false negative when identifying pathogens, which leads them to identifying targets with no explicit pathogenic risk, as pathogenic risks. For example, trypophobia (the fear of small clusters of holes) inducing objects have been found to elicit pathogen disgust responses (Imaizumi et al., 2016) despite not presenting an explicit pathogen risk. This overreaction may be due to the relative risks of a false positive (e.g. illness or death), compared to the risks of a false negative. The overapplication of pathogen disgust could also explain attitudes towards biotechnology, as it has been found to be associated with attitudes towards biotechnologies that are deemed ‘unnatural’, such as GM crops (Tenbült et al., 2005) and cultured meat (Siegrist et al., 2018). Biotechnologies are often labelled as unnatural, and involve potentially invasive treatments (such as injections from vaccinations), which may trigger a person’s pathogen disgust in response to a possible illness vector. Consequently, pathogen disgust sensitivity was included as a key variable in Study 1, which

aimed to examine whether pathogen disgust sensitivity predicted opposition towards biotechnologies.

The measure of pathogen disgust sensitivity in Study 1 is a subscale taken from the Three Domain Disgust Scale, developed by Tybur et al., (2009). Participants read a series of scenarios such as *Stepping on dog poop* or *Accidentally touching someone's bloody cut*. They are then asked to indicate whether they found the scenario disgusting using a 7-point Likert scale, with responses ranging from *Not at all disgusting* to *Extremely disgusting*, which are then averaged and scored in such a way that a higher score indicates higher pathogen disgust sensitivity.

### ***Trust in science***

Trust in science has been consistently identified as a predictor of attitudes towards biotechnologies (Braun & Meacham, 2019; Brunk, 2006; Casiday et al., 2006; Connor & Siegrist, 2010; Macoubrie, 2006). It was proposed as one of the key predictors of support for genetic technologies such as genetically modified foods by Siegrist (1999). Its inclusion in my research was primarily to rule it out as an alternative explanation for participants' opposition to biotechnologies. Trust in science in my primary data studies was measured using the scale developed by Nadelson et al., (2014), which is a generalised measure of trust in science as a whole, as opposed to trust in a particular biotechnology application. This is based upon the notion that generally if a person distrusts one scientific application in a particular field (e.g. vaccines in biotechnology), then it is unlikely that they are going to be more trusting of other technologies in the same field (e.g. nanotechnology). This decision is supported in our findings in Study 1, where generalised trust in science was predictive of attitudes towards a variety of biotechnologies.

This measure consists of 21 items. Examples of questions include *We should trust the work of scientists* and *Scientists ignore evidence that contradicts their own work* (Reversed).

Responses are given on a 5-point response scale, with responses ranging from 1; *Strongly disagree* to 5 *Strongly agree*. A higher score indicated a greater level of trust in science.

### ***Social Dominance Orientation.***

SDO concerns the idea there are rigid hierarchies in society, where individuals are placed higher than others, and endorsement of Social Dominance is the endorsement of inequality between social groups (Pratto et al., 1994). In Study 3, this measure consists of eight items adapted from work by Ho et al. (2012). Examples of questions include *It is unjust to try to make groups equal* and *An ideal society requires some groups to be on top and others to be on the bottom*. Participants respond using a 7-point Likert scale, with responses ranging from 1 *Strongly oppose* to 7 *Strongly favour*. A higher mean score indicates a higher level of SDO.

### ***Big 5 personality traits***

Study 1 makes use of the BFI-2 (Soto & John, 2017a), which is a 60 item measure of extraversion, neuroticism, agreeableness, conscientiousness, and openness. Study 1 used the neuroticism subscale. This is a 12-item measure with responses based on a 7-point Likert scale with responses ranging from 1; *Strongly disagree* to 7; *Strongly agree*. Scores were reverse coded where appropriate so that a higher score represented a higher level of neuroticism. The mean of this measure was used for analysis.

Study 5 used the BFI-2-S (Soto & John, 2017b), which is a shorter, 15-item measure of the Big 5 Personality traits compared to the full BFI-2. This measure consists of 5 subscales with 3 items for each of the following constructs: Conscientiousness, Agreeableness, Openness, Neuroticism, and Extraversion. Participants were asked to respond to statements such as *I see myself as someone who is sometimes rude to others* (Agreeableness, reversed). *I see myself as someone who worries a lot* (Neuroticism). *I see myself as someone who values artistic, aesthetic experiences* (Openness). *I see myself as someone who is outgoing, sociable* (Extraversion). *I see myself as someone who does things efficiently* (Conscientiousness).

Responses were recorded using a 7-point Likert scale, ranging from 1; *Does not apply to me at all*, to 7; *Applies to me perfectly*. Scores were reverse coded where appropriate and the means of each subscale were used for analysis.

As Study 5 used secondary data, this was the only personality measure available to us. However, despite the shorter measure possessing approximately 10% less reliability than the full Big 5 Personality battery, the sample size used in Study 5 ( $N = 9667$ ) more than compensates for the loss of statistical power associated with this decrease in reliability (Soto & John, 2017b). Furthermore, it is the same measure that has been used in the other studies cited in Study 5, which we were wishing to compare our findings to (e.g. Lee et al., 2017; Lin & Wang, 2020; Murphy et al., 2021).

### ***Intelligence***

In Study 5, general intelligence was measured using a battery composed of the following cognitive tests.

#### ***Numerical ability***

Numerical ability was measured using a task adapted from McArdle and Woodcock (2009). This task consists of 5 items. Participants were asked to answer questions such as *In a sale, a shop is selling all items at half price. Before the sale, a sofa costs £300. How much will it cost in the sale?* The number of correct answers were used for analysis. A higher score indicated a higher level of numeric ability.

#### ***Verbal fluency***

Verbal fluency was measured using a task adapted from Strauss et al. (2006). Participants were asked to list all the animals that they could think of within 60 seconds. The number of correct answers was used for analysis. A higher score indicated a higher level of verbal fluency.

#### ***Subtraction***



Participants were also issued the subtract 7 task, which is a component of the Mini-Mental State Examination (MMSE) (Folstein et al., 1975). Participants were asked to complete a serial subtraction task, where they initially subtracted 7 from 100, and then repeated this process on the resulting numbers on 5 separate occasions (i.e. 93, 86, 79, 72, 65). The number of correct subtractions was used for analysis. A higher number of correct subtractions indicates a higher level of subtraction ability.

### *Memory*

Memory was measured using a word recall task. Participants were given the following message: *The computer will now read a set of 10 words. I would like you to remember as many as you can. We have purposely made the list long so it will be difficult for anyone to remember all the words. Most people remember just a few.* Participants were then asked to immediately recall the words they had been given. Later on, they received this message: *A little while ago you were read a list of words and you repeated the ones you could remember. Please tell me any of the words that you can remember now.* The mean number of correctly remembered words from both tasks was used for analysis. A higher score indicated better recall.

These tests were selected primarily due to their availability in the secondary data used in Study 5. However, they also adequately captured several different facets of intelligence (Kretzschmar et al., 2016), and were moderately associated with one another. The results from our principal component analysis also indicated that the principal component explained .39 of the variance our measure of intelligence, which we used to justify the use of this single component (For more details, see Study 5).

### *Measuring omission bias*

In Study 2, we examined omission bias using the design developed by DiBonaventura and Chapman (2008), which itself was based upon the most common omission bias measure, the so called risk balancing design (Asch et al., 1994; Baron & Ritov, 2004; Ritov & Baron,

1999). This is typically done by presenting participants with a static illness risk (e.g. 10%), and then participants are expected to choose a level of risk they would vaccinate at, typically on a scale from 1% to 10%. If participants indicate a risk below the static risk of the disease, then this is taken as omission bias.

In our study, we made several improvements based on discussions between leading omission bias researchers and their critics (Baron & Ritov, 2004; Connolly & Reb, 2003). Firstly, we accounted for scale length, as previously scales bias themselves towards finding omission bias through limiting scale length from 1% to 10%. This prevents participants from being able to express a commission bias (a preference for action). In our study we allowed participants to respond from 1% to 100%, so that they may express omission bias, no bias, or commission bias. Secondly, we accounted for risk anchoring (i.e. whether they are comparing a static vaccine risk against the disease, or vice versa), by including both ways of anchoring in our conditions (labelled as basic when anchored around the disease and reversed when anchored around the vaccine). Thirdly, we explicitly mention the lack of risks beyond the risk presented by the vaccine or illness, and that there are no monetary or time costs associated with the vaccine, in order to avoid participants considering hidden risks or costs in their decision-making. Given that the risk balancing paradigm has been identified as the best method to elicit omission responses (Yeung et al., 2021), and our modifications to address its methodological criticisms, our design functions as an effective but fairer measure of omission bias.

Participants were required to read a vignette (see Chapter 4 appendix for full details) about a fictitious illness (COVID-23), that has become common in the United States, and is deadly to both older people and children. They were told that there is a 10% chance of contracting the illness naturally, and that there is a vaccination/gene editing/nanotechnology procedure (participants were assigned to only one of these vignettes) that prevents a person from catching the illness (at this stage it was explicitly stated that there are no costs, i.e., money

or time, associated with the procedure). However, there is a risk that the vaccination/gene editing/nanotechnology procedure may cause a person to become more vulnerable to the illness through the process itself (it was made explicit that this is the only risk associated with the procedure). Participants were then asked to indicate, on a slider varying from 0 to 100, the highest level of risk from the vaccination/gene editing/nanotechnology procedure they would accept, for them to be willing to vaccinate/gene edit, or use nanotechnology, on their child.

This is reversed for the participants in the reverse conditions, where the vaccine/gene edit/nanotechnology is given to the populace, but 10% of them become ill with COVID-23 because of the process. Participants are asked to indicate the percentage chance of contracting the illness naturally they would accept, if it meant they avoided having the vaccination/gene editing/nanotechnology procedure. The design of these vignettes was intended to allow participants a chance to express an omission bias, a commission bias, or neither, as well as making it clear that there are no hidden costs or extra risks associated with the vaccination/gene edit/nanotechnology. After indicating their acceptable risk, they were then asked to confirm their responses by responding *True* or *False* to a statement using the percentage they responded with (e.g. *True or false: You would vaccinate your child if the risk of contracting COVID-23 due to the vaccine was 12%. Selecting "False" will put you back to the previous screen to amend your selection. Be careful, as you are only allowed one opportunity to amend your response*). If they selected false, then they were sent back to the previous page to allow them to amend their response but were only allowed to do this once.

## **2.5 The Use of Latent Class Analysis (LCA)**

LCA is a method for examining patterns of responding using categorical data. It sorts the participant into a class according to their pattern of responding. It is a measurement model in a similar way to factor analysis, except that it examines how participants responses cohere into discrete classes, rather than items clustering based on their loadings on a factor. It can use

a mixture of categorical and continuous variables to assign participants according to latent class (e.g. class 1, class 2 or class 3). Participants are sorted into these classes based upon their conditional probabilities of answering in a particular pattern (e.g. the probability of selecting option B of question 1 and option A of question 2), which is then able to be interpreted by the researcher and given labels based on their pattern of responding (e.g. class 1 – strong opposition, class 2 – ambivalent support, or class 3 – fence sitters).

LCA is often used to examine attitudes or opinions that researchers suspect may be more nuanced than a simple for/against dichotomy. For example, this technique has been used to tease apart the nuances of people's attitudes towards controversial issues such as Brexit (G. J. Lewis & de-Wit, 2019), finding that support or opposition to Brexit was motivated by different reasons for each class. For example, in the context of biotechnologies, participants may express moral concerns but positively appraise its safety and effectiveness, and overall hold a positive opinion. This approach is considered a more statistically complex way of examining nuance of opinion compared to similar methods such as K-means clustering (Magidson & Vermunt, 2002), with a higher degree of accuracy when estimating the correct number of classes. LCA also provides a number of fit statistics (such as the Bayes information criterion and entropy) which aid the researcher in determining how many classes to retain, rather than the semi-arbitrary class selection method associated with K-means clustering.

Additionally, it is possible to incorporate multinomial logistic regression into the class estimation process. This simultaneously estimates the class membership accounting for predictor variables, while also providing information on whether the classes significantly differ on the predictor variables. For example, education could be entered into an LCA regression model, which would provide an insight into whether there is a significant difference between those that strongly oppose and strongly support a biotechnology. The benefit of this technique

is that it provides information on the statistically significant differences between classes, rather than having to make inferences from descriptive statistics alone.

However, some considerations are necessary to avoid experiencing issues. Firstly, it is important to consider the number of response items selected for LCA analysis – increasing the number of response items can dramatically increase the number of classes that are estimated. In addition to this, the selection of predictor variables must be quite conservative – as the number of predictor variables and response options to these variables increases, the time it takes to reach class estimation increases exponentially and is more prone to failures or crashes. Thus, when it was used in my research, I attempted to minimise the number of response items to those that would provide the opportunity for interesting divisions of opinion (e.g. Is gene editing morally acceptable?), and were all associated with the latent construct we were attempting to tap into (i.e. Gene editing attitudes).

Class extraction (the number of classes that we chose to interpret) for each model was based on a number of criteria. We first examined the Bayes information criterion (BIC), and took a lower BIC value for each class solution as an indicator of better fit (Nylund et al., 2007). We also examined the class population share (the proportion of the overall sample that is in a particular class), to see if there were any classes with especially small shares, which can be a sign of over extraction. Finally, we examined the interpretability of each class, and whether additional classes provided meaningful or novel additions above the previous models.

# **Chapter 3: Understanding Opposition to Human Gene Editing: A Role for Pathogen Disgust Sensitivity?**

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### **3.1 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 associated with 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.

### 3.2 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 tryphobia 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 (G. J. 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.

### **3.3 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  $\geq .15$ , and ii) an increase in  $R^2$  of  $\geq .02$  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<sup>1</sup>.

### ***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

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

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 scores were constructed following the exploratory factor analyses, as detailed more fully below, with higher scores indicated greater opposition to gene editing. Cronbach’s alpha for gene editing enhancement and treatment were .915 and .841, respectively.

*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. Cronbach's alpha for the vaccination and cultured meat measures were .925 and .834, respectively.

*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. Cronbach's alpha = .762.

*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. Cronbach's  $\alpha = .458$ . Given the low reliability of this measure, results using this measure should be interpreted with caution (despite not being a part of our hypotheses), as the magnitude of any effect size using this measure may be distorted.

*Neuroticism.* Neuroticism was measured using the 12-item scale from the Big Five inventory-2 (BFI-2) (Soto & John, 2017a). 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. Cronbach's  $\alpha = .920$ .

*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. Cronbach's  $\alpha = .859$ .

*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. Cronbach's  $\alpha = .881$ .



*Religiosity.* Religiosity was measured using the mean score of three items used in previous work (G. J. 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. Cronbach’s alpha = .919.

*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. Cronbach’s alpha = .815.

*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. Cronbach’s  $\alpha = .870$ .

*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.

### **3.4 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.

### **3.5 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:  $\alpha=.92$  and  $\alpha=.84$ , 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 ( $\beta=.16$ ,  $p=.006$ ), more educated ( $\beta=.18$ ,  $p<.001$ ), female ( $\beta=.16$ ,  $p=.003$ ),

and less sensitive to pathogen disgust ( $\beta = -.17$ ,  $p = .002$ ) 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	<b>-.11</b>	-.04	-.07													
5. Risk aversion	<b>.26</b>	<b>.13</b>	-.07	<b>.23</b>												
6. Political ideology	<b>.18</b>	-.03	<b>-.23</b>	.00	.04											
7. Neuroticism	<b>-.23</b>	<b>.13</b>	-.09	<b>.39</b>	.06	<b>-.12</b>										
8. Religiosity	-.02	.01	<b>.12</b>	.04	-.04	<b>.12</b>	-.09									
9.Trust in scientists	<b>-.16</b>	-.07	.10	.00	-.01	<b>-.13</b>	-.04	<b>-.21</b>								
10. Genetic knowledge	-.07	.02	.04	-.04	.02	-.02	.01	-.06	.02							
11.Vaccination opposition	.07	-.02	<b>-.26</b>	-.07	.05	.09	.00	.08	<b>-.31</b>	<b>-.15</b>						
12. Cultured meat opposition	.10	<b>.22</b>	.02	<b>.11</b>	<b>.14</b>	.05	.10	<b>.11</b>	<b>-.25</b>	-.03	<b>.18</b>					
13. GM crop opposition	.05	.10	-.07	.04	.06	.09	.04	.09	<b>-.30</b>	-.07	<b>.21</b>	<b>.58</b>				
14. Opposition to GE-treatment	.04	.02	<b>.17</b>	.08	-.03	-.07	.05	<b>.14</b>	<b>-.29</b>	.00	.08	<b>.27</b>	<b>.14</b>			
15. Opposition to GE-enhancement	<b>.11</b>	<b>.13</b>	<b>.17</b>	.01	-.04	-.05	.08	.05	-.09	.06	-.10	<b>.19</b>	.06	<b>.50</b>		
16. Core disgust sensitivity	.08	<b>.19</b>	<b>-.13</b>	<b>.15</b>	<b>.28</b>	<b>.15</b>	<b>.12</b>	.05	.04	-.09	.10	<b>.23</b>	<b>.15</b>	<b>-.11</b>	-.10	
17. Pathogen disgust sensitivity	-.03	.09	<b>-.12</b>	<b>.17</b>	<b>.23</b>	.09	.09	.04	.08	-.07	.05	<b>.12</b>	<b>.15</b>	<b>-.20</b>	<b>-.18</b>	<b>.47</b>

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.

Variable	<u>GE-enhancement</u>		<u>GE-treatment</u>	
	$\beta$	p	$\beta$	p
Age	<b>.16</b>	.006	.02	.774
Sex	<b>.16</b>	.003	.03	.520
Knowledge	.06	.271	-.00	.937
Educational attainment	<b>.18</b>	<.001	<b>.19</b>	<.001
Resistance to change	.05	.368	<b>.13</b>	.027
Risk taking	-.06	.265	-.01	.826
Trust in science	-.06	.267	<b>-.29</b>	<.001
Neuroticism	.11	.069	.02	.689
Pathogen disgust sensitivity	<b>-.17</b>	.002	<b>-.18</b>	.001
F	<b>5.166</b> (p<.001)		<b>7.518</b> (p<.001)	
R <sup>2</sup> /Adjusted R <sup>2</sup>	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<sup>2</sup> of the model for enhancement was 0.15. Those who were more resistant to change ( $\beta=.13$ ,  $p=.027$ ), more educated ( $\beta=.19$ ,  $p<.001$ ), less trusting in science ( $\beta=-.29$ ,  $p<.001$ ), and lower in pathogen disgust sensitivity ( $\beta=-.18$ ,  $p=.001$ ) 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 negative (for both GE-treatment and GE-enhancement) rather than positive, 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  $\beta > -.18$ , 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, ( $\beta = .16$ ,  $p = .010$ )).

*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 ( $\beta = -.30$ ,  $p < .001$ ) and higher in pathogen disgust sensitivity ( $\beta = .16$ ,  $p = .003$ ) 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 ( $\beta=.19$ ,  $p<.001$ ) and less trusting in science ( $\beta=-.24$ ,  $p<.001$ ) were more likely to oppose cultured meat. Pathogen disgust sensitivity showed a non-significant positive association ( $\beta=.10$ ,  $p=.072$ ). 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

Variable	<u>GM crops</u>		<u>Cultured meat</u>	
	$\beta$	p	$\beta$	p
Age	.01	.833	.08	.167
Sex	.06	.272	<b>.19</b>	<.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	<b>-.30</b>	<.001	<b>-.24</b>	<.001
Neuroticism	.00	.937	.04	.490
Pathogen disgust sensitivity	<b>.16</b>	.003	.10	.072
F	<b>5.35</b> ( $p<.001$ )		<b>6.43</b> ( $p<.001$ )	
$R^2$ /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 ( $\beta=.14$ ,  $p = .017$ ), 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 association with core disgust sensitivity ( $r=-.11$ ,  $p=.039$ ). Opposition to GE-enhancement did not show a significant association 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 ( $\beta=-.10$ ,  $p=.072$ ), whereas GE-

enhancement was significant ( $\beta = -.12$ ,  $p = .039$ ) (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).

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

Variable	<u>GM crops</u>		<u>Cultured meat</u>	
	$\beta$	p	$\beta$	p
Age	-.01	.906	.06	.261
Sex	.05	.384	<b>.17</b>	.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	<b>-.30</b>	<.001	<b>-.25</b>	<.001
Neuroticism	.00	.952	.03	.624
Core disgust sensitivity	<b>.14</b>	.009	<b>.19</b>	<.001
F	<b>5.08</b>		<b>7.64</b>	
	(p<.001)		(p<.001)	
R <sup>2</sup> /Adjusted R <sup>2</sup>	0.12/0.10		0.17/0.15	

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

### 3.6 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* associated 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 not associated with political ideology.

Pathogen disgust sensitivity was positively associated 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., 2021; 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 associated with 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 associated – 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 associated, 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.

# **Chapter 4: Opposition to Novel Biotechnologies:**

## **Testing An Omission Bias Account**

**Isaac N. Halstead, Gary J. Lewis, Ryan T. McKay**

## 4.1 Abstract

The COVID-19 pandemic has taken a significant toll on the global population, but biotechnology has a big role to play in arresting the spread of the virus. However, the adoption of biotechnologies may be held back by cognitive biases. In particular, omission bias – the observation that people are more sensitive to the negative outcomes of acting than to those of failing to act – has been suggested to influence vaccination decision making. Omission bias might also underpin attitudes towards newer biotechnologies. In this study, we explored the role of omission bias in vaccination, gene editing, and nanotechnology decision-making using a US sample ( $N = 613$ ). We examined participant's risk choices across these three biotechnologies, focussing on the point at which they would use the respective biotechnology to treat a fictional illness (COVID-23). Although our findings are nuanced, overall we observed evidence consistent with an omission bias across all three biotechnologies.

## 4.2 Introduction

We are entering a brave new world of biotechnology, allowing unprecedented control over the course of our own development and unrivalled capacity to combat biological hazards. Biotechnology, for instance, is at the forefront of the global responses to the COVID-19 pandemic (Callaway, 2020). Though the most important of these responses is the development of novel vaccines to provide protection against disease and/or transmission of COVID-19 (The World Health Organization, 2021), other biotechnologies such as gene editing (the manipulation of DNA) (Berber et al., 2020; Straiton, 2020) and nanotechnology (the manipulation of matter on an atomic and molecular scale) (Khurana et al., 2021) may also play an important role.

Despite their potential benefits, these biotechnologies also present a range of concerns – challenges to our sense of self, concerns about societal change, and fears of their unintended side effects (Akin et al., 2019; Macoubrie, 2006; Robillard et al., 2014; Xiang et al., 2015). Public attitudes toward gene editing and nanotechnology parallel those towards vaccination, where people who oppose the use of vaccines often cite concerns regarding the safety of vaccination and the possibility of unintended side effects (Horne et al., 2015). However, the probability of experiencing vaccination side effects is vastly lower than the risks associated with contracting an illness (The World Health Organization, 2019b), so researchers have investigated psychological biases that motivate anti-vaccination attitudes (Asch et al., 1994; Baron & Ritov, 2004; Brown et al., 2010; DiBonaventura & Chapman, 2008).

Here we focus on the vaunted *omission bias*, the tendency to evaluate harms caused through inaction as less morally wrong and blameworthy than those caused through action (Baron & Ritov, 2004; Ritov & Baron, 1990; Yeung et al., 2021). Omission bias has been observed in a range of situations, including medical care decisions (Aberegg et al., 2005), moral

decision making (DeScioli et al., 2012), and social interactions (Pittarello et al., 2016); and has been highlighted as one of the major cognitive barriers to vaccination uptake (Miton & Mercier, 2015).

However, despite the abundance of articles that discuss the importance of omission bias in decision making (e.g., Brannigan et al., 2020; Costa-Font et al., 2021; Halpern et al., 2020; Mello et al., 2020; Miton & Mercier, 2015; Trueblood et al., 2021), there is a disproportionately small evidence base supporting the existence of the bias, especially in the area of vaccination (see Yeung et al., 2021). In concluding their recent meta-analytic review of omission bias research, Yeung et al. call for more highly powered, pre-registered work on omission bias in the health-medical domain. In the present study we answer this call. We leverage insights from discussions within the existing literature (Baron & Ritov, 2004; Connolly & Reb, 2003) to re-examine omission bias in the vaccination domain, as well as expanding into two new biotechnological domains: gene editing and nanotechnology. We also explore a range of attitudinal and decision-making predictors of omission bias.

We hypothesised that participants would exhibit omission bias across the vaccination, gene editing and nanotechnology domains (H1); that this tendency would be predicted by opposition to these respective technologies (H2); and that bias in general (whether omission bias or *commission* bias) would be negatively associated with cognitive reflection (H3), positively associated with aversion, anxious, and intuitive decision-making styles (H4), and negatively associated with vigilant decision-making style (H5).

### **4.3 Method**

#### **Participants**

To determine our sample, we used Gpower 3.1 (Faul et al., 2007). We based sample size calculations on a single t-test against a constant (10%; see design section below for context), to detect a Cohen's *d* of .3, with 80% power and an alpha of .05 (two-tailed). This

gave us a recommended sample size of 90, which was then multiplied by six (to account for each of our conditions), giving a total of 540 participants across all the groups. We then added approximately 15% to account for participants that might be removed due to exclusion criteria, giving us a final sample goal of 618 (103 per condition). For the correlation portion of the study, our sample was powered to detect  $r = .2$  with 80% power (two-tailed) if the reverse/basic conditions (see below) are aggregated, or  $r = .3$  with 80% power (two-tailed) if the reverse/basic conditions are not aggregated. Our participants were sampled from Prolific, with the requirement that they be current residents of the United States of America.

In a deviation from our planned exclusion criteria, we removed eight participants whose coordinates at time of participating indicated that they were in other countries. We also removed 11 participants who gave nonsensical open text responses, or responses that were exactly the same as other participants and who had exactly the same geographical coordinates as another participant, based on the possibility that they were bots. After replacing these participants, removing any participants that failed to complete the entire battery of tests ( $n=4$ ) and one more potential bot, our final sample was 613.

Our sample was on average 33.7 ( $SD=11.7$ ) years old, 45.9% female, 52.9% male, and 1.1% identified as other. They were also well educated, with the median level of achievement being a bachelor's degree, and were predominantly white (73.5%), with a minority that identified as Black/African American (14%), Native American (1.1%), Asian (7.5%), Native Hawaiian/Pacific Islander (.3%), or Other (3.6%).

## **Design**

Omission bias in the vaccine domain is often measured using a hypothetical scenario describing the outbreak of an illness and a vaccine that prevents the illness. Participants decide what level of risk from vaccination side effects they would be willing to tolerate in order to vaccinate. When participants choose a level of vaccination risk that is lower than the specified

illness risk, this is taken as indicative of omission bias (e.g., in the context of a 5% risk of illness, only being willing to vaccinate if the risk of side effects is 3% or lower).

We used this risk balancing paradigm, adapting materials developed by DiBonaventura and Chapman (2008), with several improvements based on subsequent developments in the literature (Baron & Ritov, 2004; Connolly & Reb, 2003), such as a longer response scale (0-100) and an explicit clarification of the lack of hidden risks/costs beyond what is mentioned in the vignette. We also included a basic condition (where the risk participants compare to is anchored around the virus), and a reverse condition (where the risk is anchored around the biotechnology) for each biotechnology application. In the basic condition a risk choice lower than 10%, on a risk scale of 0-100, would be interpreted as evidence of omission bias, whereas in the reversed condition a risk choice higher than 10% would be evidence of omission bias. The study thus consisted of six conditions (a basic and reversed condition for each of the three biotechnologies).

## **Measures**

### *Omission bias*

Participants were required to read a vignette (see Appendix for full details) about a fictitious illness (COVID-23), that has become common in the United States, and is deadly to both older people and children. They were told that there is a 10% chance of contracting the illness naturally, and that there is a vaccination/gene editing/nanotechnology procedure (participants were assigned to only one of these vignettes) that prevents a person from catching the illness (at this stage it was explicitly stated that there are no costs (i.e., money or time) associated with the procedure). However, there is a risk that the vaccination/gene editing/nanotechnology procedure may cause a person to become more vulnerable to the illness through the process itself (it was made explicit that this is the only risk associated with the procedure). Participants were then asked to indicate, on a slider varying from 0 to 100, the



highest level of risk from the vaccination/gene editing/nanotechnology procedure they would accept, for them to be willing to vaccinate/gene edit, or use nanotechnology, on their child.

This was reversed for the participants in the reverse conditions, who were told the vaccine/gene edit/nanotechnology is given to the populace, but that 10% of them become ill with COVID-23 because of the process. Participants in the reverse conditions were asked to indicate the percentage chance of contracting the illness naturally that they would accept, if it meant they avoided having the vaccination/gene editing/nanotechnology procedure. The design of these vignettes was intended to allow participants a chance to express an omission bias, a commission bias, or neither, as well as making it clear that there are no hidden costs or extra risks associated with the vaccination/ gene edit/nanotechnology. After indicating their acceptable risk, they were then asked to confirm their responses by responding *True* or *False* to a statement using the percentage they had responded with. If they selected false, they were sent back to the previous page to allow them to amend their response.

Participants in the gene editing conditions were given information regarding gene editing beforehand, to ensure that they understood what the biotechnology was. The gene editing information was adapted from related work (Weisberg et al., 2017), and read as follows: *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. The technology could also be used to improve genes to enhance normal traits.*

Similar information was provided in the nanotechnology conditions, which read as follows: *Recently, scientists have figured out a way to use nanotechnology – which involves manipulating matter on the scale of atoms and molecules – in medicine. This technology means they might be able to perform microsurgeries or deliver medications to specific areas of the*

*body to treat or prevent health problems. This technology could also be used to enhance normal traits.*

#### *Demographics*

Participants were asked to indicate their age, sex, race, religious denomination, and highest level of education.

#### *Cognitive reflection task*

This measure was taken from work by Frederick (2005) and consists of 3 items intended to test a person's ability to inhibit an intuitive but incorrect answer in favour of a more effortful but correct one. An example of this measure is *A bat and a ball cost \$1.10 in total. The bat costs \$1.00 more than the ball. How much does the ball cost?* Correct answers were summed for analysis purposes. The Cronbach's alpha for cognitive reflection showed it was a reliable measure ( $\alpha = .76$ ).

#### *Attitudes towards vaccination, gene editing, and nanotechnology*

Vaccination attitudes were measured using a measure that we created but were based upon themes that arise in vaccination literature (Bond & Nolan, 2011; Hornsey et al., 2018; Marlow et al., 2007). This is a 5-item measure that is scored on a 5-point Likert scale, with responses ranging from 1 *Strongly agree* to 5 *Strongly disagree*. An example of the items is *I trust those who administer vaccinations*. Items were reverse coded where necessary so that a higher score indicates more opposition to vaccines. The mean scores of these items were used for analyses.

Gene editing and nanotechnology attitudes were likewise measured using five items that we created, but which were based upon existing themes in gene editing research (Robillard et al., 2014; Xiang et al., 2015). Participants responded using a 5-point Likert scale, with responses ranging from 1 *Strongly agree* to 5 *Strongly disagree*. Examples of these items include *I think gene editing is immoral*. Scores were reverse coded where necessary so that

higher scores indicate opposition to the respective biotechnology. Scores were averaged by biotechnology type for analyses. The Cronbach's alphas for vaccination, gene editing, and nanotechnology attitudes showed they were reliable measures ( $\alpha = .79$ ,  $\alpha = .79$ , and  $\alpha = .71$ , respectively).

#### *Decision-making style*

This measure was taken from Leykin and DeRubeis (2010). We chose the avoidant, anxious, vigilant, and intuitive decision-making style subscales. These measures consist of 5 items each, for a total of 20 items, with responses measured on a 5- point Likert scale, with responses ranging from 1 *Strongly disagree* to 5 *Strongly agree*. Examples of each type of decision-making style include *I put off making many decisions because thinking about them makes me uneasy* (avoidant), *When making a decision, I am afraid that I might be wrong* (anxious), *My decision making requires careful thought* (vigilant), *When I make a decision, I trust my inner feelings and reactions* (intuitive). Scores for each of these decision-making styles were averaged for the purposes of analysis. The Cronbach's alphas for avoidant, anxious, vigilant, and intuitive decision-making styles showed they were reliable measures ( $\alpha = .88$ ,  $\alpha = .89$ ,  $\alpha = .85$ , and  $\alpha = .85$ , respectively).

## **4.4 Results**

### **Results**

Summary statistics are presented in Table 1. Due to the non-normality and asymmetry of the risk choice distributions (see Figure 1), we performed non-parametric equivalents of our planned analyses<sup>2</sup> (one-sample sign tests and Spearman correlations, instead of one-sample t-

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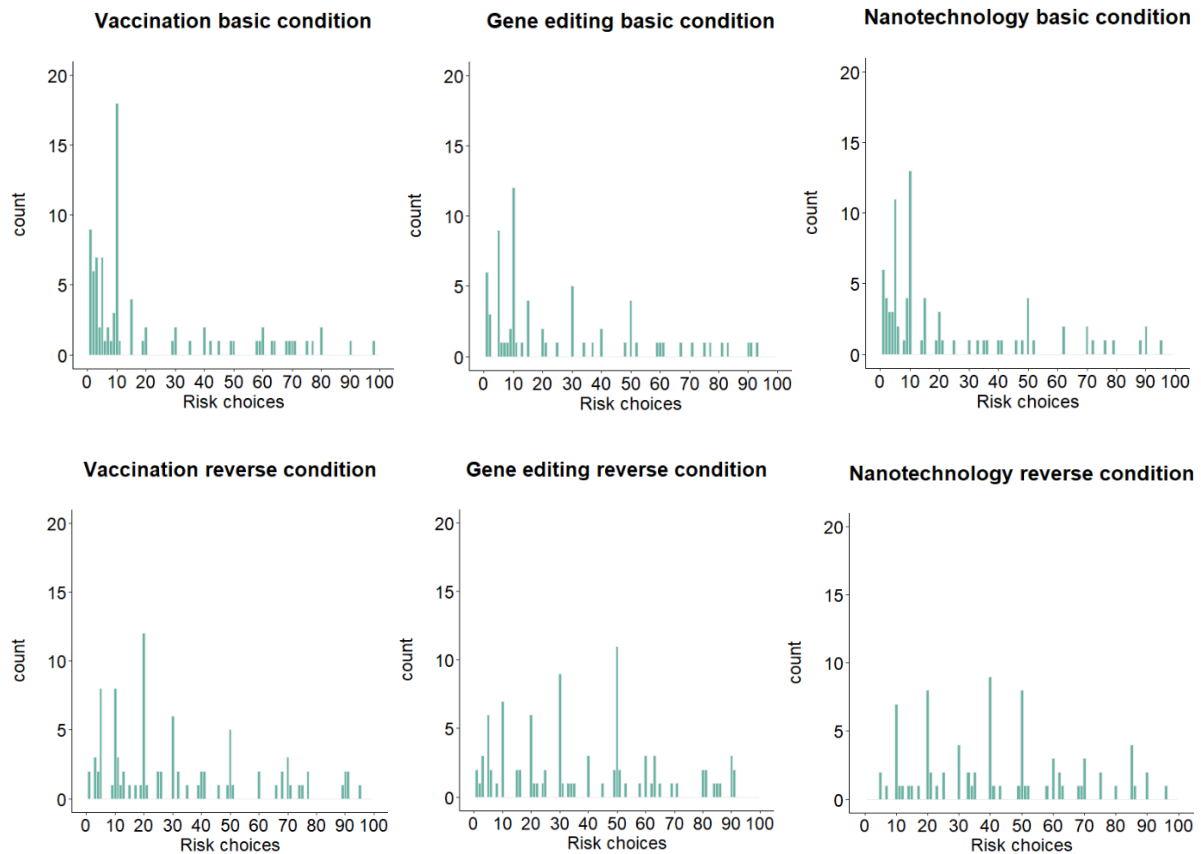
<sup>2</sup> For transparency we report the pre-registered parametric analyses in the supplementary materials.

tests and Pearson correlations). Given the nature of these distributions, we report additional exploratory analyses below.

**Table 1.** Descriptive statistics for main study variables.

Variable	Mean (SD)	Median*
Vaccination basic risk choice	19.8 (26.4)	10
Vaccination reverse risk choice	33 (30.4)	20
Gene editing basic risk choice	19.9 (26.7)	9.5
Gene editing reverse risk choice	35.2 (28.3)	30
Nanotechnology basic risk choice	20.3 (26.5)	9.5
Nanotechnology reverse risk choice	35.9 (28.7)	33
Vaccination opposition	1.9 (0.9)	
Gene editing opposition	2.8 (0.9)	
Nanotechnology opposition	2.5 (0.8)	
Vigilant decision making	4.3 (0.7)	
Avoidant decision making	2.9 (1.1)	
Anxious decision making	3.2 (1.0)	
Intuitive decision making	3.4 (0.9)	
Cognitive reflection	1.5 (1.2)	1

\* Medians are reported where variables are not normally distributed.



**Figure 1.** Histograms of risk choice for each condition.

### Pre-registered analyses using non-parametric tests

#### *Sign tests*

**H1)** *Participants will choose risks significantly lower than 10% in the basic condition and significantly higher than 10% in the reversed condition. This pattern will be found across vaccination (H1a), gene editing (H1b) and nanotechnology (H1c) domains.*

We conducted one-sample sign tests against a constant of 10% to examine whether participants' risk choices significantly differed from the optimal risk choice. Participants who chose risks significantly lower than 10% in the basic condition and significantly higher than 10% in the reversed condition were interpreted as exhibiting omission bias.

The median risk choice indicated the presence of omission bias in all reverse conditions ( $>10\%$ , all  $ps < .001$ ). Risk choices were not significantly different from the optimum in any of the basic conditions (all  $ps > .05$ ).

### *Spearman correlations*

**H2)** *Opposition to vaccination (H2a), gene editing (H2b), and nanotechnology (H2c), as measured by our biotechnology attitude items, will predict greater tendency towards exhibiting omission bias, in their respective biotechnology scenarios.*

We found positive associations between biotechnology opposition and a greater tendency to exhibit omission bias in the vaccination reverse ( $r_s = .26$ ;  $p = .008$ ), and nanotechnology reverse ( $r_s = .36$ ;  $p < .001$ ) conditions. The rest of our predicted associations were non-significant (for all results see Table 2).

**Table 2.** Biotechnology opposition and omission bias correlations.

	Vaccination opposition	Gene editing opposition	Nanotechnology opposition
Vaccination basic	0.01		
Vaccination reverse	0.26*		
Gene editing basic		0.07	
Gene editing reverse		0.16	
Nanotechnology basic			0.18
Nanotechnology reverse			0.36**

Note. \* =  $p < .05$ , and \*\* =  $p < .001$ .

**H3)** *Higher scores on the cognitive reflection task will correspond with a lower absolute deviation from the optimal risk (10%) in the vaccination (H3a), gene editing (H3b), and nanotechnology conditions (H3c).*

As predicted, cognitive reflection was negatively associated with absolute deviation from the optimal risk choice in the nanotechnology basic condition ( $r_s = -.25$ ;  $p = .015$ ). The rest of our predicted associations were non-significant (for all results see Table 3).

**H4)** *Higher scores on avoidant, anxious, and intuitive decision-making styles will correspond with a greater absolute deviation from the optimal risk (10%) in the vaccination (H4a), gene editing (H4b), and nanotechnology (H4c) conditions.*

As predicted, higher avoidant decision-making scores were positively associated with deviating from the optimal risk choice in the gene editing reverse condition ( $r_s = .28$ ;  $p = .005$ ). In addition, higher intuitive decision-making scores were positively associated with deviating from the optimal risk choice in the gene editing basic and nanotechnology basic conditions ( $r_s = .24$ ;  $p = .017$ ;  $r_s = .27$ ;  $p = .008$ , respectively). The rest of our predicted associations were non-significant (for all results see Table 3).

**H5)** *Higher scores on vigilant decision-making style will correspond with a lower absolute deviation from the optimal risk (10%) in the vaccination (H5a), gene editing (H5b), and nanotechnology (H5c) conditions.*

None of the predicted relationships for this hypothesis were significant (see Table 3 for full details).

**Table 3.** Spearman correlations for decision-making style, cognitive reflection, and absolute deviation from optimal risk choice.

	Avoidant	Anxious	Vigilant	Intuitive	Cognitive reflection
Avoidant					
Anxious	0.78**				
Vigilant	-0.01	0.16**			
Intuitive	0.13*	0.10*	0.01		
Cognitive reflection	0.05	0.02	0.11*	-0.20**	
Vaccination basic	0.14	0.18	-0.17	0.14	-0.04
Vaccination reverse	-0.04	-0.06	-0.13	0.10	0.02
Gene editing basic	-0.02	-0.03	-0.12	0.24*	-0.19
Gene editing reverse	0.28*	0.12	0.01	0.15	0.14
Nanotechnology basic	0.14	0.03	-0.06	0.27*	-0.25*

Nanotechnology reverse	0.08	0.10	-0.19	0.18	-0.10
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\* =  $p < .05$ ; \*\* =  $p < .001$ . For the risk choice variables, omission is denoted by positive correlations in the reverse conditions and negative correlations in the basic conditions.

## Exploratory analyses

### *Eliminating extreme responders*

One striking feature of the histograms presented in Figure 1 is that responses are not tightly bound around the optimal response of 10% (see Table 4 for detailed percentage responses within specified ranges). For example, a substantial portion of respondents in the basic conditions reported percentages greater than 20%. At face value this suggests their preference for the relevant biotechnology is so strong that they would accept more than double the risk of naturally acquiring the illness. Similarly, a large number of respondents in the reverse conditions are seemingly so opposed to biotechnology that they would be willing to endure a 50%+ risk of illness via normal channels of infection. One possibility is that these extreme responses are due to inattentiveness or to miscomprehension of our risk choice paradigm. Recent work indicates that even commonly used measures produce skewed distributions, with scores artificially inflated by inattentive responding (Chandler et al., 2020; Ophir et al., 2020).

**Table 4.** Proportion of responses in the risk selection task.

Condition	Less than 10%	Chose 10%	Greater than 10%	Equal to or less than 20%	Greater than 20%
Vaccination basic	49.52%	17.14%	33.33%	74.29%	25.71%
Vaccination reverse	23.81%	7.62%	68.57%	51.43%	48.57%
Gene editing basic	50.00%	12.00%	38.00%	70.00%	30.00%



Gene editing reverse	23.30%	6.80%	69.90%	39.81%	60.19%
Nanotechnology basic	50.00%	13.27%	36.73%	72.45%	27.55%
Nanotechnology reverse	19.80%	6.93%	73.27%	39.60%	60.40%

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As we did not include any deliberate checks of participant (in)attention in our design, we conducted exploratory risk choice analyses where we designated scores in excess of 20% as extreme responses, and treated these as a proxy for inattention. Specifically, we elected to truncate our data, removing any participant whose risk score exceeded 20%. Doing so enabled us to combine basic and reversed conditions (reversing the latter) for each biotechnology, which provided our biotechnology conditions with symmetry around 10%. Sign tests conducted on the corresponding median risk choices indicated the presence of omission bias (risk responses significantly lower than 10%) in the vaccination (Median = 8;  $p = .001$ ), gene editing (Median = 6;  $p = .004$ ), and nanotechnology (Median = 8;  $p = .001$ ) combined conditions.<sup>3</sup>

### ***Testing the attitudinal explanation for the presence of omission bias***

The case could be made that risk choices indicative of omission bias were made so as to signal simple dislike of a particular biotechnology, rather than being reflective of an underlying cognitive bias. To investigate this alternative explanation, we carried out a series of one sample t-tests against the midpoint (3 - which represents attitudes neither for nor against

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<sup>3</sup> See the supplementary material for risk choice analyses of truncated data across the six conditions (i.e., without combining the basic and reversed conditions for each biotechnology domain), and for correlational analyses of truncated data (with and without combining basic and reversed conditions).

biotechnology) on each biotechnology attitude scale. If participants expressed attitudes in favour of their respective biotechnology (despite exhibiting omission bias), we interpreted this as evidence of attitudes being unable to completely explain the overall presence of omission bias in our sample. We found that participants significantly differed (all  $p < .001$ ) from 3, in favour of supporting vaccination, gene editing, and nanotechnology. Thus, despite choosing risk choices in line with omission bias, participants were, overall, supportive of biotechnologies.

To examine this finding in further detail, we examined the percentage of participants that exhibited omission bias and held positive attitudes towards their respective biotechnology. Overall, 55.3%, 54.05% and 55.86%, of participants expressed omission bias in the vaccination, gene editing, and nanotechnology combined conditions, respectively. Of those who exhibited omission bias, 87.67%, 56.67%, and 70.97% of participants in the vaccination, gene editing, and nanotechnology combined conditions respectively, held positive attitudes towards biotechnology. From this examination, we conclude that the majority of the risk choices in the sample are not a simple expression of dislike for their respective biotechnology.

To summarise, we observe some tentative support for our key hypothesis – that participants would display an omission bias across three biotechnology domains. With the full range of responses included, this finding emerged only in the reverse conditions. Once putatively inattentive responders were removed, however, and basic and reversed conditions were combined (reversing the latter), we observed significant omission bias across all three biotechnology domains.

Through exploring the attitudes of our participants, we also conclude that the presence of omission bias was at least partially independent of participants' attitudes. However, although

the results for our correlational hypotheses were mixed overall, at least some of these omission bias responses are consistent with an individual's attitudes in a correlational sense.

#### 4.5 Discussion

Our primary goal in this study was to examine the role of omission bias in three biotechnology domains: vaccination, gene editing, and nanotechnology. We also examined whether opposition to biotechnology predicted a greater tendency to exhibit omission bias, and whether measures of cognitive reflection and decision-making style predicted tendency to exhibit bias (omission or commission). Our pre-registered analyses revealed partial evidence for an omission bias in the reverse conditions. Evidence for the role of biotechnology opposition in tendency to exhibit omission bias was mixed, as was cognitive reflection and decision-making style in tendency to exhibit bias. Finally, when we truncated and combined conditions by biotechnology, we found consistent evidence of omission bias across all three biotechnologies. However, as these analyses were not pre-registered, they should be interpreted with a degree of caution.

These findings may reflect the lability of the omission bias effect, as mentioned by Baron and Ritov (2004). The suggestion of omission bias being labile is supported by the findings of Yeung et al. (2021), who identified a number of moderators that can influence the magnitude of omission bias. Given the present study's use of multiple conditions and biotechnologies, it is perhaps unsurprising that we see somewhat mixed results. However, our findings appear to show a general preference for inaction.

Previous research has found that some paradigms are better suited to eliciting omission than others. For example, using choice designs (e.g. giving participants static vaccination/illness risks and asking if they would/would not vaccinate), Connolly and Reb (2003) and Zikmund-Fisher et al. (2006) found evidence of *commission* bias. Our design was

based instead on the risk-balancing paradigm, which generally favours finding omission bias (Asch et al., 1994; DiBonaventura & Chapman, 2008; Ritov & Baron, 1990), however we made several changes in an attempt to remove previous methodological flaws, such as constrained scale length, risk anchoring, and lack of explicit negative outcome severity. When accounting for these methodological issues, we continue to find evidence for omission bias.

Taken at face value, these results have important implications for the current pandemic, and the way that vaccine and virus risks are framed. It appears that a large number of people require a risk premium before they are willing to vaccinate. Given the current attempts by conspiracy theorists to simultaneously downplay the risk of the virus, and exaggerate the risks of the vaccine (Rooke, 2021), which can increase vaccination hesitancy (Ruiz & Bell, 2021), a desire for a risk premium before vaccinating could be holding back significant proportions of the population from taking action, based on misinformation or distorted risk balancing trade-offs. This issue is exacerbated when we account for the large number of participants in our sample that seemingly did not understand the risk balancing paradigm, which worryingly, may also translate to real-world decision making.

This lack of understanding is an important methodological issue with risk balancing paradigms, that has not been acknowledged sufficiently in previous literature. As most previous risk balancing studies have constrained possible responses within a much more limited range, it may be that prior designs have concealed substantial rates of inattentive responding. The lability of omission bias findings may thus be partially due to the noise from inattentive responders. When we truncated and combined the scales, thus removing a large proportion of potentially inattentive responders, we found much stronger, more consistent evidence for omission bias. Given recent evidence that inattentive responding can distort scores in other

commonly used paradigms (Chandler et al., 2020; Ophir et al., 2020), we recommend that future studies of omission bias take pains to identify and remove inattentive responders.

During the COVID-19 pandemic, there have been a number of articles that have cited the importance of omission bias in decision-making associated with COVID-19 (e.g., Brannigan et al., 2020; Costa-Font et al., 2021; Halpern et al., 2020; Mello et al., 2020; Trueblood et al., 2021). As noted earlier, however, that the role of omission bias in decision making has become something of a received view is belied by the relatively scant evidence base. Indeed, the past decade or so has seen a curious omission of research into the omission bias, and to our knowledge the present study is the only one to have empirically examined omission bias in the context of COVID. In closing, therefore, we echo the sentiments of Yeung et al., (2021), who call for more research into the omission bias. Given its potential importance for public health, a bias toward research inaction in this domain may be a substantial missed opportunity.

# **Chapter 5: The Role of Social Dominance Orientation in Attitudes Towards Animal Centred Gene Editing**

**Isaac N. Halstead and Ryan T. McKay**

### **5.1 Abstract**

The use of animal centred gene editing has progressed more rapidly than that of human centred gene editing and promises a wider range of applications such as the control of invasive pest populations. However, the adoption of gene editing techniques is contingent upon public support. Previous research indicates that Social Dominance Orientation (SDO) is associated with willingness to exploit animals, which we suggest may also be associated with willingness to use gene editing and gene drive to control pest populations. Consequently, we examined SDO, as well as a range of other possible predictors of willingness to use gene editing to control pest populations, in a large New Zealand sample (N = 8199). We also examined predictors of willingness to use selective breeding, to test whether the relationship between SDO and gene editing attitudes would generalise to other biotechnological pest control techniques. Using a mixture of correlational and multinomial logistic regression analyses we identified SDO, Human Exceptionalism, Environmental Concern, and Synthetic Aversion as independent predictors of attitudes towards gene editing and gene drive for pest control. These findings are consistent with SDO playing a role in moral distancing strategies, which allow humans to support the use of gene editing techniques to control pest populations. The need to explore gene editing that is beneficial to animals is also discussed.

## 5.2 Introduction

Gene editing is a rapidly progressing technology that has the potential to treat a number of genetic disorders in humans, using CRISPR-Cas 9 (Oude Blenke et al., 2016). Gene editing technologies, however, also have a number of potential applications for non-human animals. Gene drives, for instance – which are applications of gene editing technology – involve modifying genes so that a desired gene (e.g., a gene creating sterile offspring) is passed on at a rate higher than the typical 50% found in conventional reproduction. This technology can be used to control pest populations such as mosquitoes (Kirk et al., 2019).

However, gene editing and its associated applications require support from the public if they are to be used. The gene editing of animals appears to trigger similar opposition from the public to that elicited by other biotechnologies (Funk & Hefferon, 2018), such as genetically modified (GM) crops – which have not seen widespread adoption due to concerns expressed about their safety (Scott et al., 2016). At present, the population control of disease-carrying species such as mosquitoes, which present a significant health threat to much of the world (The World Health Organization, 2019a), is being constrained due to psychological concerns, rather than the practical limitations of the technology (Rudenko et al., 2018).

Initial studies indicate apprehension about animal gene editing, with concerns regarding the safety and morality of editing animal genomes arising as themes within the literature (Lunshof, 2015; Ormandy & Schuppli, 2014). A recent survey by Funk and Hefferon (2018) revealed that attitudes towards animal gene editing are nuanced, with a minority (29%) of participants indicating that editing mosquitoes to prevent the spread of disease would be taking technology too far, whereas a majority (77%) of participants thought editing aquarium fish to cause them to glow was taking technology too far. The use of gene editing to increase meat



production was especially divisive; 55% of participants thought using gene editing to increase meat production was taking technology too far (Funk & Hefferon, 2018).

It is important to understand what underlies these attitudes, given the promise that animal centred gene editing presents and its growing importance in the biotechnology sector (Jones et al., 2019). To date, however, notwithstanding some formative research (Critchley et al., 2019), we know little about the psychological predictors of animal centred gene editing attitudes. In the present study we seek to address this deficit by examining several plausible predictors of attitudes towards animal centred gene editing, using a large secondary dataset from New Zealand that has previously been used to examine attitudes towards novel pest control techniques (MacDonald et al., 2020).

Firstly, we wish to examine the role of Social Dominance Orientation (SDO). SDO is the belief that a rigid natural hierarchy exists in society – with some people being naturally higher in this hierarchy. Those who strongly believe in this hierarchy appear to be more sensitive to differences between human groups, and more inclined to derogate perceived outgroups (Dru, 2007; Pratto & Shih, 2000). Individuals high in SDO are also more likely to believe that humans are superior to animals, which may allow them to exploit animals without guilt (Dhont et al., 2016; Dhont & Hodson, 2014). Such individuals may also be more likely to believe that the use of gene editing to control animal populations is acceptable.

Secondly, we wish to examine the role of New Ecological Paradigm related constructs. The New Ecological Paradigm is a scale that consists of a mix of pro-environmental attitudes (with the pro-environmental attitudes being labelled here as Environmental Concern) and beliefs about humanity's ability to mitigate environmental issues and shape nature, and having the right to do so (labelled here as Human Exceptionalism). While Human Exceptionalism is conceptually similar to SDO, the Human Exceptionalism construct is more directly associated

with the environment and the ability of humans to change it (e.g. *Human ingenuity will insure that we do not make the Earth unliveable*), whereas SDO is more strongly associated with the endorsement of a social hierarchy (e.g. *An ideal society requires some groups to be on top and others to be on the bottom*), with no mentions of ecological concerns. Furthermore, in previous research they have been shown to be only moderately associated ( $r = .30$ ) (Stanley et al., 2017), which suggests they are distinct, but related constructs. The items that are associated with pro-environmental attitudes warrant inclusion based on them capturing environmental concerns that may be held by those who oppose animal centred gene editing (e.g. the possible spread of the gene editing to non-target populations).

Thirdly, we wish to examine whether attitudes towards animal centred gene editing can be explained by people's aversion to artificial or synthetic entities. Biotechnologies such as cultured meat, gene editing, or GM crops are often seen as unnatural (Hendriks et al., 2018; Pivetti, 2007; Tenbült et al., 2005). Previously, aversion to the unnaturalness associated with biotechnology has been attributed to religious beliefs and concerns of 'playing god', or pathogenic risks (Dragojlovic & Einsiedel, 2013; Halstead & Lewis, 2020, respectively). However, the possibility of a more direct aversion to artificial or synthetic materials per se has not been empirically examined, only discussed (Lustig, 2013). To that end, we intend to construct a measure of what we label 'Synthetic Aversion', which we believe will capture this synthetic-based biotechnology aversion.

Fourthly, we intend to include a number of predictor variables (aside from the usual demographic variables) that have been previously identified as being associated with gene editing attitudes. For example, trust in science and scientific knowledge have been shown to be consistently associated with attitudes towards gene editing (Delhove et al., 2020; Halstead & Lewis, 2020). Their inclusion in the current study serves as an indicator of any issues with

the data or models used (for example, a negative association between trust in science and support for a biotechnology would raise a red flag). Political ideology has also been shown to be associated with gene editing attitudes (Delhove et al., 2020), as well as with several of our predictor variables, such as SDO, Human Exceptionalism, and Environmental Concern (Pratto et al., 1994; Xiao et al., 2019). Thus, the inclusion of political ideology as a control variable will support the robustness of any associations we may find between SDO, Human Exceptionalism, Environmental Concern and animal centred gene editing attitudes.

We also elected to include three different biotechnologies: gene editing, selective breeding, and gene drive. As gene drive is an application of gene editing, one would expect the relationships found between our predictor variables and these biotechnologies to be the same, and if they were different then that may imply a failure to explain gene editing or gene drive on behalf of the researchers, or a failure to understand on the part of participants. The decision to include selective breeding was made with the intention to examine an alternative, less novel biotechnology (which is itself also intended to control pest populations) that may be perceived as more natural and thus more acceptable, which would allow for a clearer differentiation in the role of our predictor variables (in particular, Synthetic Aversion) between novel biotechnology and conventional biotechnology attitudes.

Finally, we wish to control for the variance in attitudes towards animal centred gene editing explained by religiosity, in order to examine whether our novel Synthetic Aversion variable provides an alternative explanation for opposition rooted in concerns surrounding the unnatural aspect of gene editing. Religiosity has also been found to predict attitudes towards gene editing (Delhove et al., 2020), and has been found to be associated with SDO (Oxendine, 2018; Wilson & Sibley, 2013), which further justifies its inclusion to control for its potentially confounding influence.

## **Hypotheses**

H1) Higher SDO scores will be associated with support for the gene editing, selective breeding and gene drive pest control techniques.

H1a) This relationship will be independent of religiosity, political ideology, trust in science, scientific knowledge, and Human Exceptionalism.

H2) Higher Human Exceptionalism scores will be associated with support for the gene editing, selective breeding and gene drive pest control techniques.

H2a) This relationship will be independent of religiosity, political ideology, trust in science, scientific knowledge and SDO.

H3) Lower Environmental Concern scores will be associated with greater support for the gene editing, selective breeding and gene drive pest control techniques.

H3a) This relationship will be independent of religiosity, Synthetic Aversion, trust in science, scientific knowledge, and political ideology.

H4) Lower Synthetic Aversion scores will be associated with greater support for the gene editing and gene drive pest control techniques.

H4a) This relationship will be independent of religiosity, trust in science, scientific knowledge, political ideology and Environmental Concern.

## **5.3 Methods**

### **Participants**

Participants were taken from the ‘Public opinions towards novel pest control’ dataset (Available from <https://data.bioheritage.nz/dataset/public-opinion-pest-control-methods>). These data were collected as part of a previous study by MacDonald et al. (2020). When carrying out the Spearman correlations, all participants that indicated *don't know* in response

to the items asking for their attitudes towards gene editing, selective breeding, and gene drive were removed. The majority of these removals were from the gene drive item, which had a higher level of don't know responses (30% of respondents to the gene drive question, compared to 10.3% for selective breeding responses, and 9% for gene editing responses). Before any removals, the dataset consisted of 8199 complete cases (55.14% female). The median age category of the participants was 50-54 years old. After these removals, the dataset consisted of 5554 complete cases (49.10% female). The median age category of the participants was still 50-54 years old.

## Measures

### *Biotechnology support*

Survey respondents were provided with information concerning gene drive before indicating their attitudes; *In the future, gene drive could be developed to rid New Zealand of rats. Gene drive is where an animal's DNA is edited in the lab. These animals can only produce male offspring. The lab animals are then released into the environment and when they breed with wild animals, the number of females declines. With fewer females to breed with, the entire population size falls over time.* No information regarding the gene editing or selective breeding techniques was given.

Attitudes towards gene editing, selective breeding, and gene drives for pest control were measured using 3 items – one for each of the biotechnology methods. Participants were asked to respond to the statement *There are a number of ways to control species which are considered to be pests. Please indicate your general attitude towards the pest control methods listed below.* Participants then indicated their support using a 5-point Likert scale, with responses ranging from 1; *Should never be used under any circumstances*, 2; *Should only be used as a last resort*, 3; *I am uncomfortable with this method but will accept it as long as appropriate controls are*

*in place, 4; I am comfortable with this method as long as appropriate controls are in place, 5; I have no concerns at all about this method.* Each biotechnology was analysed separately. Higher scores indicated a higher level of support for either gene editing, selective breeding, or gene drives. For details of responses to these items, see Table 1.

Table 1. Descriptive statistics of biotechnology attitudes.

Biotechnology	Response options	Valid percent (N)
Gene editing	Should never be used under any circumstances	18.2 (1493)
	Should only be used as a last resort	17.1 (1405)
	I am uncomfortable with this method but will accept it as long as appropriate controls are in place	22.6 (1857)
	I am comfortable with this method as long as appropriate controls are in place	23.6 (1937)
	I have no concerns at all about this method	8.1 (661)
	Don't Know	10.3 (846)
Selective breeding	Should never be used under any circumstances	12.3 (1008)
	Should only be used as a last resort	14.8 (1217)
	I am uncomfortable with this method but will accept it as long as appropriate controls are in place	21.6 (1773)
	I am comfortable with this method as long as appropriate controls are in place	30.8 (2525)
	I have no concerns at all about this method	11.4 (935)
	Don't Know	9.0 (741)
Gene drive	Should never be used under any circumstances	9.8 (802)
	Should only be used as a last resort	13.3 (1092)
	I am uncomfortable with this method but will accept it as long as appropriate controls are in place	19.8 (1621)
	I am comfortable with this method as long as appropriate controls are in place	21.0 (1718)
	I have no concerns at all about this method	6.1 (503)
	Don't Know	30.0 (2463)

### ***Psychological measures***

#### ***Social Dominance Orientation.***

This construct was measured using the SDO-8 (Ho et al., 2012). This measure consists of 8 items (e.g. *It is unjust to try to make groups equal* and *An ideal society requires some groups to be on top and others to be on the bottom*). Participants responded using a 7-point Likert scale, with responses ranging from 1; *Strongly disagree* to 7; *Strongly agree*. Items were

reverse coded where appropriate and averaged so that higher mean scores indicated a higher level of SDO. Cronbach's alpha = .814.

*Human Exceptionalism.*

This construct was measured using items taken from the *Revised New Ecological Paradigm* scale (Dunlap et al., 2000). This measure consists of 7 items (e.g. *Humans have the right to modify the natural environment to suit their needs* and *Human ingenuity will insure that we do not make the Earth unliveable*). Participants responded using a 7-point Likert scale, with responses ranging from 1; *Strongly disagree* to 7; *Strongly agree*. Items were averaged, with a higher mean indicating a higher level of Human Exceptionalism. Cronbach's alpha = .800.

*Environmental Concern*

This construct was measured using the pro-environmental attitudes items taken from the *Revised New Ecological Paradigm* scale (Dunlap et al., 2000). This measure consists of 8 items (e.g. *When humans interfere with nature it often produces disastrous consequences* and *Plants and animals have as much right as humans to exist*). Participants responded using a 7-point Likert scale, with responses ranging from 1; *Strongly disagree* to 7; *Strongly agree*. Items were averaged, with a higher mean indicating a higher level of Environmental Concern. Cronbach's alpha = .844.

*Synthetic Aversion.*

This construct was measured using 4 items (e.g. *I am scared of chemical substances and the risks associated with them* and *I would like to eat only organically grown vegetables*). Participants responded using a 7-point Likert scale, with responses ranging from 1; *Strongly disagree* to 7; *Strongly agree*. To examine how these items clustered we conducted a principal component analysis, which indicated that the first component explained 64% of the variance.

Furthermore, to test their reliability we conducted a Cronbach's alpha test on the items, which gave  $\alpha = .83$ . From these tests we elected to average the items, with a higher mean indicating a higher level of Synthetic Aversion. Cronbach's alpha = .827.

*Trust in science.*

This construct was measured using 6 items taken from the Trust in science and scientist inventory (Nadelson et al., 2014) (e.g. *We can trust science to find the answers that explain the natural world* and *We should trust that scientists are being ethical in their work*). Participants responded using a 7-point Likert scale, with responses ranging from 1; *Strongly disagree* to 7; *Strongly agree*. Items were reverse coded where appropriate and averaged so that a higher mean score would indicate a higher level of trust in science. Cronbach's alpha = .720.

*Political ideology.*

Participants were asked to indicate where on the liberal-conservative political spectrum they felt they were. This was measured on a 7-point Likert scale, ranging from 1; *Extremely liberal* to 7; *Extremely conservative*.

*Religiosity.*

Participants were asked to indicate how much guidance religion provides in their daily life as a measure of religiosity. They were asked to respond using a 7-point Likert scale, with responses ranging from 1; *No guidance at all* to 7; *Great deal of guidance*.

*Scientific knowledge.*

This construct was measured using the scientific fact items from the Ordinary Science Intelligence (OSI) scale (Kahan, 2017). Participants were asked to respond to 6 items, using a true/false/don't know paradigm. Examples of these questions are *The centre of the earth is very hot* and *Antibiotics kill viruses as well as bacteria*. Scores were constructed based upon the number of correct answers.



### *Education.*

Participants were asked to indicate their highest level of educational achievement. Response options ranged from 1; *None*, 2; *High school qualification*, 3; *Tertiary diplomas/certificates*, 4; *Bachelor's degree or higher*.

## **5.4 Analysis plan**

Step 1) In order to test whether SDO, Human Exceptionalism, Environmental Concern, Synthetic Aversion, trust in science, and scientific knowledge are associated with support for animal gene editing, selective breeding and gene drives (H1, 2, 3, 4), Spearman correlations were carried out using all study variables.

Step 2) In order to examine whether the relationships between SDO, Human Exceptionalism, Environmental Concern, Synthetic Aversion and support for gene editing, selective breeding, and gene drive are independent of potential confounding variables (H1a, 2a, 3a, 4a), a multinomial logistic regression was carried out (as the DV is plausibly non-linear, not normally distributed and contains the 'Don't know' category), for each biotechnology, with SDO, religiosity, political ideology, Environmental Concern, Human Exceptionalism, education, scientific knowledge, and Synthetic Aversion as predictor variables. The first response option of the gene editing/selective breeding/gene drive support items (those most strongly opposed to the respective biotechnology) was used as the reference category for the outcome variable.

## **5.5 Results**

Descriptives are detailed in Table 2. Participants generally were older, New Zealand Europeans, who are centrist in their political ideology, low in religiosity, with a high level of scientific knowledge.

Table 2. Descriptive statistics of study variables.

Variable	Mean	SD	Median
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CENTRED GENE EDITING

Social Dominance Orientation	3.13	0.96
Human Exceptionalism	3.60	1.04
Environmental Concern	5.41	0.89
Synthetic Aversion	4.32	1.28
Trust in science	4.03	0.88
Political ideology	3.99	1.17
Religiosity	2.77	2.03
Scientific knowledge	4.06	1.58
Education	Tertiary diploma/certificates	
Ethnicity	New Zealand European	
Age	50-54 Years old	

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### *Correlation results*

In line with our predictions, higher SDO scores (**H1**) showed a small, but positive correlation with support for gene editing in pest control ( $r_s = .07$ ,  $p < .001$ ) the use of gene drives ( $r_s = .06$ ,  $p < .001$ ), but not selective breeding ( $p > .05$ ). In addition to this, higher Human Exceptionalism scores (**H2**) were positively associated with support for gene editing ( $r_s = .12$ ,  $p < .001$ ), selective breeding ( $r_s = .06$ ,  $p < .001$ ), and gene drive ( $r_s = .12$ ,  $p < .001$ ). Lower Environmental Concern scores (**H3**) were positively associated with support for gene editing ( $r_s = .08$ ,  $p < .001$ ) and gene drive ( $r_s = .07$ ,  $p < .001$ ), but not selective breeding ( $r_s = .02$ ,  $p > .05$ ). Lower Synthetic Aversion scores (**H4**) were positively associated with support for gene editing ( $r_s = -.21$ ,  $p < .001$ ), selective breeding ( $r_s = -.16$ ,  $p < .001$ ), and gene drive ( $r_s = -.18$ ,  $p < .001$ ). For full details of correlations, see Table 3.

Table 3. Spearman correlations for study variables.

	1	2	3	4	5	6	7	8	9	10	11
1. Social Dominance Orientation											
2. Human Exceptionalism	0.35**										
3. Environmental Concern	-0.30**	-0.52**									
4. Synthetic Aversion	-0.10**	-0.16**	0.30**								
5. Trust in science	-0.03*	0.08**	-0.03*	-0.19**							
6. Political ideology	0.29**	0.27**	-0.19**	0.02	-0.08**						
7. Religiosity	0.05**	0.22**	-0.14**	0.12**	-0.12**	0.27**					
8. Scientific knowledge	-0.16**	-0.16**	0.09**	-0.13**	0.11**	-0.12**	-0.09**				
9. Education	-0.13**	-0.11**	0.09**	0.00	0.13**	-0.12**	0.06**	0.29**			
10. Gene editing support	0.07**	0.12**	-0.08**	-0.21**	0.29**	-0.02	-0.07**	0.21**	0.07**		
11. Selective breeding support	0.02	0.06**	-0.02	-0.16**	0.26**	-0.03*	-0.07**	0.26**	0.11**	0.71**	
12. Gene drive support	0.06**	0.12**	-0.07**	-0.18**	0.29**	0.00	-0.07**	0.17**	0.08**	0.71**	0.64**

Note. \*\* indicates  $p < .001$ , \* indicates  $p < .05$ .

***Multinomial logistic regression results***

*Gene editing model.*

In this model, higher levels of SDO, Human Exceptionalism, trust in science, and education were all consistent, independent predictors of every category of endorsement relative to the reference (lowest) category and corresponded with a greater likelihood to support gene editing, compared to the most opposed response option.

There we also a number of less consistent relationships. Relative to the most opposed group, those who were uncomfortable with gene editing but would accept it if appropriate controls were in place, scored significantly lower on Environmental Concern and Synthetic Aversion. Those who were comfortable with gene editing as long as appropriate controls were in place scored lower on Synthetic Aversion. Those who had no concerns about the use of gene editing scored lower on Synthetic Aversion. Those who responded with *Don't know* scored significantly lower on Environmental Concern and Synthetic Aversion and were significantly more liberal. See Table 4 for full details of the model and Table 7 for descriptive statistics.

*Selective breeding model.*

In this model, higher levels of SDO, trust in science, and education were all consistent, independent predictors of every category of endorsement relative to the reference (lowest) category and corresponded with a greater likelihood to support selective breeding.

There we also a number of less consistent relationships. Relative to the most opposed group, those who believed selective breeding should only be used as a last resort scored significantly higher in scientific knowledge. Those who were uncomfortable with selective breeding but would accept it if appropriate controls were in place scored significantly higher in Human Exceptionalism. Those who were comfortable with selective breeding as long as

appropriate controls were in place scored significantly higher on Human Exceptionalism and scientific knowledge, and lower on Synthetic Aversion and religiosity. Those who had no concerns about the use of gene editing scored significantly higher on Human Exceptionalism and lower on Synthetic Aversion. Those who responded with *Don't know* scored significantly lower on Environmental Concern and Synthetic Aversion and were significantly more liberal. See Table 5 for full details of the model and Table 7 for descriptive statistics.

*Gene drive model.*

In this model, lower levels of Synthetic Aversion, and higher levels of trust in science and education were all consistent, independent predictors of every category of endorsement relative to the reference (lowest) category and corresponded with a greater likelihood to support gene drive. Higher levels of SDO and Human Exceptionalism were independent predictors across all response categories, barring those who responded with *Don't know*, and corresponded with a greater likelihood to support gene drive.

There we also a number of less consistent relationships. Relative to the most opposed group, those who were uncomfortable with gene drive but would accept it if appropriate controls were in place scored significantly lower on Environmental Concern. Those who were comfortable with gene drive as long as appropriate controls were in place scored significantly lower in religiosity. Those who responded with *Don't know* scored significantly lower on Environmental Concern, Synthetic Aversion, and religiosity and scored higher on trust in science and scientific knowledge. See Table 6 for full details of the model and Table 7 for descriptive statistics.

Table 4. Multinomial logistic regression model for gene editing support.

Characteristic	2			3			4			5			6		
	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value
Social Dominance Orientation	1.17	1.08, 1.28	<b>&lt;0.001</b>	1.26	1.16, 1.37	<b>&lt;0.001</b>	1.24	1.14, 1.35	<b>&lt;0.001</b>	1.30	1.16, 1.45	<b>&lt;0.001</b>	1.23	1.11, 1.37	<b>&lt;0.001</b>
Human Exceptionalism	1.12	1.03, 1.22	<b>0.01</b>	1.11	1.02, 1.21	<b>0.012</b>	1.26	1.15, 1.37	<b>&lt;0.001</b>	1.54	1.37, 1.72	<b>&lt;0.001</b>	1.10	0.99, 1.21	0.078
Environmental Concern	1.00	0.90, 1.10	0.948	0.90	0.81, 0.99	<b>0.026</b>	1.03	0.93, 1.13	0.613	1.02	0.90, 1.16	0.763	0.75	0.67, 0.84	<b>&lt;0.001</b>
Synthetic Aversion	0.96	0.90, 1.03	0.234	0.92	0.87, 0.98	<b>0.007</b>	0.80	0.75, 0.85	<b>&lt;0.001</b>	0.73	0.68, 0.79	<b>&lt;0.001</b>	0.88	0.81, 0.95	<b>&lt;0.001</b>
Trust in science	1.43	1.31, 1.57	<b>&lt;0.001</b>	1.60	1.47, 1.74	<b>&lt;0.001</b>	2.21	2.02, 2.42	<b>&lt;0.001</b>	2.78	2.46, 3.14	<b>&lt;0.001</b>	1.71	1.52, 1.91	<b>&lt;0.001</b>
Political ideology	0.99	0.93, 1.06	0.823	0.95	0.89, 1.01	0.112	0.95	0.89, 1.02	0.128	0.98	0.89, 1.07	0.637	0.89	0.82, 0.97	<b>0.008</b>
Religiosity	1.01	0.97, 1.05	0.621	0.99	0.95, 1.02	0.485	0.97	0.93, 1.00	0.081	0.96	0.91, 1.01	0.108	1.00	0.96, 1.05	0.991
Scientific knowledge	1.03	0.94, 1.12	0.535	1.05	0.97, 1.14	0.225	1.03	0.95, 1.12	0.47	1.04	0.93, 1.16	0.532	0.98	0.89, 1.08	0.702
Education	1.19	1.13, 1.25	<b>&lt;0.001</b>	1.27	1.21, 1.33	<b>&lt;0.001</b>	1.45	1.38, 1.53	<b>&lt;0.001</b>	1.54	1.44, 1.65	<b>&lt;0.001</b>	0.86	0.81, 0.91	<b>&lt;0.001</b>

<sup>1</sup>OR = Odds Ratio, CI = Confidence Interval. Note: 1; *Should never be used under any circumstances*, 2; *Should only be used as a last resort*, 3; *I am uncomfortable with this method but will accept it as long as appropriate controls are in place*, 4; *I am comfortable with this method as long as appropriate controls are in place*, 5; *I have no concerns at all about this method*, 6; *Don't Know*.

Table 5. Multinomial logistic regression model for selective breeding support.

Characteristic	2			3			4			5			6		
	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value
Social Dominance Orientation	1.15	1.04, 1.27	<b>0.006</b>	1.18	1.07, 1.29	<b>&lt;0.001</b>	1.13	1.04, 1.24	<b>0.006</b>	1.27	1.14, 1.42	<b>&lt;0.001</b>	1.21	1.08, 1.37	<b>0.001</b>
Human Exceptionalism	1.09	0.98, 1.20	0.104	1.11	1.01, 1.22	<b>0.026</b>	1.17	1.07, 1.28	<b>&lt;0.001</b>	1.42	1.27, 1.58	<b>&lt;0.001</b>	1.03	0.92, 1.15	0.654
Environmental Concern	0.94	0.84, 1.06	0.315	0.91	0.82, 1.01	0.09	1.00	0.90, 1.11	0.972	1.11	0.98, 1.27	0.101	0.75	0.66, 0.86	<b>&lt;0.001</b>
Synthetic Aversion	0.96	0.89, 1.03	0.22	0.95	0.88, 1.01	0.114	0.87	0.82, 0.93	<b>&lt;0.001</b>	0.77	0.71, 0.83	<b>&lt;0.001</b>	0.88	0.81, 0.96	<b>0.003</b>
Trust in science	1.42	1.28, 1.58	<b>&lt;0.001</b>	1.51	1.37, 1.67	<b>&lt;0.001</b>	2.07	1.88, 2.27	<b>&lt;0.001</b>	2.68	2.39, 3.02	<b>&lt;0.001</b>	1.70	1.50, 1.93	<b>&lt;0.001</b>
Political ideology	0.96	0.89, 1.04	0.364	0.95	0.89, 1.03	0.22	0.98	0.91, 1.05	0.541	0.96	0.87, 1.04	0.312	0.87	0.79, 0.95	<b>0.003</b>
Religiosity	1.00	0.95, 1.04	0.878	1.00	0.96, 1.04	0.858	0.97	0.93, 1.01	<b>0.1</b>	0.98	0.93, 1.03	0.331	1.02	0.97, 1.07	0.5
Scientific knowledge	1.11	1.01, 1.22	<b>0.034</b>	1.09	1.00, 1.19	0.059	1.10	1.01, 1.20	<b>0.024</b>	1.11	0.99, 1.23	0.062	1.01	0.90, 1.12	0.923
Education	1.17	1.10, 1.23	<b>&lt;0.001</b>	1.28	1.21, 1.35	<b>&lt;0.001</b>	1.57	1.49, 1.66	<b>&lt;0.001</b>	1.68	1.57, 1.80	<b>&lt;0.001</b>	0.86	0.81, 0.92	<b>&lt;0.001</b>

<sup>1</sup>OR = Odds Ratio, CI = Confidence Interval. Note: 1; *Should never be used under any circumstances*, 2; *Should only be used as a last resort*, 3; *I am uncomfortable with this method but will accept it as long as appropriate controls are in place*, 4; *I am comfortable with this method as long as appropriate controls are in place*, 5; *I have no concerns at all about this method*, 6; *Don't Know*.

Table 6. Multinomial logistic regression model for gene drive support.

Characteristic	2			3			4			5			6		
	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value	OR <sup>1</sup>	95% CI <sup>1</sup>	p-value
Social Dominance Orientation	1.18	1.06, 1.31	<b>0.003</b>	1.18	1.07, 1.31	<b>0.001</b>	1.18	1.07, 1.31	<b>0.001</b>	1.29	1.13, 1.48	<b>&lt;0.001</b>	1.07	0.98, 1.18	0.148
Human Exceptionalism	1.14	1.03, 1.27	<b>0.016</b>	1.15	1.04, 1.27	<b>0.008</b>	1.29	1.17, 1.43	<b>&lt;0.001</b>	1.65	1.44, 1.89	<b>&lt;0.001</b>	0.98	0.89, 1.08	0.716
Environmental Concern	0.98	0.86, 1.11	0.71	0.88	0.78, 0.99	<b>0.034</b>	0.96	0.85, 1.08	0.461	1.08	0.93, 1.26	0.326	0.86	0.77, 0.97	<b>0.012</b>
Synthetic Aversion	0.91	0.84, 0.98	<b>0.017</b>	0.92	0.86, 1.00	<b>0.043</b>	0.82	0.76, 0.88	<b>&lt;0.001</b>	0.71	0.64, 0.78	<b>&lt;0.001</b>	0.82	0.76, 0.88	<b>&lt;0.001</b>
Trust in science	1.48	1.33, 1.66	<b>&lt;0.001</b>	1.95	1.75, 2.16	<b>&lt;0.001</b>	2.51	2.25, 2.79	<b>&lt;0.001</b>	2.94	2.55, 3.39	<b>&lt;0.001</b>	1.80	1.63, 1.98	<b>&lt;0.001</b>
Political ideology	1.04	0.96, 1.14	0.338	1.01	0.93, 1.09	0.872	1.03	0.95, 1.12	0.453	1.08	0.97, 1.21	0.154	0.95	0.88, 1.02	0.171
Religiosity	0.98	0.94, 1.03	0.464	0.97	0.93, 1.02	0.248	0.94	0.90, 0.98	<b>0.006</b>	0.95	0.89, 1.01	0.111	0.94	0.90, 0.98	<b>0.005</b>
Scientific knowledge	1.04	0.94, 1.15	0.478	1.06	0.96, 1.17	0.218	1.10	1.00, 1.22	0.053	1.07	0.94, 1.23	0.298	1.12	1.03, 1.23	<b>0.012</b>
Education	1.09	1.02, 1.16	<b>0.007</b>	1.15	1.08, 1.22	<b>&lt;0.001</b>	1.33	1.25, 1.41	<b>&lt;0.001</b>	1.39	1.28, 1.51	<b>&lt;0.001</b>	0.97	0.92, 1.02	0.223

<sup>1</sup>OR = Odds Ratio, CI = Confidence Interval. Note: 1; *Should never be used under any circumstances*, 2; *Should only be used as a last resort*, 3; *I am uncomfortable with this method but will accept it as long as appropriate controls are in place*, 4; *I am comfortable with this method as long as appropriate controls are in place*, 5; *I have no concerns at all about this method*, 6; *Don't Know*.

Table 7. Descriptive statistics for each response option by biotechnology.

Response		Gene Editing						Selective Breeding						Gene drive					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Social Dominance Orientation	Mean	2.97	3.12	3.17	3.12	3.22	3.29	3.02	3.15	3.16	3.07	3.18	3.30	2.96	3.18	3.18	3.16	3.30	3.08
	SD	0.96	0.94	0.91	1.01	1.08	0.86	0.95	0.92	0.91	0.99	1.06	0.85	1.00	0.90	0.92	0.99	1.06	0.95
Human Exceptionalism	Mean	3.40	3.57	3.59	3.64	3.87	3.76	3.44	3.58	3.61	3.57	3.77	3.74	3.37	3.62	3.65	3.70	3.98	3.49
	SD	1.02	0.99	1.00	1.06	1.22	0.95	1.01	1.01	1.01	1.03	1.20	0.96	1.09	1.01	1.01	1.05	1.24	0.96
Environmental Concern	Mean	5.55	5.46	5.38	5.42	5.30	5.16	5.52	5.42	5.38	5.45	5.39	5.16	5.58	5.43	5.37	5.38	5.30	5.40
	SD	0.84	0.84	0.85	0.90	1.12	0.84	0.88	0.85	0.86	0.86	1.05	0.86	0.91	0.86	0.87	0.92	1.10	0.83
Synthetic Aversion	Mean	4.67	4.50	4.37	4.08	3.83	4.27	4.65	4.47	4.42	4.22	3.92	4.27	4.76	4.47	4.41	4.14	3.85	4.29
	SD	1.31	1.19	1.18	1.25	1.54	1.18	1.31	1.24	1.17	1.22	1.52	1.23	1.32	1.18	1.16	1.27	1.50	1.28
Trust in science	Mean	3.64	3.92	4.01	4.29	4.48	4.03	3.61	3.89	3.94	4.20	4.43	4.01	3.52	3.86	4.05	4.28	4.42	4.02
	SD	0.89	0.79	0.78	0.89	1.02	0.71	0.87	0.78	0.78	0.88	1.02	0.70	0.89	0.81	0.77	0.88	1.02	0.84
Political ideology	Mean	4.03	4.05	3.99	3.92	4.00	4.02	4.07	4.03	4.02	3.94	3.95	4.01	4.01	4.11	4.03	3.99	4.13	3.89
	SD	1.15	1.12	1.14	1.23	1.37	1.04	1.14	1.13	1.10	1.20	1.39	1.05	1.19	1.12	1.12	1.23	1.35	1.13
Religiosity	Mean	2.93	2.92	2.77	2.56	2.54	2.86	2.95	2.87	2.86	2.61	2.58	2.91	3.06	2.96	2.86	2.62	2.70	2.64
	SD	2.18	2.08	1.94	1.93	2.01	2.05	2.18	2.04	2.00	1.97	2.00	2.06	2.23	2.06	1.97	1.94	2.04	2.03
Scientific knowledge	Mean	3.67	4.02	4.17	4.50	4.62	3.12	3.49	3.83	4.02	4.52	4.66	2.97	2.73	2.77	2.83	2.94	2.92	2.83
	SD	1.54	1.49	1.53	1.45	1.46	1.73	1.52	1.48	1.56	1.42	1.43	1.68	0.94	0.95	0.93	0.92	0.94	0.93
Education	Median	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Note: 1; *Should never be used under any circumstances*, 2; *Should only be used as a last resort*, 3; *I am uncomfortable with this method but will accept it as long as appropriate controls are in place*, 4; *I am comfortable with this method as long as appropriate controls are in place*, 5; *I have no concerns at all about this method*, 6; *Don't Know*. For education, 3 = Tertiary diploma/certificates.



## 5.6 Discussion

The primary aim of this study was to explore the role of SDO in a novel context - whether it predicted support for the use of biotechnology, specifically gene editing animals for the purposes of pest control. Our findings support our hypotheses - SDO was positively associated with support for gene editing and gene drive for pest control. While modest in magnitude, this relationship was robust to the inclusion of other related variables, such as Human Exceptionalism, Environmental Concern, political ideology, religiosity, and education.

These findings are consistent with the idea that SDO functions as a moral distancing strategy; endorsing a natural hierarchy allows an individual to place themselves above others (i.e. non-human animals), which increases the acceptability of exploiting or gene editing them. This idea is supported by the positive association between Human Exceptionalism scores and support for the use of gene editing and gene drive. This scale contains items that tap into the idea that humans have the moral authority to shape their environment and have the ability to do so. Given that SDO and Human Exceptionalism were both significant, independent predictors, they provide unique but complimentary contributions to the acceptability of using biotechnologies on animals for pest control purposes.

We also found evidence for the role of a novel variable – Synthetic Aversion. This variable was constructed with the intention to tap into concerns regarding the synthetic or artificial aspects of biotechnology, which have previously been grouped together with unnaturalness concerns (Dragojlovic & Einsiedel, 2013; Goss et al., 2012; Pivetti, 2007). While concerns about the unnatural are often attributed to concerns of ‘playing god’, our findings indicate that some of these concerns are based in the synthetic or artificial nature of the biotechnology. In this study lower Synthetic Aversion scores consistently predicted support for gene editing and gene drive technologies, while religiosity was only a significant predictor in

16.67% of response options across all three biotechnologies. Furthermore, Synthetic Aversion only partially predicted opposition towards selective breeding, the least novel and most natural of the three biotechnologies. Together, these findings suggest that a naturalness bias may be at work in biotechnology attitudes, where the public prefer natural alternatives to technologies they consider artificial, and that this is a better explanation for negative attitudes than religious concerns. However, there is limited research that has explored this (i.e. one study that examined vaccines; DiBonaventura & Chapman, 2008).

There are limitations associated with this study. The sample was taken solely from New Zealand, which limits the inferences that can be made regarding the rest of the world. As New Zealand is an island nation that hosts several unique species and is currently carrying out a nationwide program to control invasive species (Predator free 2050), New Zealanders may be especially sensitive to the ecological threat that pests represent. Consequently, the level of support for gene editing to control pests may be higher than in other countries where they present less of a direct threat to the ecology. This sensitivity to ecological threats presented by invasive species may outweigh the environmental risks of the various pest control techniques, which may distort the magnitude of association between Environmental concern and support for the biotechnologies.

Furthermore, this study was limited to examining the role of SDO in gene editing techniques that were solely for the benefit of humans, and the detriment of animals. Future research would benefit from examining whether predictors of attitudes towards gene editing in animals differ by application. If the gene editing application were to provide a more direct benefit to humans, such as more meat from livestock, then there may be a more pronounced influence of SDO. Alternatively, if the gene editing provided clearer benefits to the animal, such as increased health or longevity, those higher in SDO may be less likely to support them,

as it may upset their perception of the natural hierarchy. The potential target of the gene editing may also change levels of support and predictors of attitudes. For example, controlling the population of rats may be seen as more desirable than controlling the population of other animals, such as goats, as rats have historically negative associations with disease. There are a greater number of interactions between target and type of gene editing than humans, and each may have a different level of acceptability. These nuances need to be explored further.

In summary, this study found that SDO, Human Exceptionalism, Environmental Concern and Synthetic Aversion play statistically significant roles in the attitudes that people hold towards gene editing for the purpose of pest control. Our findings regarding SDO may provide evidence for hierarchical beliefs inclining a person towards morally distancing themselves from animals, allowing them to be used in ways that would be unacceptable if used on humans. Our findings regarding Synthetic Aversion also suggests that associations of artificiality with biotechnology may drive some of the opposition towards them. In combination these findings provide initial insights into the role of these variables in biotechnology attitudes; future research needs to explore the nuances of animal centred gene editing, to examine if this relationship is stable across different applications and targets.

# **Chapter 6: Heterogeneous Attitudinal Profiles Towards Gene Editing: Evidence From Latent Class Analysis**

**Isaac N. Halstead, Jan R. Boehnke, and Gary J. Lewis**

## 6.1 Abstract

Advances in gene editing technology have important implications for the treatment and prevention of disease. Accordingly, it is important to understand public perceptions towards gene editing, as the public's willingness to endorse gene editing may be as important as technological breakthroughs themselves. Previous research has almost exclusively examined attitudes towards gene editing on specific issues, but hasn't addressed how attitudes towards gene editing across a range of issues coalesce in individuals: i.e. the degree to which discrete, heterogeneous attitudinal profiles exist vs a simple support/oppose continuum. Here we addressed this issue using latent class analysis on data from The Pew Research Center (N = 4726; US residents) across a wide range of gene editing topics. We found that attitudes towards gene editing cohere into 10 distinct latent classes that showed evidence of a support/oppose continuum, but also for clear qualitative differences between each class, even with support or oppose classes, on a number of issues. The most opposed classes significantly differed from the supporter classes in age, sex, political ideology, and self-rated knowledge. These findings provide evidence that attitudes towards gene editing are heterogeneous and public discourse, as well as policy making need to consider a range of arguments when evaluating this technology.

## 6.2 Introduction

Advances in molecular biology in recent years have meant that DNA can be sequenced at low cost and precise changes to a given DNA sequence can be performed (Feng et al., 2018; Gilles & Averof, 2014; Oude Blenke et al., 2016). For example, gene-editing techniques, such as CRISPR-Cas9, allow silencing of particular genes or introducing new genes. Such technologies have shown important benefits – not least the capability of treating a variety of genetic disorders and diseases (Gilles & Averof, 2014).

However, the use of this novel technology is met with a range of ethical and philosophical concerns well-documented in academic discourse (de Araujo, 2017; Howell et al., 2020; K. M. Vogel & Ouagrham-Gormley, 2018), it remains under-researched which attitudes toward this technology are held by the public and how they may influence public discourse and policy. Research on gene editing attitudes has noted several themes. Firstly, gene editing is often seen as immoral, unnatural, or humans 'playing god' (Robillard et al., 2014; Xiang et al., 2015). People also often show trepidation about the use of gene editing in babies (compared to adults) (Delhove et al., 2020; Uchiyama et al., 2018). There is also concern surrounding whether gene editing will be used for medical purposes (e.g. curing or preventing disease) or for enhancement purposes (e.g. giving a person greater intelligence or strength) (Critchley et al., 2019; Delhove et al., 2020; McCaughey et al., 2016; Scheufele et al., 2017). Finally, people are often worried regarding the impact gene editing will have on society, such as creating inequality or access to such technologies being limited to the wealthy (Robillard et al., 2014; Xiang et al., 2015). Building from these observations, recent work has indicated that gene editing attitudes – at least across themes such as enhancement of physical and cognitive abilities, the treatment of physical and cognitive illnesses, and whether the target of gene

editing is a baby or adult– can be described fairly well by two (moderately associated) latent factors representing ‘treatment’ and ‘enhancement’ (Halstead & Lewis, 2020).

While a representation of attitudes towards gene editing on two dimensions allows for a relative and quantitative comparison across individuals (i.e. whether attitudes are held more or less strongly), it does not speak to the question of how attitudes towards a range of gene editing topics cohere within individuals. For example, there may be people who are opposed to gene editing across the board. But people could also be opposed in general terms, but while not feeling that gene editing is morally unacceptable or 'playing God', they could instead be concerned specifically about the impacts on social equality. Qualitatively discrete classes of attitudes have been seen across a range of socio-political attitudes research (e.g. Feldman & Johnston, 2014; Lewis & de-Wit, 2019). Understanding how gene editing attitudes cohere as well as what predicts membership of these classes (e.g. gender, education, religiosity) provides an important window into the structure of these attitudes not revealed by more traditional, variable-centred approaches such as factor analysis (Halstead & Lewis, 2020) or the investigation of associations with individual topics (Critchley et al., 2019).

This implies that attitudes towards gene editing are unlikely to be comprehensively assessable through single questions or topics. An attitude is an evaluative tendency toward an entity and this tendency is composed of one’s beliefs about the entity (e.g., gene editing is immoral), one's affect associated with the entity (e.g., feelings associated gene editing), and recollections of past behaviours or interactions with the entity (in this case it is more likely past discussions about and portrayals of this entity, as personal experience is less likely) (Richardson et al., 2020). When investigating attitudes towards "gene editing", which comprises many techniques, and may be applied in a range of contexts and for a range of

reasons, it seems relevant to cover a range of topics covering varied areas of attitude formation as well as options to indicate beliefs and feelings.

Here we exploited the opportunity offered by the American Trends Panel Survey, that in its 15th wave covered a broad range of aspects around the topic of gene editing, such as its moral acceptability, consequences for society, and affective response to the technology. We use latent class analysis (LCA), which allows one to formally examine whether specific subsets of attitudes coalesce within groups of individuals. As such, one is able to discern if attitude coherence on a given topic reflect discrete ‘types’, or classes. The use of LCA also allows an examination of whether membership of these discrete latent classes differ on candidate predictor socio-demographic variables. For example, political conservatism and religiosity have been shown to predict opposition towards gene editing (Weisberg et al., 2017; Critchley et al., 2019; Delhove et al., 2020). And those who self-report higher levels of gene editing knowledge are more likely to support the use of such technology (Cebesoy & Öztekin, 2016; Črne-Hladnik et al., 2012). But it remains unknown whether these candidate predictors show links to gene editing attitudes across attitudes all/most latent classes of opposers vs supporters, or only to specific latent classes.

## **6.3 Methods**

### **Participants**

The data used in the current study was collected by The Pew Research Center as part of Wave 15 (between the 2<sup>nd</sup> and 28<sup>th</sup> of March, 2016) of the American Trends Panel, using a combination of online and mail questionnaires with US residents. The full panel consists of 8,314 respondents of which 4,726 took part in Wave 15 (4,243 in web-based interviews and 483 in mail-based interviews). Of the sample, 49.4% identified as male and 80% as White



(8.7% Black, 2.5% Asian, 3.5% Mixed race and the rest identifying as Other or Don't Know).

The modal age category was 50-64 years old (31.5%; Pew provided data on age bucketed into 4 categories; see details below). This data set is available to download from the Pew Research Centre (<https://www.pewresearch.org/science/datasets/>).

## Measures

Participants were given the following passage of information before responding to the gene editing questions: *New developments in genetics and gene-editing techniques are making it possible to treat some diseases and conditions by modifying a person's genes. In the future, gene-editing techniques could be used for any newborn, by changing the DNA of the embryo before it is born, and giving that baby a much reduced risk of serious diseases and conditions over his or her lifetime. Any changes to a baby's genetic make-up could be passed on to future generations if they later have children, and over the long term this could change the genetic characteristics of the population.*

### ***Subjective gene editing knowledge***

Subjective gene editing knowledge was measured using the following question: *How much have you heard or read about this idea before today?* The response options ranged from: 1 = *A lot*, 2 = *A little*, 3 = *Not at all*. These responses were recoded so that a higher score represented a greater level of self-rated gene editing knowledge.

### ***Gene editing attitude selection***

This dataset contained a range of gene editing variables. Given our specific focus here on gene editing attitudes (i.e. an evaluative tendency toward an entity: Richardson et al., 2020) we selected a sub-set of these items for the current analysis. These items are detailed in full in Table 1. Our question selections reflected the following themes: 1) Levels of excitement about gene editing; 2) Levels of worry about gene editing; 3) Beliefs regarding gene editing crossing

a natural boundary; 4) Concerns about the consequences if gene editing was adopted; 5) Whether using gene editing to give babies a reduced risk of disease is morally wrong; 6) Whether the use of gene editing to give a person average/above average health is an appropriate use of technology.

### ***Demographics***

#### *Age*

Age was measured using the following question: *What is your age?* followed by a free-text response, which was then recoded (by Pew) into 4 categories – 1 = 18-29, 2 = 30-49, 3 = 50-64, 4 = 65+.

#### *Education*

Education was measured using the following question: *What is the highest degree or level of school that you have COMPLETED?* The response options ranged from: *No schooling completed to Doctorate degree*, which was then recoded into 3 categories: 1= *High school or less*, 2= *Associates degree or equivalent*, 3= *College graduate or higher*.

#### *Income*

Income was measured using the following question: *Last year, that is in 2015, what was your total family income from all sources, before taxes?* The response options ranged from: 1= *Less than \$10,000*, 2= *\$10,000 to less than \$20,000*, 3= *\$20,000 to less than \$30,000*, 4= *\$30,000 to less than \$40,000*, 5= *\$40,000 to less than \$50,000*, 6= *\$50,000 to less than \$75,000*, 7= *\$75,000 to less than \$100,000*, 8= *\$100,000 to less than \$150,000*, 9= *\$150,000 or more*.

*Race*

Race was measured using the following question: *Which of the following describes your race?* The response options ranged from 1= *White*, 2= *Black or African American*, 3= *Asian or Asian American*, 4= *Mixed Race*, 5= *Or some other race*, and 6= *Don't know/Refuse to answer*.

*Religiosity*

Religiosity was measured using the following question: *Aside from weddings and funerals, how often do you attend religious services?* The response options ranged from 1 = *More than once a week* to 6= *Never*. These responses were reverse coded so that a higher score represented a higher level of religiosity.

*Political ideology*

Political ideology was measured using the following question: *In general, would you describe your political views as...* The response options ranged from 1= *Very Conservative* to 5 = *Very Liberal*. A higher score represented a higher level of political liberalism. Participants were also asked *In politics today, do you consider yourself a...* The response options ranged from 1 = *Republican*, 2 = *Democrat*, 3 = *Independent*, 4 = *Something else*, and 5 = *Refuse to answer*.

**Table 1.** Questions selected for analysis.

Prompt	Question	Response options	Valid percent (N)
Thinking about the possibility of this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions...	How ENTHUSIASTIC are you, if at all, about this possibility for society as a whole?	<ul style="list-style-type: none"> <li>Very enthusiastic</li> <li>Somewhat enthusiastic</li> <li>Not too enthusiastic</li> <li>Not at all enthusiastic</li> <li>Don't know/Refuse to answer</li> </ul>	14.3 (677) 36.9 (1746) 30.6 (1445) 17 (803) 1.2 (55)
	How WORRIED are you, if at all, about this possibility for society as a whole?	<ul style="list-style-type: none"> <li>Very worried</li> <li>Somewhat worried</li> <li>Not too worried</li> <li>Not at all worried</li> <li>Don't know/Refuse to answer</li> </ul>	20.3 (960) 48.9 (2313) 23.6 (1117) 5.9 (280) 1.2 (56)
	Which of these statements comes closer to your view, even if neither is exactly right?	<ul style="list-style-type: none"> <li>As humans, we are always trying to better ourselves and this idea is no different.</li> <li>This idea is meddling with nature and crosses a line we should not cross.</li> <li>Don't know/Refuse to answer</li> </ul>	53.8 (2543) 44.3 (2093) 1.9 (90)
	If this gene-editing become available, giving HEALTHY babies a much reduced risk of serious diseases and conditions, do you think the following are likely or not likely to happen as a result?	<ul style="list-style-type: none"> <li>People who have this gene-editing will be more productive at their jobs</li> </ul>	<ul style="list-style-type: none"> <li>Yes, likely</li> <li>No, not likely</li> <li>Don't know/Refuse to answer</li> </ul> 32.5 (1538) 64.5 (3047) 3 (141)
		<ul style="list-style-type: none"> <li>People who have this gene-editing will feel superior to people who do not</li> </ul>	<ul style="list-style-type: none"> <li>Yes, likely</li> <li>No, not likely</li> <li>Don't know/Refuse to answer</li> </ul> 55.8 (2638) 41.6 (1964) 2.6 (124)
		<ul style="list-style-type: none"> <li>People who have this gene-editing will feel more confident and better about themselves</li> </ul>	<ul style="list-style-type: none"> <li>Yes, likely</li> <li>No, not likely</li> <li>Don't know/Refuse to answer</li> </ul> 54.6 (2580) 42.6 (2012) 2.8 (134)
	Widespread use of this option will lead to new innovation and problem-solving in society	<ul style="list-style-type: none"> <li>Yes, likely</li> <li>No, not likely</li> <li>Don't know/Refuse to answer</li> </ul>	45.7 (2161) 51.5 (2435) 2.8 (130)
	Do you think using this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions is...	<ul style="list-style-type: none"> <li>Do you think using this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions is...</li> </ul>	<ul style="list-style-type: none"> <li>Morally acceptable</li> <li>Morally UNacceptable</li> <li>Not sure</li> <li>Don't know/Refuse to answer</li> </ul> 32.6 (1543) 29.4 (1389) 36.8 (1738) 1.2 (56)
		<ul style="list-style-type: none"> <li>Would you say this is an appropriate use of technology or taking technology too far if the effects were such that those who had this gene-editing were...</li> </ul>	<ul style="list-style-type: none"> <li>An appropriate use of technology</li> <li>Taking technology too far</li> <li>Don't know/Refuse to answer</li> </ul> 58.4 (2759) 38.8 (1836) 2.8 (131)
	MUCH HEALTHIER than the average person today	<ul style="list-style-type: none"> <li>An appropriate use of technology</li> <li>Taking technology too far</li> <li>Don't know/Refuse to answer</li> </ul>	53.7 (2536) 43.1 (2035) 3.3 (155)

## 6.4 Analysis

### *Latent class analysis*

The LCA was carried out using R (R Core Team, 2016) and the poLCA package (Linzer & Lewis, 2011). Our criteria for model selection was based upon the Bayesian Information Criteria (Nylund et al., 2007), the entropy values for each class, and the interpretability of each class extraction (Marsh et al., 2009; Meeus et al., 2011; Schreiber, 2017). LCA was seen as particularly suited to investigate the overarching structure of an "attitude towards gene editing". LCA assumes a categorical trait that causally determines the responses to the attitude items. But in contrast to other available methods, it does not assume that the indicators themselves are interval-scaled, nor does it assume that the latent trait is a single underlying quantitative dimension (or set of dimensions) on which quantitative differences are characterised. Nevertheless, the resulting classes can be ordered (hinting at quantitative inter-class differences) or they can be heterogeneous patterns including ambivalent attitudes towards the gene editing. Therefore, the model matches our theoretical intention of measuring a latent variable through a set of manifest indicators, while offering flexibility in indicator scaling and shape of the results.

### *Multinomial logistic regression*

We first assigned participants a class based on their highest membership probability. Next, the multinomial logistic regression was conducted (*nnet* package; Venables et al., 2002), using class membership as the dependent variable (in line with Bakk & Kuha, 2021), using Class 8 as the reference class as it was the class most opposed to gene editing. This was done to examine if there were significant differences in the demographic variables of each of the classes, and whether these differences predicted an increased level of support for gene editing.

## 6.5 Results

Summary statistics are presented in Table 2. Our sample was predominantly older, politically liberal leaning, with relatively low levels of education. They had low levels of religiosity and had “a little” pre-existing self-rated knowledge about gene editing.

**Table 2.** Descriptive statistics for the complete sample.

Variable	Response options	Valid percent (N)
Age	18-29	12.9 (608)
	30-49	28 (1322)
	50-64	31.6 (1492)
	65+	27.5 (1300)
	Missing	0.1 (4)
Education	Highschool or less	18.3 (865)
	Associates degree or equivalent	32.1 (1518)
	College graduate or higher	49.6 (2343)
	Missing	0 (0)
Political party	Republican	27.6 (1285)
	Democrat	36.1 (1682)
	Independent	26.9 (1253)
	Something else	8.5 (396)
	Refuse to answer	1.0 (46)
	Missing	1.4 (64)
Income	<\$10	7.1 (328)
	\$10-20	8.6 (397)
	\$20-30	9.2 (428)
	\$30-40	9.8 (454)
	\$40-50	9.1 (420)
	\$50-75	16.8 (779)
	\$75-100	14.1 (655)
	\$100-150	14.5 (671)
	\$150>	10.9 (508)
	Missing	1.8 (86)
Religiosity (as measured by church attendance)	More than once a week	19.8 (937)
	Once a week	21.8 (1030)
	Once or twice a month	15.7 (744)
	A few times a year	9.4 (445)
	Seldom	21.6 (1022)
	Never	11.6 (547)
	Missing	0.0 (1)

Knowledge	A lot	35.1 (524)
	A little	53.7 (2511)
	Not at all	11.2 (1644)
	Missing	1.0 (47)
Political ideology	Mean (SD)	1.1 (3)
	Missing	0.3 (16)

Note. Income reported in 1000's of USD. A higher score in political ideology represents a more liberal political ideology.

**Table 3.** Fit statistics for latent class model solutions

Model	Log likelihood	Residual df	BIC	aBIC	cAIC	Likelihood ratio	Entropy
1	-43637.4	4701	87486.39	87406.95	87511.39	26218.03	-
2	-37869.1	4675	76169.75	76007.69	76220.75	14681.41	0.89
3	-36298.1	4649	73247.73	73003.06	73324.73	11539.42	0.901
4	-35612	4623	72095.4	71768.1	72198.4	10167.1	0.805
5	-35024.1	4597	71139.71	70729.8	71268.71	8991.431	0.795
6	-34690.8	4571	70693.1	70200.57	70848.1	8324.839	0.778
7	-34479.9	4545	70491.28	69916.13	70672.28	7903.036	0.777
8	-34305.2	4519	70361.78	69704.01	70568.78	7553.55	0.779
9	-34155.8	4493	70282.92	69542.53	70515.92	7254.713	0.775
<b>10</b>	<b>-34020.9</b>	<b>4467</b>	<b><u>70233.15</u></b>	<b><u>69410.14</u></b>	<b><u>70492.15</u></b>	<b>6984.958</b>	<b>0.759</b>
11	-33918.4	4441	70248.17	<u>69342.55</u>	70533.17	6779.998	0.763

Note. Bolded indicates retained model. Underscores indicate lowest observed information criterion.

### **Class discussion (organised from most supportive to least supportive)**

Table 4 presents the conditional response probabilities for the 10 latent classes, which were chosen as the optimal solution. In the following discussion we organise the classes as a rough continuum, from most supportive to least supportive, and highlight the notable differences in configuration of each class.

#### ***Classes supportive towards gene editing***

Those in Class 1 are consistently supportive of gene editing. They are very likely to respond in a positive manner to most of the items, apart from whether gene editing will lead to

people feeling superior, which they are divided on. We describe this class as ‘Committed Futurists’.

Class 2 is similar to Class 1 across the bulk of the items; however, they are differentiated from Class 1 by virtue of being ‘somewhat worried’ of the technology (despite their enthusiasm) and being unsure of whether gene editing babies to increase their disease resistance is morally acceptable. We describe this class as ‘Anxious Futurists’.

Class 3, again, is generally supportive, being very likely to respond positively to the majority of items. However, compared to classes 1 and 2, individuals in this class do not tend to think there will be societal implications with regards to productivity, superiority, confidence and innovation. We describe this class as One might describe this class as ‘Doubtful supporters’.

#### ***Classes opposed to gene editing***

Class 4 is the first class to show a likelihood for responding with lower levels of enthusiasm as well as higher levels of worry. Nevertheless, they tend to not think that gene editing will have societal implications. And they think that the technology is appropriate for bettering ourselves. However, they tend to be unsure whether it is moral to use this technology on babies. We describe this class as ‘Cautious Pragmatists’.

Class 5 is similar to Class 4 inasmuch that the members show a likelihood for responding with lower levels of enthusiasm and higher levels of worry. In contrast, the members of this class tend to think gene editing is unnatural and using it to better ourselves is not appropriate. But they feel that societal implications - i.e. increases in productivity, perceptions of superiority, confidence, and innovation - are likely. And like Class 4 they also tend to be unsure whether it is moral to use this technology on babies. We describe this class as ‘Cautious Moralists’.



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Class 6 is the first class where we see a high likelihood of negative sentiment across the items. Members of this class are likely to be unenthusiastic and worried about the use of gene editing, to think that it is taking technology too far, and to not feel it will have societal implications. We describe this class as ‘Moderate Opposers’, due to their more muted opposition compared to the following 2 classes.

Class 7 is a near-mirror of Class 6, except members of this class show a likelihood to report that there will be societal implications with respect to people who have had gene editing feeling superior and more confident. We describe this class as ‘Social Justice Opposers’.

Class 8 is the mirror opposite of Class 1, being opposed/negative to all of the items. We describe this class as ‘Outright opposers’, as they believe all negative consequences of gene editing are likely, and they have the strongest negative affect towards the technology.

### Don’t know/Unsure classes

Finally, Classes 9 and 10 generally respond with ‘Refused to answer/Don’t know’. These two classes were differentiated by members of Class 9 showing a likelihood for negative sentiments towards gene editing across a handful of the items, such as believing it to be unnatural.

**Table 4.** Conditional probabilities for each class.

	Class									
	1	2	3	4	5	6	7	8	9	10
Class Share	8.4	17.9	14.3	8.7	15.7	10.8	11.4	9.2	2.6	0.8
Average probability of class membership	8.8	17.0	14.1	9.7	15.7	10.8	11.6	8.6	2.7	0.8
How ENTHUSIASTIC are you, if at all, about this possibility for society as a whole?										
Very enthusiastic	0.82	0.12	0.25	0.03	0.06	0.02	0	0.01	0.04	0.03
Somewhat enthusiastic	0.15	0.77	0.64	0.42	0.38	0.16	0.05	0	0.27	0.05
Not too enthusiastic	0.01	0.1	0.1	0.5	0.43	0.77	0.42	0.11	0.42	0
Not at all enthusiastic	0.01	0	0	0.06	0.13	0.04	0.53	0.88	0.18	0.07
Don’t know/Refuse to answer	0	0	0	0	0	0	0	0.01	0.09	0.85
How WORRIED are you, if at all, about this possibility for society as a whole?										
Very worried	0.07	0.06	0.03	0.14	0.2	0.1	0.62	0.62	0.15	0

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Somewhat worried	0.22	0.62	0.39	0.69	0.65	0.67	0.34	0.12	0.51	0.04
Not too worried	0.45	0.31	0.51	0.15	0.09	0.22	0.03	0.07	0.2	0
Not at all worried	0.26	0	0.07	0.02	0.04	0	0.01	0.19	0.05	0.09
Don't know/Refuse to answer	0	0	0	0	0.01	0	0	0	0.09	0.88

Which of these statements comes closer to your view, even if neither is exactly right?

As humans, we are always trying to better ourselves and this idea is no different.

This idea is meddling with nature and crosses a line we should not cross.

Don't know/Refuse to answer

0.99	0.94	0.99	0.55	0.31	0.17	0.02	0.07	0.26	0.04
0.01	0.05	0	0.44	0.69	0.83	0.97	0.92	0.56	0.08
0.01	0.01	0	0.01	0	0	0.01	0.01	0.18	0.88

People who have this gene-editing will be more productive at their jobs

Yes, likely

No, not likely

Don't know/Refuse to answer

0.8	0.69	0.18	0.11	0.66	0.04	0.19	0.02	0.09	0
0.19	0.29	0.82	0.89	0.33	0.96	0.81	0.97	0.37	0
0.01	0.02	0	0	0.01	0	0	0.01	0.54	1

People who have this gene-editing will feel superior to people who do not

Yes, likely

No, not likely

Don't know/Refuse to answer

0.56	0.81	0.13	0.52	0.89	0.37	0.95	0.31	0.3	0.03
0.43	0.18	0.87	0.48	0.1	0.62	0.05	0.68	0.25	0
0.01	0.01	0	0	0.01	0.01	0	0.01	0.46	0.97

People who have this gene-editing will feel more confident and better about themselves

Yes, likely

No, not likely

Don't know/Refuse to answer

0.9	0.97	0.25	0.39	0.93	0.19	0.77	0	0.18	0
0.1	0.02	0.75	0.6	0.07	0.81	0.23	0.98	0.25	0
0	0.01	0	0	0	0	0	0.02	0.57	1

Widespread use of this option will lead to new innovation and problem-solving in society

Yes, likely

No, not likely

Don't know/Refuse to answer

0.94	0.8	0.49	0.36	0.71	0.12	0.17	0.06	0.24	0
0.05	0.19	0.51	0.64	0.28	0.88	0.82	0.93	0.3	0
0.01	0.01	0	0.01	0.01	0	0.01	0.02	0.46	1

Do you think using this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions is...

Morally acceptable

Morally UNacceptable

Not sure

Don't know/Refuse to answer

0.93	0.59	0.72	0.15	0.08	0.02	0.01	0.03	0.11	0
0.01	0.03	0.01	0.17	0.37	0.5	0.89	0.72	0.19	0.03
0.06	0.38	0.27	0.68	0.55	0.47	0.1	0.24	0.57	0.09
0	0	0	0	0	0	0	0	0.12	0.88

Always EQUALLY HEALTHY as the average person today

An appropriate use of technology

Taking technology too far

Don't know/Refuse to answer

0.95	0.93	0.93	0.86	0.39	0.09	0.14	0.04	0.24	0
0.05	0.06	0.06	0.14	0.6	0.9	0.86	0.93	0.31	0.12
0	0.01	0.01	0	0.01	0.01	0	0.02	0.44	0.88

MUCH HEALTHIER than the average person today

An appropriate use of technology

Taking technology too far

Don't know/Refuse to answer

0.96	0.92	0.9	0.76	0.3	0.03	0.07	0.03	0.23	0
0.03	0.07	0.09	0.23	0.68	0.97	0.93	0.94	0.26	0.1
0.01	0.01	0.02	0.01	0.01	0.01	0	0.03	0.51	0.9

*Multinomial regression*

The multinomial regression analysis revealed several noteworthy differences when comparing our reference class (Class 8) to the rest of the classes. Firstly, being younger is significantly associated with being strongly opposed to gene editing (consistent across all classes, save Class 9). There was also a significant association between sex and class membership, with females being more likely to be in the strongly opposed classes compared to four more positive classes (Classes 1-3, 6). Higher levels of education were associated with being less opposed (Classes 2, 3, 5). Regarding political ideology, being more conservative was significantly associated with being in the strongly opposed classes. Higher self-rated knowledge and lower income were significantly associated with being in the most opposed class. Higher levels of religiosity were associated with being less likely to be a member of any of the more positive classes (1-5). For full details of the multinomial logistic regression, see Table 5.

Table 6 presents summary statistics to describe the distribution of the attributes within the ten classes. The more positive classes (Classes 1-3) were generally older, and more likely to be democrats, male, liberal leaning, better educated, rate their levels of gene editing knowledge to be lower, and possess lower levels of religiosity than the opposer classes. As we move from the supporter classes to the moderate (4, 5, 6) and strong opposition classes (7 and 8), the classes get progressively younger, more republican, female, and conservative leaning. The classes also progressively decrease in their education levels, rate their gene editing knowledge to be higher and sharply increase in their levels of religiosity.

**Table 5.** Multinomial regression with class 8 ('outright opposers') as the reference class (coefficients reported as odds ratios).

Variable	Classes																	
	OR	1 95% CI	OR	2 95% CI	OR	3 95% CI	OR	4 95% CI	OR	5 95% CI	OR	6 95% CI	OR	7 95% CI	OR	9 95% CI	OR	10 95% CI
Age	1.64	1.42, 1.90	1.64	1.44, 1.85	1.37	1.20, 1.56	1.35	1.17, 1.56	1.13	1.00, 1.28	1.15	1.01, 1.32	1.2	1.05, 1.37	1.26	0.70, 2.25	1.99	1.58, 2.49
Sex	0.46	0.34, 0.62	0.55	0.43, 0.71	0.57	0.43, 0.74	1.17	0.87, 1.56	0.81	0.63, 1.05	0.73	0.56, 0.96	1.06	0.81, 1.38	1.77	0.46, 6.82	1.16	0.75, 1.79
Education	1.21	0.98, 1.51	1.21	1.01, 1.45	1.43	1.17, 1.74	0.97	0.79, 1.19	1.25	1.04, 1.50	1.04	0.86, 1.26	1.12	0.92, 1.35	0.62	0.26, 1.50	0.99	0.73, 1.35
Income	1.04	0.97, 1.11	1.07	1.01, 1.14	1.12	1.06, 1.19	0.99	0.93, 1.06	1.06	1.00, 1.13	1.05	0.99, 1.11	1.09	1.03, 1.16	0.85	0.63, 1.13	1.02	0.92, 1.13
Political ideology	1.71	1.48, 1.98	1.55	1.37, 1.76	1.57	1.37, 1.79	1.26	1.09, 1.45	1.36	1.20, 1.55	1.16	1.01, 1.32	0.97	0.85, 1.11	1	0.56, 1.78	1.23	1.00, 1.52
Knowledge	0.37	0.29, 0.47	0.47	0.38, 0.57	0.46	0.37, 0.57	0.65	0.51, 0.82	0.61	0.50, 0.76	0.86	0.69, 1.08	0.68	0.54, 0.85	0.84	0.31, 2.27	0.67	0.47, 0.95
Religiosity	0.73	0.67, 0.80	0.77	0.71, 0.83	0.72	0.67, 0.79	0.89	0.81, 0.97	0.88	0.81, 0.95	0.93	0.85, 1.01	0.96	0.88, 1.04	0.88	0.62, 1.25	0.88	0.78, 1.00

Note. Significant variables are in bold. All variance inflation factors below 2. Number of observations used for analysis = 4640.

**Table 6.** Descriptive statistics by class membership.

		Classes									
		1	2	3	4	5	6	7	8	9	10
		Valid percentages									
Sex	Male	60.96	56.37	57.10	37.05	46.97	47.84	42.22	39.22	37.90	41.03
	Female	39.04	43.63	42.90	62.95	53.03	52.16	57.78	60.78	62.10	58.97
Age	18-29	16.12	10.50	14.07	12.59	16.98	11.98	9.63	13.33	4.84	12.82
	30-49	21.16	23.70	26.81	27.36	28.84	32.22	32.22	35.63	18.55	33.33
	50-64	23.43	31.49	31.70	31.23	32.88	32.81	33.89	32.87	35.48	20.51
	65+	39.29	34.32	27.41	28.81	21.29	22.99	24.26	18.16	41.13	33.33
Education	Highschool or less	14.36	15.45	10.21	26.63	15.61	24.12	17.59	25.92	29.03	38.46
	Associates degree or equivalent	30.48	29.60	28.11	34.14	32.30	32.16	36.67	36.93	31.45	33.33
	College graduate or higher	55.16	54.95	61.69	39.23	52.09	43.73	45.74	37.16	39.52	28.21
Political party	Republican	20.72	21.92	19.52	23.65	25.17	37.62	37.64	40.09	27.64	34.21
	Democrat	45.27	42.40	43.09	39.16	39.59	27.13	22.66	25.17	30.08	28.95
	Independent	26.34	27.07	30.33	28.33	25.03	26.14	28.28	21.91	30.89	21.05
	Something else	7.67	7.43	6.46	7.88	8.84	8.71	10.49	11.42	8.94	10.53
	Refuse to answer	.00	1.20	.60	.99	1.36	.40	.94	1.40	2.44	5.26
Knowledge	Not at all	24.18	13.40	15.09	8.29	9.18	5.29	8.36	6.70	7.56	8.33
	A little	50.38	60.97	61.09	50.00	56.55	49.02	51.12	39.49	50.42	33.33
	A lot	25.44	25.62	23.82	41.71	34.28	45.69	40.52	53.81	42.02	58.33
Political ideology	Mean (SD)	3.31 (1.13)	3.16 (1.06)	3.25 (1.04)	2.99 (1.08)	2.84 (1.07)	2.73 (1.05)	2.55 (1.08)	2.57 (1.07)	2.61 (1.20)	2.74 (1.17)
Religiosity	Median	1	2	1	2	5	5	5	5	5	5

Note. Mode and median reported where appropriate. Income is in \$1,000's of USD. Higher scores in political ideology and religiosity reflect greater levels of liberalism and religiosity. Highest N = 4726, lowest N = 4640.

## 6.6 Discussion

The current study sought to understand the structure of attitudes toward gene editing. In particular, we focused on how sentiment on a range of gene editing issues coalesce *within* groups of individuals (i.e. latent classes), and to test some potential predictors of membership of these classes. We observed evidence for 10 latent classes – consisting of 3 supportive of gene editing and 5 opposed to gene editing (with two further and small-sized classes that reflected a strong propensity to report majority ‘don’t know’ responses and so are not discussed further).

The coherence of sentiment in these classes is of some interest because while we saw some evidence for a continuum of support/opposition, we also noted clear qualitative distinctions between classes on specific items, where the classes were otherwise highly similar. While the analysis with the available indicators clearly identifies a group of respondents that is largely in favour and cannot see drawbacks (class 1, 9%) and three class that are opposed under all circumstances (classes 6 – 8, together 32%), the majority of respondents shows more mixed attitudes towards gene editing. The items about enthusiasm and worry mirror a wide range of between-class variability, while "As humans, we are always trying to better ourselves and this idea is no different", "equally healthy", and "much healthier" on the other hand lead to very clear distinctions, but conclusions based on these items alone would ignore the variability in classes 1-3 and 6-8.

For example, one of the opposing classes (Class 7) stood out from other opposer classes by virtue of a specific profile of belief that gene editing would lead to people feeling superior and more confident (but not that society would become more productive or innovative). We interpreted this as a class of people who are opposed to gene editing for social justice reasons: i.e. they view the technology as likely to create division/antipathy between those who can

afford and those who can't. And while we saw two classes (Classes 4 & 5) with very similar profiles on enthusiasm and worry about the use of gene editing (both were moderately unenthusiastic and worried), Class 4 felt gene editing was just humanity bettering itself and not a moral issue, whereas Class 5 had clear moral concerns about the technology.

This finding of qualitatively distinct profiles of attitudes even *within* classes of supporters or opposers has implications for communication strategies to the public with regard to the introduction of gene editing. For example, one take home message is that moral concerns are not monolithic across opposers and supporters: some such individuals clearly opposed gene editing because of more instrumental concerns (Class 3). Conversely, some supporters expressed a degree of uncertainty regarding the morality of gene editing (Class 4). In turn, communicating to those who oppose or support may still be advised to address moral issues (e.g. via religious leaders, or scientists respectively, as has been the case with abortion and contraception); but for some opposers and supporters, other factors clearly play a more pronounced role.

We also saw interesting links between a range of socio-demographic variables and membership of gene editing classes. Those with higher self-rated genetics knowledge were more likely to be members of the oppositional groups, which is contrary to previous research that found self-rated knowledge was positively associated with support for gene editing (Cebesoy & Öztekin, 2016; Črne-Hladnik et al., 2012). Conservatives, and those higher in religiosity were more likely to be members of oppositional groups, in line with previous findings (Critchley et al., 2019; Delhove et al., 2020; Hendriks et al., 2018; Scheufele et al., 2017). We also observed that women are more likely to be members of oppositional classes, a finding that aligns with several previous studies (Critchley et al., 2019; Delhove et al., 2020; Gaskell et al., 2017; Jedwab et al., 2020).

Some limitations of the current study are as follows. Firstly, the items used in our analyses refer to adults and babies interchangeably, which means we could not establish if the latent class structure was further differentiated across that important issue (Delhove et al., 2020). Secondly, whether gene editing constituted a treatment, or an enhancement was not specified in the item wordings, leaving participants to use their own interpretation (as discussed in Howell et al., 2020; So et al., 2017). Finally, these data were collected in 2016, and attitudes may have changed in the intervening time period in light of increasing knowledge and understanding (or misunderstanding) of gene editing technologies.

### ***Conclusion***

Our findings show that while attitudes towards gene editing can be organised roughly on a support/oppose continuum. There also exist attitudinal coherence within both supporter and opposer classes such that it is clear that the reasons for supporting (or opposing) often reflect different combinations of beliefs. In addition, several demographic predictors, such as sex, political ideology, self-rated gene editing knowledge, and religiosity significantly differed between strongly opposed and supportive groups. Overall, these results help to deepen our understanding of the ways in which people support or oppose gene editing technology, and the factors that may shape these attitudes.



# **Chapter 7: COVID-19 and seasonal flu vaccination hesitancy: Links to personality and general intelligence in a large, UK cohort**

**Isaac N. Halstead, Ryan T. McKay, & Gary J. Lewis**

## 7.1 Abstract

Vaccines are a powerful and relatively safe tool to protect against a range of serious diseases. Nonetheless, a sizeable minority of people express ‘vaccination hesitancy’. Accordingly, understanding the bases of this hesitancy represents a significant public health challenge. In the present study we sought to examine the role of Big Five personality traits and general intelligence as predictors of vaccination hesitancy, across two vaccination types, in a large (N= 9667) sample of UK adults drawn from the Understanding Society longitudinal household study. We found that lower general intelligence was associated with COVID-19 and seasonal flu vaccination hesitancy, and lower neuroticism was associated with COVID-19 vaccination hesitancy. Although the self-reported reasons for being vaccine hesitant indicated a range of factors were important to people, lower general intelligence was associated with virtually all of these reasons. In contrast, Big 5 personality traits showed more nuanced patterns of association. These findings provide important insights into vaccination hesitancy and help to reconcile some of the inconsistencies found in previous literature.

## 7.2 Introduction

Vaccines are among the most powerful disease-prevention tools medical science has at its disposal (Tahamtan et al., 2017.), and are leading the fight against the spread of COVID-19 (The World Health Organization, 2021). However, despite the success of vaccines in preventing the spread of disease, some individuals oppose their use. For example, recent polls indicate that 20% and 31% of the UK and US populations, respectively, are hesitant to take a COVID-19 vaccine (Funk & Tyson, 2021; Oxford University, 2021). Beyond COVID-19, vaccination hesitancy is a well-observed phenomenon extending to vaccines for human papillomavirus (Ziarnowski et al., 2009), influenza (Velan et al., 2011), and measles (Zimmerman et al., 1995).

These observations of vaccination hesitancy are of substantial medical and social importance as the rejection of vaccines can enable the spread of otherwise preventable diseases (Benecke & DeYoung, 2019; Hussain et al., 2018). For example, vaccination hesitancy can accelerate the rise of new disease variants, which may be resistant to the current suite of vaccines (Sah et al., 2021). With this in mind, there is a clear public health need to understand the factors that underpin vaccination hesitancy.

Research on this topic to date has highlighted a plethora of links. With regard to socio-demographic factors these include age (Schwarzinger et al., 2021), sex (Murphy et al., 2021), income (Feiring et al., 2015), education (Bertoncello et al., 2020), ethnicity (Nguyen et al., 2021; Razai et al., 2021) and political ideology (Hornsey et al., 2018). Specifically, younger people, women, those with lower income and education, those from minority ethnic backgrounds, and political conservatives are all more likely to reject vaccines. Reviews of the vaccination hesitancy literature suggest these relationships are relatively stable across studies (Dubé et al., 2015; Larson et al., 2014; Schellenberg & Crizzle, 2020).

Psychological constructs associated with vaccination hesitancy have also been reported. For example, an emerging literature has reported links to Big Five personality traits across a handful of studies. Lin and Wang (2020) observed that higher openness, agreeableness, and conscientiousness, and lower neuroticism were associated with a belief in the health benefits of vaccination. Lee et al. (2017) reported somewhat similar findings inasmuch as higher agreeableness and conscientiousness were associated with positive vaccination attitudes; but these authors also observed that *lower* openness was associated with positive vaccination attitudes, and no association with neuroticism was found. And Murphy et al. (2021) found only higher agreeableness to be predictive of pro-vaccination attitudes in an Irish sample: whereas in a UK sample they found higher agreeableness and conscientiousness, and lower neuroticism to be predictive of pro-vaccination attitudes. Across all of these studies, then, agreeableness and conscientiousness appear to show somewhat consistent links to vaccine sentiment, with tentative evidence for neuroticism and openness.

A range of cognitive traits have also shown links to vaccine sentiment. For example, Murphy et al. (2021) identified a negative relationship between vaccination hesitancy and cognitive reflection (operationalised as the ability to choose a correct but cognitively demanding answer over what on the face of it appears obvious but is nonetheless incorrect; Frederick, 2005). And a number of studies have indicated that vaccination hesitancy is associated with so-called ‘omission bias’ (Baron & Ritov, 2004), a cognitive bias whereby people are inclined to favour inaction over action, even when the relative risks across such decisions are held constant.

Collectively, then, these findings indicate that individual differences in a range of personality and cognitive traits are likely to be important for understanding why some people

are vaccine hesitant. However, a number of open questions remain that the current study sought to address.

Firstly, although associations between Big 5 traits and vaccination hesitancy have been reported, the nature of these associations has been somewhat mixed across studies. As detailed above, all of the Big Five traits (bar extraversion) have been linked to vaccination hesitancy. But these associations have not been consistent across studies, with openness even showing changes in direction.

Secondly, while cognitive traits have been linked to vaccination hesitancy, there has been no assessment yet of a role for general intelligence. Yet general intelligence is a clear candidate on several grounds. Firstly, general intelligence is typically considered to reflect the ability to solve complex problems, broadly conceived (Gottfredson, 1997). The question of whether to support or oppose vaccines would appear, in essence, to be a complex problem, inasmuch as it requires one to appraise and compare the risk probabilities and costs of two different phenomena: the vaccine side effect and the disease itself. More broadly, cognitive reflection scores are moderately associated ( $r \approx .40$ ) with a range of numerical ability measures (a facet of general intelligence), but both are independent predictors of performance in decision making tasks (Sobkow et al., 2020). General intelligence is also associated with educational attainment (Deary et al., 2005), with links in turn to vaccination attitudes (Bertoncello et al., 2020; Gilkey et al., 2014; Mora & Trapero-Bertran, 2018). As such, general intelligence may provide an important piece of the broader puzzle regarding vaccination hesitancy.

Thirdly, we sought to assess not just predictors of vaccination hesitancy per se, but how these predictors are associated with underlying self-reported reasons for being vaccine hesitant. It is well established that people have a variety of reasons for being opposed to vaccines,

including fear of side effects, not considering themselves to be at risk, or believing that vaccines are part of a ‘Big Pharma’ conspiracy. These reasons for vaccination hesitancy, at least *prima facie*, appear to reflect quite different underlying psychological bases. With this in mind it is important to establish not only what factors predict vaccination hesitancy *per se*, but whether there is differential prediction across the various reasons for being vaccination hesitant.

Finally, little is known of whether predictors of vaccination hesitancy generalise across diseases. On the one hand, Miton and Mercier (2015) highlight cognitive obstacles to vaccination, and discuss them in universal terms (e.g., all vaccines require counter-intuitive decision making, they are all informed by the same cognitive biases). On the other, there is evidence for differences between predictors across different vaccinations (e.g. the differences in personality predictors found in Lee et al., 2017 and Murphy et al., 2021 which examined childhood vaccines and COVID-19, respectively). Here we assess the extent to which predictors of vaccination hesitancy generalise across the emerging COVID-19 vaccine and the long-established seasonal flu vaccine.

To address these questions we used data from the Understanding Society longitudinal cohort study (University Of Essex, Institute for Social and Economic Research, 2020) , which has followed several thousand UK residents across 12 years and assessed a wide variety of socio-demographic and psychological traits – including the Big Five traits and intelligence. Importantly, the most recent waves of data have included measures of vaccination hesitancy both for COVID-19 vaccination (which at the time of data collection was not yet available) and for a seasonal flu vaccination (in a sub-sample of the dataset: 50-65 year olds). These data afforded us a powerful means to address our study questions.

### 7.3 Methods

#### *Participants*

Understanding Society (<https://www.understandingsociety.ac.uk/>) is a cohort study with a main survey, which is administered every year (currently up to Wave 12). There is also a survey that is specifically centred around the current COVID-19 pandemic which is sent out at irregular intervals to households who complete the main survey (currently up to Wave eight). We chose respondents who had completed Waves three (2013) and nine (2019) of the main survey (as they contained the personality and intelligence variables), and Wave six (November 2020) of the COVID-19 specific survey (for vaccination hesitancy variables). After removing participants who did not complete each of these waves, the sample used for analysis consisted of 9667 participants. A subset of this sample (N = 1485) was used for the analysis using the seasonal flu likelihood item, which was only issued to those aged 50-65 years. The main study sample was 58.2% female, with an average age of 54.75 years, and a median education level of A-level or equivalent. The seasonal flu subsample was 56% female, with an average of 53.9 years, and a median education level of A-level or equivalent.

#### *Measures*

##### ***COVID-19 vaccination hesitancy***

COVID-19 vaccination hesitancy was measured using a single item. Participants were asked to respond to the question *Imagine that a vaccine against COVID-19 was available for anyone who wanted it. How likely or unlikely would you be to take the vaccine?* Note, again, that at the point of assessment no COVID-19 vaccine had been approved for use in the UK and so the participants were responding to a hypothetical. Responses were recorded using a 4-point Likert scale, ranging from 1 = *Very likely* to 4 = *Very unlikely*.

### ***Reasons for declining the vaccine***

Participants who indicated they were unlikely or very unlikely to take the vaccine were asked *What is the main reason you would not take the vaccine?* There were 11 options given, as well as one *Other* option. Examples include: *The chances of me catching the coronavirus are low*; and *I am worried about unknown future effects of the vaccine* (see Table 6 for the full list of reasons).

### ***Seasonal flu vaccination hesitancy***

Seasonal flu vaccination hesitancy was measured using a single item, which was given to participants aged 50-65 who had not received the seasonal flu jab ( $n = 1433$ , after removing missing responses). Participants were asked to respond to the question *The Government has indicated that it may offer flu jabs to all those aged 50 – 64 in November and December. If this is offered to you, how likely are you to have a flu jab this autumn/winter?* Responses were recorded using a 4-point Likert scale, ranging from 1 = *Very likely* to 4 = *Very unlikely*.

### ***General Intelligence***

We operationalised general intelligence as the first principal component (which explained .39 of the total variance) from the following cognitive tests:

#### ***Numerical ability***

Numerical ability was measured using a task adapted from McArdle and Woodcock (2009). This task consists of five questions such as *In a sale, a shop is selling all items at half price. Before the sale, a sofa costs £300. How much will it cost in the sale?* The number of correct answers were used for analysis. A higher score indicated a higher level of numerical ability.

#### ***Verbal fluency***



Verbal fluency was measured using a task adapted from Strauss et al. (2006). Participants were asked to list all the animals that they could think of within 60 seconds. The number of correct answers were used for analysis. A higher score indicated a higher level of verbal fluency.

#### *Number series task*

The number series task was adapted from McArdle and Woodcock (2009). Participants are given up to six sequences of numbers that contain gaps that the participants are expected to fill (e.g. 2,4,?,8,10). A higher score on this measure indicates a greater quantitative reasoning ability.

#### *Subtraction*

Participants were also issued the subtract 7 task, which is a component of the Mini-Mental State Examination (MMSE) (Folstein et al., 1975). Participants were asked to complete a serial subtraction task where they initially subtracted seven from 100 and then repeated this process on the resulting numbers on five separate occasions (i.e. 93, 86, 79, 72, 65). The number of correct subtractions was used for analysis. A higher score indicates a higher level of subtraction ability.

#### *Delayed and immediate recall*

Memory was measured using a word recall task. Participants were given the following message: *The computer will now read a set of 10 words. I would like you to remember as many as you can. We have purposely made the list long so it will be difficult for anyone to remember all the words. Most people remember just a few.* Participants were then asked to immediately recall the words they had been given. Later on, they received this message: *A little while ago you were read a list of words and you repeated the ones you could remember. Please tell me any of the words that you can remember now.* A higher number of correctly recalled items on

each task indicated a better memory. Delayed and immediate recall were included as separate measures in the principal component analysis.

### ***Personality***

Big 5 personality traits were measured using the short form of the Big Five Inventory–2 (BFI-2-S; Soto & John, 2017). This measure consists of five subscales, one for each of the following constructs: agreeableness, extraversion, neuroticism, openness, and conscientiousness. Participants were asked to respond to statements (three per subscale) such as *I see myself as someone who is sometimes rude to others* (Agreeableness [reversed]); *I see myself as someone who is outgoing, sociable* (Extraversion); *I see myself as someone who worries a lot* (Neuroticism); *I see myself as someone who values artistic, aesthetic experiences* (Openness); and *I see myself as someone who does things efficiently* (Conscientiousness). Responses were recorded using a 7-point Likert scale, ranging from 1 = *Does not apply to me at all*, to 7 = *Applies to me perfectly*. The means of each subscale were used for analysis. The Cronbach's alpha for each trait is as follows: Agreeableness = .595; Extraversion = .681; Neuroticism = .740; Openness = .639; Conscientiousness = .540. Due to the low reliability of both conscientiousness and agreeableness, there may be a greater amount of measurement error in these variables. However, this has been noted before in these measures and is partially rectified by the large sample size used in this study (Perkins et al., 2000; Soto & John, 2017b).

### ***Self-rated COVID risk***

Self-rated COVID risk was measured using a single item. Participants were asked to answer the question: *In your view, how likely is it that you will contract COVID-19 in the next month?* Responses were recorded using a 4-point Likert scale, ranging from 1 = *Very likely*, to 4 = *Very Unlikely*, and reverse coded so that a higher score indicated a higher self-rated COVID risk.

### ***Mental health problems***

Mental health problems were measured using the scaled version of the General Health Questionnaire (GHQ12; Goldberg & Hillier, 1979). This measure consists of 12 items. Participants were asked to respond to questions such as *Have you recently felt that you were playing a useful part in things?* Responses were recorded using a 4-point Likert scale, ranging from 1 = *More so than usual*, to 4 = *Much less than usual*. The means of all the items were used for analysis. A higher score represents greater mental health problems. Cronbach's alpha = .923.

### ***Demographics***

Participants were asked to indicate their age, sex, income, and highest level of education. Sex was coded as Male = 0 and Female = 1. We collapsed education into five categories; *none, other (such as vocational qualifications that sit between no education and GCSE), GCSE or equivalent, A-level or equivalent, graduate or other higher degree* (as per Robertson et al., 2021). Participants were asked to estimate their income derived from all possible sources (i.e., social benefit, pension, labour income, miscellaneous income, private benefit income, and investment income).

## 7.4 Results

Summary statistics for all study variables are presented in Table 1.

**Table 1. Descriptive statistics for study variables**

Variable	Mean	SD	Response options	Valid Percent
COVID-19 vaccination hesitancy	-	-	Very Likely	61.35
			Likely	25.77
			Unlikely	8.13
			Very Unlikely	4.75
Seasonal flu vaccination hesitancy	-	-	Very Likely	40.20
			Likely	28.22
			Unlikely	18.18
			Very Unlikely	13.40
Numerical ability	3.96	0.99		
Verbal fluency	23.8	6.56		
Number series score	2.09	0.89		
Subtraction ability	4.63	0.83		
Delayed word recall	5.76	1.90		
Immediate word recall	6.73	1.49		
Agreeableness	5.62	0.94		
Extraversion	4.54	1.26		
Neuroticism	3.56	1.36		
Openness	4.62	1.17		
Conscientiousness	5.57	0.97		
Self-rated COVID-19 risk	-	-	Very Likely	24.94
			Likely	66.87
			Unlikely	7.36
			Very Unlikely	0.82
Mental health problems	1.56	0.49		
Education	-	-	None	17.68
			Other	1.37
			GCSE	23.03
			A-level	9.53
			Graduate	48.40
Income (month)	2160.57	1743.73		

Note: *Very Likely* indicates very likely to take the vaccine.

### ***COVID-19 Vaccination Hesitancy (full sample)***

We first examined zero-order correlations for COVID-19 vaccination hesitancy. These analyses showed several significant links to COVID-19 vaccination hesitancy. Of the

psychological variables, individuals with lower general intelligence and openness, higher neuroticism and self-rated COVID risk and poorer mental health were more likely to be vaccine hesitant. Regarding demographic variables, younger respondents, women, and those with lower education and income were more likely to be vaccine hesitant (see Table 2 for full results).

We next conducted an ordinal logistic regression analysis using COVID-19 vaccination hesitancy as the dependent variable and the full collection of demographic, personality, and cognitive traits as independent variables. Of the psychological variables, lower intelligence and neuroticism, and worse mental health predicted greater COVID-19 vaccination hesitancy. Regarding demographic variables, COVID-19 vaccination hesitancy was positively and significantly predicted by being younger, female, and less educated, with a lower income. For full information, see Table 3.

The ordinal logistic regression model assumes that the link function between each predictor and each category of the dependent variable has the same shape. This can be examined with the Brant test (Brant, 1990; Williams, 2006). For our key study variables (i.e., general intelligence and Big five personality traits) we saw no evidence of assumption violations (all  $p$ 's  $> .05$ ). However, the test indicated potential violations for self-rated COVID risk and mental health problems ( $\chi^2_{df=2} = 60.71, p < .001$  and  $\chi^2_{df=2} = 9.41, p = .01$ , respectively). As such, the reported odds ratio may differ across the levels of these independent variables.

#### ***Seasonal Flu and COVID-19 Vaccination Hesitancy (50-65 Years Sub-sample)***

We next moved to our sub-sample of 50–65-year-olds for whom we had additional information on seasonal flu vaccination hesitancy. As above, we first examined zero-order correlations. These analyses showed several significant links to seasonal flu vaccination hesitancy: specifically, younger respondents, those with lower general intelligence and

education, and those with higher neuroticism and self-rated COVID-19 risk were more likely to be vaccine hesitant (see Table 4 for full results). We also performed these analyses for COVID-19 vaccination hesitancy with just the 50–65-year sub-sample to provide a direct comparison (see Table 4). The associations between COVID-19 vaccination hesitancy and the demographic variables were broadly as reported in the full sample, with those who are younger, women, less educated and with a lower income being higher in COVID-19 vaccination hesitancy. Of the psychological measures, lower intelligence and worse mental health were associated with greater vaccination hesitancy across both samples. However, self-rated COVID-19 risk was not significantly associated with COVID-19 vaccination hesitancy in the 50-65 sample, and higher agreeableness and extraversion predicted greater COVID-19 vaccination hesitancy.

We next performed two ordinal logistic regression analyses with COVID-19 and seasonal flu vaccination hesitancy as the dependent variables and the full collection of demographic, psychological variables as well as COVID and seasonal flu vaccination hesitancy as independent variables in the 50-65 year sub-sample.

#### *Seasonal Flu*

Of the psychological variables, higher COVID vaccination hesitancy and lower self-rated COVID risk predicted greater seasonal flu vaccination hesitancy. Regarding demographic variables, seasonal flu vaccination hesitancy was positively predicted by being younger, male and less educated. For full information, see Table 5.

#### *COVID-19*

Of the psychological variables, higher seasonal flu vaccination hesitancy, lower intelligence and higher extraversion predicted greater COVID-19 vaccination hesitancy.

Regarding demographic variables, those who were younger, female, and with a lower income had greater COVID-19 vaccination hesitancy. For full information, see Table 5.

As before, we tested for assumption violation using the Brant test. Across seasonal flu and COVID-19 we again saw no evidence of assumption violations for the key study variables (all  $p > .05$ ). However, the test indicated potential violations in the seasonal flu model for COVID 19 vaccination hesitancy ( $\chi^2_{df=2} = 10.39, p = .01$ ) age ( $\chi^2_{df=2} = 11.17, p < .001$ ) and income ( $\chi^2_{df=2} = 6.89, p = .03$ ). And in the COVID-19 model, the test indicated a potential violation for seasonal flu vaccination hesitancy ( $\chi^2_{df=2} = 13.92, p = < .001$ ) and self-rated COVID risk ( $\chi^2_{df=2} = 10.13, p = .01$ ). Again, the reported odds ratio may differ across the levels of these independent variables.

### ***Reasons for Vaccination hesitancy***

In a final set of steps, we sought to understand a) the reasons given for being hesitant to take the COVID-19 vaccine and b) whether our demographic and psychological variables showed differential prediction across these reasons.

Table 6 outlines the possible response options and the relative importance of each of these reasons for vaccination hesitancy. The top five specific concerns (i.e., excluding “Other”) were: *I am worried about unknown future effects of the vaccine* (49.70%); *I am worried about side effects* (10.55%); *Vaccines are limited and other people need it more than me* (8.64%); *I don't trust vaccines* (5.79%); and *The chances of me becoming seriously unwell from the coronavirus are low* (5.27%).

We next conducted a multinomial logistic regression, with vaccine acceptance as the reference outcome, and the top 5 reasons to decline vaccination as the other outcomes (which constituted ~80% of total responses; all other response options had <4% (excluding the “Other” responses)), to examine whether our study variables predicted membership to these vaccination

hesitancy groups. Descriptive statistics for all study variables across these six categories (i.e. vaccine acceptance and the top 5 reasons for vaccination hesitancy) are detailed in Table 7.

Relative to the vaccine accepters, those that reported vaccination hesitancy due to doubting they would personally become severely unwell from COVID-19 were significantly less agreeable and neurotic, but more conscientious, and (perhaps unsurprisingly) rated themselves to be at a lower risk of catching COVID-19. Those who reported vaccination hesitancy because others need the vaccine more than themselves were more likely to be young and female, significantly less neurotic, rated themselves to be at lower risk of catching COVID-19, scored lower in intelligence, and had better mental health. Those who reported vaccination hesitancy due to the immediate side effects of the vaccine scored lower in intelligence, rated their COVID-19 risk to be lower, had worse mental health, were younger, and more likely to be female. Those who reported vaccination hesitancy because they were concerned about the future effects of the vaccine scored significantly lower in intelligence and extraversion, higher on conscientiousness, and were younger, less educated, and more likely to be female. Those who reported vaccination hesitancy because they do not trust vaccines scored significantly lower on intelligence, higher in extraversion and openness, had poorer mental health, had a lower self-rated COVID-19 risk, were younger, less educated, and more likely to be female. Full results are detailed in Table 7 and 8.



**Table 2.** Spearman correlations for COVID-19 vaccination hesitancy using the full sample.

	COVID vaccination hesitancy	Intelligence	Agreeableness	Extraversion	Neuroticism	Openness	Conscientiousness	Self-rated COVID risk	Mental health problems	Age	Sex	Education
<b>COVID</b>												
Intelligence	-0.09**											
Agreeableness	0.00	-0.08**										
Extraversion	0.00	0.00	0.19**									
Neuroticism	0.06**	-0.02	-0.09**	-0.20**								
Openness	-0.06**	0.13**	0.20**	0.25**	-0.11**							
Conscientiousness	-0.01	-0.04*	0.33**	0.21**	-0.16**	0.17**						
Self-rated COVID risk	0.04**	0.04*	-0.02	-0.04**	0.11**	-0.04*	-0.06**					
Mental health problems	0.09**	0.00	-0.02*	-0.07**	0.35**	-0.01	-0.11**	0.14**				
Age	-0.31**	-0.16**	0.04*	-0.02	-0.18**	0.03*	0.07**	-0.17**	-0.18**			
Sex	0.13**	-0.04*	0.17**	0.13**	0.20**	-0.08**	0.12**	0.07**	0.16**	-0.11**		
Education	-0.06**	0.32**	-0.06**	-0.01	0.02	0.15**	-0.05**	0.03*	0.05**	-0.16**	0.04*	
Income	-0.07**	0.25**	-0.10**	-0.01	-0.12**	0.05**	0.00	0.02*	-0.07**	-0.14**	-0.29**	0.26**

Note: \*\* =  $p < .001$ , \* =  $p < .05$ . Male = 0, Female = 1.

**Table 3.** Ordinal logistic regression model for COVID-19 vaccination hesitancy using the full sample.

<b>Characteristic</b>	<b>OR<sup>1</sup></b>	<b>95% CI<sup>1</sup></b>	<b>p-value</b>
Intelligence	<b>0.86</b>	<b>0.83, 0.89</b>	<b>&lt;0.001</b>
Agreeableness	0.96	0.91, 1.02	0.163
Extraversion	0.97	0.93, 1.01	0.143
Neuroticism	<b>0.94</b>	<b>0.90, 0.98</b>	<b>0.002</b>
Openness	0.97	0.93, 1.01	0.144
Conscientiousness	1.03	0.97, 1.09	0.327
Self-rated COVID risk	0.93	0.86, 1.02	0.113
Mental health problems	<b>1.19</b>	<b>1.07, 1.32</b>	<b>0.001</b>
Age	<b>0.95</b>	<b>0.95, 0.95</b>	<b>&lt;0.001</b>
Sex	<b>1.44</b>	<b>1.29, 1.61</b>	<b>&lt;0.001</b>
Education	<b>0.91</b>	<b>0.88, 0.94</b>	<b>&lt;0.001</b>
Income	<b>1.00</b>	<b>1.00, 1.00</b>	<b>&lt;0.001</b>

<sup>1</sup> OR = Odds Ratio, CI = Confidence Interval

**Table 4.** Spearman correlations for seasonal flu and COVID-19 hesitancy in the 50-65 years sub-sample.

	Seasonal flu vaccination hesitancy	COVID vaccination hesitancy	Intelligence	Agreeableness	Extraversion	Neuroticism	Openness	Conscientiousness	Self- rated COVID risk	Mental health problems	Age	Sex	Education
<b>Seasonal flu</b>													
<b>COVID</b>	0.55**												
<b>Intelligence</b>	-0.10*	-0.18**											
<b>Agreeableness</b>	-0.01	0.06*	-0.12**										
<b>Extraversion</b>	0.04	0.06*	-0.02	0.20**									
<b>Neuroticism</b>	-0.08**	0.02	-0.04	-0.09**	-0.21**								
<b>Openness</b>	-0.01	-0.02	0.13**	0.16**	0.25**	-0.06*							
<b>Conscientiousness</b>	0.01	0.02	-0.08**	0.34**	0.23**	-0.17**	0.13**						
<b>Self-rated COVID risk</b>	-0.09*	-0.02	0.00	-0.02	-0.01	0.02	-0.03	-0.06*					
<b>Mental health problems</b>	-0.04	0.08**	-0.04	-0.03	-0.02	0.33**	0.00	-0.17**	0.11**				
<b>Age</b>	-0.14**	-0.12**	-0.02	0.02	-0.04	-0.02	-0.04	0.05	-0.04	-0.12**			
<b>Sex</b>	-0.04	0.08**	-0.03	0.20**	0.18**	0.13**	-0.04	0.16**	0.01	0.12**	-0.03		
<b>Education</b>	-0.12**	-0.14**	0.30**	-0.06*	-0.02	0.01	0.20**	-0.02	-0.02	0.02	-0.04	0.06	
<b>Income</b>	-0.05	-0.14**	0.22**	-0.12**	-0.02	-0.14**	0.04	0.00	0.01	-0.14**	-0.09**	-0.32**	0.20**

Note: \*\* =  $p < .001$ , \* =  $p < .05$ . Male = 0, Female = 1.

**Table 5.** Ordinal logistic regression models for seasonal flu and COVID-19 vaccination hesitancy in the 50-65 sample.

<b>Characteristic</b>	Seasonal Flu			COVID-19		
	<b>OR1</b>	<b>95% CI<sup>1</sup></b>	<b>p-value</b>	<b>OR1</b>	<b>95% CI<sup>1</sup></b>	<b>p-value</b>
COVID/Seasonal flu vaccination hesitancy	<b>4.98</b>	<b>4.22, 5.90</b>	<b>&lt;0.001</b>	<b>3.70</b>	<b>3.22, 4.27</b>	<b>&lt;0.001</b>
Intelligence	1.01	0.94, 1.10	0.725	<b>0.84</b>	<b>0.77, 0.92</b>	<b>&lt;0.001</b>
Agreeableness	0.89	0.77, 1.02	0.093	1.10	0.95, 1.29	0.199
Extraversion	0.95	0.86, 1.06	0.366	<b>1.12</b>	<b>1.00, 1.25</b>	<b>0.046</b>
Neuroticism	<b>0.90</b>	<b>0.82, 0.99</b>	<b>0.035</b>	1.09	0.98, 1.21	0.120
Openness	1.06	0.95, 1.18	0.307	0.95	0.84, 1.07	0.391
Conscientiousness	1.00	0.87, 1.15	0.989	1.00	0.86, 1.15	0.951
Self-rated COVID risk	<b>0.73</b>	<b>0.60, 0.90</b>	<b>0.003</b>	1.18	0.94, 1.47	0.147
Mental health problems	0.84	0.64, 1.11	0.217	1.24	0.93, 1.66	0.144
Age	<b>0.96</b>	<b>0.94, 0.99</b>	<b>0.006</b>	<b>0.97</b>	<b>0.94, 1.00</b>	<b>0.042</b>
Sex	<b>0.77</b>	<b>0.59, 0.99</b>	<b>0.043</b>	<b>1.47</b>	<b>1.11, 1.95</b>	<b>0.008</b>
Education	<b>0.89</b>	<b>0.82, 0.97</b>	<b>0.010</b>	0.97	0.88, 1.06	0.481
Income	1.00	1.00, 1.00	0.405	<b>1.00</b>	<b>1.00, 1.00</b>	<b>0.005</b>

<sup>1</sup> OR = Odds Ratio, CI = Confidence Interval

**Table 6.** Reasons to decline vaccination in those who are vaccine hesitant.

Item	Response frequency (N)	Response frequency (%)
<b>I am worried about unknown future effects of the vaccine</b>	<b>575</b>	<b>49.70</b>
<b>I am worried about side effects</b>	<b>122</b>	<b>10.55</b>
Other	105	9.08
<b>Vaccines are limited and other people need it more than me</b>	<b>100</b>	<b>8.64</b>
<b>I don't trust vaccines</b>	<b>67</b>	<b>5.79</b>
<b>The chances of me becoming seriously unwell from the coronavirus are low</b>	<b>61</b>	<b>5.27</b>
The chances of me catching the coronavirus are low	38	3.28
The impact of the coronavirus is being greatly exaggerated	35	3.03
I have a condition which would make it unsafe for me	22	1.90
I don't think it would be effective at stopping me catching the coronavirus	18	1.56
I don't think I would be offered the vaccine for free and I wouldn't pay for it	8	0.69
Herd immunity will protect me even if I don't have the vaccine	6	0.52

**Note:** Reasons that were retained for multinomial logistic regression analysis are bolded.

**Table 7.** Descriptive statistics for each of the top 5 reasons for COVID-19 vaccination hesitancy.

	Intelligence		Agreeableness		Extraversion		Neuroticism		Openness		Conscientiousness		Self-rated COVID risk		Mental health problems		Age		Sex	Education		Income	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	% Male	M	SD	M	SD
1	0.05	1.51	5.62	.93	4.53	1.26	3.54	1.35	4.64	1.16	5.57	.96	1.84	.56	2.02	.47	56.09	13.77	42.83	4	1.51	2213.31	1777.64
2	-0.16	1.59	5.68	.95	4.58	1.31	3.69	1.45	4.55	1.24	5.66	1.00	1.90	.65	2.10	.56	47.26	12.22	25.09	4	1.44	1939.76	1425.63
3	-0.76	1.57	5.65	.94	4.57	1.04	3.86	1.28	4.5	1.17	5.51	1.03	1.79	.61	2.11	.50	48.92	13.97	35.00	3	1.40	1741.99	1430.89
4	-0.41	1.57	5.52	1.11	4.64	1.24	3.46	1.19	4.49	1.20	5.54	.92	1.79	.59	2.01	.46	45.72	13.03	33.00	4	1.38	1797.16	1305.33
5	-0.66	1.71	5.61	1.05	4.93	1.18	3.66	1.44	4.92	1.39	5.48	1.02	1.53	.73	2.28	.66	50.00	14.27	32.31	3	1.51	1678.20	1491.79
6	0.07	1.45	5.39	1.04	4.51	1.21	3.4	1.21	4.65	.95	5.50	.99	1.79	.55	2.11	.45	39.79	9.78	36.67	5	1.28	2212.21	1735.92

Note: 1 = Vaccine acceptance, 2 = I am worried about unknown future effects of the vaccine, 3= I am worried about side effects, 4= Vaccines are limited and other people need it more than me, 5 = I don't trust vaccines, 6 = The chances of me becoming seriously unwell from the coronavirus are low.

**Table 8.** Multinomial logistic regression for reasons underlying COVID-19 vaccination hesitancy.

Variable	OR <sup>I</sup>	95% CI <sup>I</sup>	p-value	OR <sup>I</sup>	95% CI <sup>I</sup>	p-value	OR <sup>I</sup>	95% CI <sup>I</sup>	p-value	OR <sup>I</sup>	95% CI <sup>I</sup>	p-value	OR <sup>I</sup>	95% CI <sup>I</sup>	p-value
	2			3			4			5			6		
Intelligence	0.92	0.76, 1.11	0.37	<b>0.79</b>	<b>0.69, 0.91</b>	<b>0.001</b>	<b>0.71</b>	<b>0.63, 0.81</b>	<b>&lt;0.001</b>	<b>0.89</b>	<b>0.84, 0.95</b>	<b>&lt;0.001</b>	<b>0.78</b>	<b>0.66, 0.92</b>	<b>0.004</b>
Agreeableness	<b>0.78</b>	<b>0.65, 0.93</b>	<b>0.006</b>	0.86	0.69, 1.07	0.17	0.99	0.80, 1.22	0.92	1.02	0.91, 1.13	0.76	0.96	0.74, 1.25	0.76
Extraversion	0.88	0.71, 1.09	0.26	0.99	0.83, 1.18	0.92	1.01	0.85, 1.19	0.95	0.93	0.86, 1.01	0.07	<b>1.3</b>	<b>1.04, 1.63</b>	<b>0.023</b>
Neuroticism	<b>0.75</b>	<b>0.62, 0.90</b>	<b>0.002</b>	<b>0.83</b>	<b>0.72, 0.95</b>	<b>0.009</b>	1.03	0.90, 1.16	0.7	0.95	0.88, 1.02	0.15	1	0.85, 1.17	0.97
Openness	1.05	0.83, 1.34	0.69	0.94	0.78, 1.13	0.48	1.03	0.86, 1.23	0.73	0.96	0.88, 1.04	0.33	<b>1.33</b>	<b>1.05, 1.68</b>	<b>0.019</b>
Conscientiousness	<b>1.14</b>	<b>1.02, 1.28</b>	<b>0.021</b>	1.05	0.84, 1.31	0.67	0.96	0.78, 1.18	0.7	<b>1.15</b>	<b>1.03, 1.28</b>	<b>0.011</b>	0.8	0.62, 1.04	0.1
Self-rated COVID risk	<b>0.6</b>	<b>0.59, 0.62</b>	<b>&lt;0.001</b>	<b>0.7</b>	<b>0.69, 0.72</b>	<b>&lt;0.001</b>	<b>0.73</b>	<b>0.72, 0.74</b>	<b>&lt;0.001</b>	0.9	0.77, 1.06	0.2	<b>0.26</b>	<b>0.26, 0.27</b>	<b>&lt;0.001</b>
Mental health problems	<b>1.21</b>	<b>1.17, 1.25</b>	<b>&lt;0.001</b>	<b>0.91</b>	<b>0.89, 0.94</b>	<b>&lt;0.001</b>	<b>1.12</b>	<b>1.09, 1.14</b>	<b>&lt;0.001</b>	1.07	0.89, 1.29	0.48	<b>2</b>	<b>1.92, 2.07</b>	<b>&lt;0.001</b>
Age	<b>0.91</b>	<b>0.89, 0.93</b>	<b>&lt;0.001</b>	<b>0.94</b>	<b>0.93, 0.95</b>	<b>&lt;0.001</b>	<b>0.95</b>	<b>0.94, 0.97</b>	<b>&lt;0.001</b>	<b>0.95</b>	<b>0.94, 0.96</b>	<b>&lt;0.001</b>	<b>0.96</b>	<b>0.95, 0.98</b>	<b>&lt;0.001</b>
Sex	<b>1.23</b>	<b>1.19, 1.28</b>	<b>&lt;0.001</b>	<b>1.39</b>	<b>1.35, 1.43</b>	<b>&lt;0.001</b>	<b>1.04</b>	<b>1.01, 1.07</b>	<b>0.008</b>	<b>1.85</b>	<b>1.47, 2.34</b>	<b>&lt;0.001</b>	<b>1.44</b>	<b>1.38, 1.50</b>	<b>&lt;0.001</b>
Education	1.01	0.82, 1.25	0.9	0.99	0.85, 1.15	0.87	0.97	0.84, 1.12	0.68	<b>0.91</b>	<b>0.85, 0.98</b>	<b>0.01</b>	<b>0.79</b>	<b>0.67, 0.94</b>	<b>0.009</b>
Income	1	1.00, 1.00	0.68	1	1.00, 1.00	0.063	<b>1</b>	<b>1.00, 1.00</b>	<b>0.015</b>	<b>1</b>	<b>1.00, 1.00</b>	<b>0.027</b>	1	1.00, 1.00	0.12

Note: 1 = Vaccine acceptance, 2 = I am worried about unknown future effects of the vaccine, 3 = I am worried about side effects, 4 = Vaccines are limited and other people need it more than me, 5 = I don't trust vaccines, 6 = The chances of me becoming seriously unwell from the coronavirus are low.

## 7.5 Discussion

The current study sought to address several outstanding questions concerning the psychological bases of vaccination hesitancy: specifically, the nature of any links to general intelligence and Big Five personality traits; whether predictors of vaccination hesitancy in the context of COVID-19 are also seen for vaccination hesitancy in the context of seasonal flu; and whether predictors of COVID-19 vaccination hesitancy differ across the (self-reported) motives for being hesitant.

Lower intelligence had a small but consistent association with greater vaccination hesitancy across both samples, and both types of vaccine. This finding is in line with findings that those with a more intuitive style of cognition were less likely to vaccinate, those with a more analytical style of cognition were more likely to vaccinate, and those with lower cognitive sophistication scores were more susceptible to vaccine misperceptions (Pennycook et al., 2020b). However, given intelligence's modest correlation with cognitive styles (Sobkow et al., 2020), it appears that intelligence provides a meaningful, independent contribution to vaccination hesitancy.

In contrast, the roles of personality traits in COVID-19 vaccination hesitancy were more mixed. When examining COVID-19 vaccination hesitancy in our full sample, we observed zero order effects of neuroticism and openness. However, we noted in the regression a reversal of the neuroticism relationship direction (from a positive association with greater vaccination hesitancy, to a negative association) and no evidence for openness. One possibility is that the pathological aspect of neuroticism tends to drive up vaccination hesitancy. But when this variance is accounted for by directly including a mental health measure in the model the



residual variance in neuroticism may reflect pessimistic appraisals of the risk presented by the virus.

In the 50-65 group, there are several noteworthy differences in the relationship between traits and hesitancy compared to the main sample. Firstly, neuroticism was not predictive of COVID-19 vaccination hesitancy in this group. This may be due to the increased risk that the virus presents to this age category, which may suppress any association between trait-level neuroticism and vaccination hesitancy. Secondly, extraversion was a significant predictor of COVID-19 vaccination hesitancy in the 50-65 group, but not in the main sample. We do not have a compelling explanation for this observation.

Beyond personality and general intelligence, we also observed additional demographic variables predictive of COVID-19 vaccination hesitancy. Results from our regression analyses indicated that younger respondents, women, those with lower income, education, and poorer mental health were more likely to be vaccine hesitant. We saw broadly equivalent results for seasonal flu vaccination hesitancy (note, restricted to 50-65 year olds): being younger and less educated, predicted hesitancy.

In our multinomial logistic regression model, intelligence was a significant negative predictor for all but one of the reasons (worry over the future effects of the vaccine) that people chose to decline COVID-19 vaccination. Personality traits differentially predicted reasons to decline COVID-19 vaccination. For example, participants with higher conscientiousness were more distrustful of the vaccine, those with lower neuroticism were worried about the vaccine's effects (presumably more than the virus symptoms), and those with higher openness and extraversion doubted the level of risk presented by the virus.

The multinomial logistic regression findings should be interpreted with a degree of caution due to the relatively small samples in some of these categories. Nonetheless, these results may help to explain mixed results between personality and vaccination hesitancy across studies. That is, if a given sample happens to have more individuals who distrust vaccines vs fear side-effects, then the profile of predictors may well look very different. These findings, then, represent an important observation in their own right with regard to understanding the underlying bases for being vaccine hesitant, but also indicate future work on this topic should assess the reasons people have for opposing vaccines and not simply assess vaccination hesitancy alone.

Some limitations of the current study bear mention. Firstly, we used short-form Big 5 personality scales, which provide lower fidelity assessment of personality traits than would be desirable. That said, this approach is recommended in large, cohort settings where long-form instruments cannot be easily administered. Moreover, these short form measures are strongly associated with longer form measures (e.g. Rammstedt et al., 2020; Soto & John, 2017); although we did not have the opportunity to validate this observation in the current sample). Secondly, while we had access to an important set of candidate predictors, clearly there are other factors that shape vaccination hesitancy. Future work should consider including factors such as pathogen disgust sensitivity, for which there is inconsistent evidence (see Inbar & Pizarro, 2021), or moral disgust sensitivity, given the anti-vaccination narratives that governments and pharmaceutical companies are misleading the public. Thirdly, the associations found with seasonal flu vaccination hesitancy may be partly explained by the current COVID-19 pandemic, which has resulted in people taking up more preventative health measures (Kapoor & Singhal, 2021; Raude et al., 2020). The seasonal flu vaccine represents a preventative health measure, as it would be protective against a flu infection occurring at the

same time as a potential COVID infection, which may lead to associations carrying over from COVID to flu. This possibility is supported by the large correlation between seasonal flu and COVID-19 vaccination hesitancy. However, from our regression results in the sub-sample, there appear to be some unique differences in their relationships to our predictor variables.

In summary, intelligence is a significant predictor of COVID vaccination hesitancy, which generalises to at least one other form of vaccination. There is also a degree of heterogeneity in predictors of specific motivations to be vaccine hesitant. However, the predictors of vaccination hesitancy across vaccination types are largely homogeneous. These results provide an important and nuanced insight into vaccination hesitancy and help to reconcile some of the inconsistencies found in previous literature.

## Chapter 8: Discussion

### 8.1 Thesis Overview

This thesis was intended to provide a number of novel insights into the under researched area of biotechnology attitudes, with a focus on gene editing. I have identified several novel relationships between a number of cognitive and personality measures and attitudes towards gene editing, cultured meat, GM crops, nanotechnology, and vaccines.

My thesis' empirical chapters were intended to focus on addressing gaps in the literature, resolving disagreements, and shedding light on particular theoretical explanations in the context of biotechnology attitudes. Firstly, I identified pathogen disgust sensitivity as a predictor of support for gene editing, and opposition to vaccination, cultured meat, and GM crops. Secondly, I identified the presence of omission bias in two novel domains – gene editing and nanotechnology, and re-examined vaccination, which provided useful insights that should inform future omission bias research. Thirdly, I found that higher SDO and lower Synthetic Aversion predicted support for animal centred gene editing for the purposes of pest control. Fourthly, I examined the underlying latent structure of gene editing attitudes and identified several heterogeneous classes of supporters and opposers, who have qualitatively different beliefs that inform their attitudes. Finally, I identified lower intelligence and neuroticism as predictors of vaccination hesitancy, as well as identifying a number of personality traits that differentially predicted reasons to decline vaccination, and compared predictors across two different types of vaccination. In combination these findings provide novel insights into the role of psychological constructs in predicting attitudes to a broad range of biotechnologies.

This final chapter is intended to discuss each of the empirical chapters, relate them to broader theory, identify limitations, and outline how both the theoretical implications and limitations of my research may be used to inform future research.

## 8.2 Main Research Questions and Findings

### Study 1 - Understanding Opposition to Human Gene Editing: A Role for Pathogen Disgust Sensitivity?

Previous research had suggested that pathogen disgust underlies some of the opposition towards biotechnologies such as GM crops and cultured meat (Scott et al., 2016; Siegrist et al., 2018), however this had not been explored in gene editing. I conducted this study with the intent to explore the potential role of pathogen disgust in gene editing attitudes.

Using 347 participants, I tested whether higher scores on pathogen disgust sensitivity and a broad range of other conceivable predictors would predict higher levels of opposition to gene editing, cultured meat, GM crops, and vaccination. Using multiple regression to control for potential confounds, such as sex, trust in science, and political ideology, I found the inverse to be the case – higher pathogen disgust sensitivity scores were associated with lower opposition to gene editing. This relationship was replicated when the conceptually similar Core disgust sensitivity measure was used (which contains items similar to pathogen disgust sensitivity), supporting the robustness of the relationship between pathogen disgust sensitivity and gene editing attitudes.

This study provides several novel insights. Firstly, it identifies the underlying latent structure of gene editing attitudes, which highlights individuals assess gene editing across two broad factors of enhancement or treatment, rather than considering the recipient of the gene editing. Typically, gene editing attitudes are measured using items that relate to enhancement or treatment applications, or whether the target of the edit is an adult or baby. This study shows evidence that the target of gene editing is interchangeable (at least in our sample), and that the key determinant of gene editing attitudes lies in whether the editing is for treatment or enhancement. Future research would benefit from clearer differentiation between whether a gene edit is a treatment or an enhancement, which can be ambiguous in some survey data (See

comments regarding the Pew Research Centre data in Study 4, or Howell et al. (2020)). Furthermore, given the clear divide in opinion between treatment and enhancement, greater lengths should be gone to in order to identify at what point the public considers a gene edit an enhancement. Currently there is no research that examines this question, with only discussions by bioethics scholars on the topic (Juengst et al., 2018). For example, is increasing a person's disease resistance an enhancement, or a preventative treatment?

Secondly, this study provides initial evidence for pathogen disgust functioning differently depending on the type of biotechnology. Pathogen disgust sensitivity showed clear positive associations with opposition to cultured meats, GM crops, and vaccination. However, this relationship was reversed for opposition to gene editing. Typically, biotechnologies share many of the same predictors and directions of association, such as gender, trust in science, religiosity, and age (Bertoncello et al., 2020; Delhove et al., 2020; Lin & Wang, 2020; Monaghan et al., 2020; Siegrist, 2010; Simon, 2012; Zarobkiewicz et al., 2017). This finding, while contrary to prediction, was not entirely surprising. Given the potential for gene editing to correct diseases causing genes, it is logical that participants may perceive it as a way to reduce pathogens, rather than representing a pathogen risk. We were led to predict the reverse primarily due to the previous findings that biotechnologies have previously constituted a pathogenic risk (Scott et al., 2016; Siegrist et al., 2018; Siegrist & Sütterlin, 2017), even if they are intended to prevent disease, such as in the case of vaccines (Reuben et al., 2020). Given we utilised robustness checks, controlled for confounds and employed a well-powered sample, this finding is more than a simple case of error.

The association between pathogen disgust and biotechnology attitudes also opens up opportunities to experimentally manipulate information given to participants, to see whether the relationship between pathogen disgust sensitivity and biotechnology attitudes are changeable depending on message framing. For example, some of the opposition to vaccination

could be mitigated with message framing that highlights the reduction of pathogens that come as a result of using this technology. Similarly, the relationship between gene editing and pathogen disgust sensitivity may be reversed if the public are provided with information that highlights the unnatural and invasive introduction of unknown substances into their bodies.

Finally, this study contributes to the literature that suggests pathogen disgust sensitivity is a conservative response. It appears that it is associated with a number of constructs that do not present *prima facie*, explicit pathogenic risks, such as cultured meat, or vaccines. This suggests that mechanisms for detecting pathogens are hypersensitive, because the cost of failing to detect a pathogen is greater than the cost of falsely detecting a non-existent pathogen. This may be explored further by researchers examining the behavioural immune system, using signal detection (Stanislaw & Todorov, 1999), or drift diffusion models (Bitzer et al., 2014) to identify whether individuals have a lower threshold for identifying potential pathogenic threats, or whether their pathogen disgust sensitivity inclines them towards exhibiting higher false positive responses to “unnatural” targets that do not present an explicit pathogenic risk.

## **Study 2 – Opposition to Novel Biotechnologies: Testing An Omission Bias Account**

There is evidence for omission bias existing in vaccination decision making, where an individual prefers, with all outcomes being equal, inaction over action (Asch et al., 1994; Baron & Ritov, 2004). However, there are also studies that cast doubt on the existence of this bias (Connolly & Reb, 2003; Tanner & Medin, 2004). This led us to re-examine the role of omission bias in vaccination decision making, while expanding into the conceptually similar domains of gene editing and nanotechnology, to see whether omission bias would generalise across biotechnologies. We also wanted to explore whether cognitive and personality variables were associated with a tendency to exhibit omission bias.

In our sample ( $N = 613$ ), we found tentative evidence for the role of omission bias in biotechnology decision making. Aside from our primary research goal, this study also showed evidence for an important methodological issue in risk balancing designs that are often used in omission bias research – there are sizeable proportions of people either unable to accurately balance risks or are inattentive during decision-making tasks. This has significant implications for previous omission bias work, which has used shorter scales which occlude the presence of nonsensical responding. By using a longer scale length, we were more capable of identifying when people were responding nonsensically (e.g. choosing a risk that was sometimes nine times greater than the risk they were comparing against). Previous designs that limit scale length were not able to identify these kinds of responses, as all responses given on these scales would seem legitimate. Future omission bias research that uses risk balancing designs needs to account for the possibility that participants may not understand the task, or be able to accurately weigh up probabilities. This should be done by manipulating the type of risk information they are given (i.e. risk percentages versus proportions such as 1 in 100). There also needs to be more robust checks that participants are understanding and paying attention to the task. This is a significant issue that can undermine the legitimacy of omission bias at worst, or account for the previous issues of inconsistent effect sizes at best.

We also found that, for the most part, biotechnology attitudes, decision making styles and cognitive reflection were not associated with displays of omission bias. From this, it would appear that omission bias is an independent process that influences decision making separately from attitudes towards a given entity or analytical thinking ability.

This study provides evidence for the generalisability of omission bias across biotechnologies. Given the amount of negative discourse surrounding vaccination, it is perhaps unsurprising that people have a degree of hesitancy about being vaccinated. However, the same discourse does not surround novel biotechnologies such as gene editing and nanotechnology.



This has important implications for understanding why individuals may be hesitant to adopt biotechnologies, even if there is an absence of negative sentiments towards them. Even in technologies that lack a negative discourse surrounding them, people expect a significant risk premium before they are willing to use them.

The lack of consistent relationship between attitude, cognitive reflection, and decision-making style measures and tendency to exhibit omission bias suggests that hesitancy towards biotechnology relies upon independent processes (i.e. omission bias hesitancy is different from hesitancy due to negative attitudes towards the technology). This suggests that different approaches should be used to tackle hesitancy. As omission-bias-based hesitancy appears when an individual desires a risk premium, those seeking to increase uptake of a biotechnology may be better served by highlighting the significant disparity in risk posed by a biotechnology, when compared to the illness it is designed to treat or prevent.

### **Study 3 – The Role of Social Dominance Orientation in Attitudes towards Animal Centred Gene Editing**

Study 3 leveraged previous research conducted on the role of SDO and willingness to exploit animals (Dhont et al., 2014; Dhont & Hodson, 2014) to examine whether this relationship would extend to willingness to support gene editing to control pest populations. This was intended to provide initial evidence for the role of SDO in gene editing attitudes. A measure of Synthetic Aversion was also included in this study, in order to explore whether opposition to biotechnologies based on the technology being unnatural (Goss et al., 2012; Pivetti, 2007) was partially based in concerns surrounding the synthetic nature of the technology, rather than the previous assumption that this kind of opposition was solely based in concerns of playing God (Dragojlovic & Einsiedel, 2013; Robillard et al., 2014; Xiang et al., 2015).

Using a large secondary dataset from New Zealand ( $N = 5554$ ) and multinomial logistic regression, I found evidence for SDO predicting attitudes towards gene editing animals for pest control purposes. This relationship was independent of potential confounds such as political ideology and religiosity. This finding provides an initial step in the investigation of socio-political variables in the context of gene editing attitudes.

For example, SDO could be examined in relation to human-centred gene editing attitudes. Research suggests that SDO has been used to justify prejudice towards humans, or inequalities between them (Dhont et al., 2014; Pratto et al., 2000). Gene editing represents a way to increase the inequalities between groups of people, if gene editing is limited to those who can afford it. Thus, those individuals who score higher on SDO may be more inclined to support gene editing under these conditions, as it acts as a way to reinforce the self-perceived social hierarchy, by providing qualitative differences between the edited and non-edited. However, if gene editing were available to everyone, with no cost associated, those who are higher in SDO may be more likely to oppose the technology, as it risks disrupting the social hierarchy by giving those lower on the hierarchy an advantage. Future research should go beyond noting that social inequality is a concern associated with gene editing (Robillard et al., 2014; Xiang et al., 2015), and quantify whether those who are more fixated on maintaining a rigid social hierarchy are more likely to support or oppose gene editing for treatment and enhancement.

Another interesting avenue of research would be to examine whether the relationship between SDO and animal gene editing attitudes changes depending on the nature and target of the edit, as is observed in human centred gene editing. For example, one can imagine that support may differ if the target of gene editing is a household pet, rather than a pest. Similarly, a person may support the use of gene editing to improve the quality of life for an animal but

oppose gene editing intended to control its population. These interesting nuances remain to be explored.

This study also provides a novel insight into the role of Synthetic Aversion in biotechnology attitudes. This finding offers a novel, alternative perspective – that naturalness concerns can originate from the synthetic or artificial nature of the technology, rather than concerns of playing God. This opens up the opportunity to formally examine whether a naturalness bias exists in gene editing attitudes, where an individual prefers “natural” alternatives to gene editing, even if they are less effective (e.g. gene editing for the treatment of HIV, compared to medications intended to treat the symptoms, but are incapable of treating the disease). Previous research has only examined this in vaccination scenarios (DiBonaventura & Chapman, 2008), and kept the efficacy of the vaccine and natural alternative the same, which is an unrealistic comparison of the two ways to prevent disease.

### **Study 4 – Heterogeneous Attitudinal Profiles Towards Gene Editing: Evidence From Latent Class Analysis**

This study was intended to address the issue of attitudes towards gene editing often being examined in a monolithic fashion, with the implicit assumption of uniform attitudes towards gene editing coalescing in an individual (e.g. I am in favour of gene editing, therefore I believe it will have no negative consequences). However, this assumption ignores the nuances and contradictions of individual beliefs that can constitute an attitude. In this study we wished to examine how different beliefs about gene editing can cohere in an individual.

In order to tease apart these nuances, Study 4 consisted of an LCA using a large, secondary dataset from the US (N = 4726). While classes broadly conformed to a support/oppose continuum, this analysis revealed a high degree of heterogeneity between different classes of opposer and supporter. Some classes were clearly more concerned about

the societal implications of gene editing, while others were more fixated with the moral issues that are associated with gene editing. This has not been previously explored, as previous research has often examined general attitude trends, neglecting the nuances that arise when individuals hold several, potentially contradictory attitudes. The use of multinomial logistic regression also revealed key demographic differences between the classes that emerged, which provides novel insights into not only why people support or oppose gene editing, but who these people are more likely to be.

Furthermore, while there was a high degree of heterogeneity between classes on the issue of enhancement versus treatment, within classes these enhancement and treatment beliefs became more homogenous – either both applications were acceptable, or neither. This confirms previous points (see Study 1) regarding the importance of the type of gene editing used. In this analysis, whether you were universally in favour or opposed to treatment and enhancement appears to determine your membership of a supporter or opposer class. In combination these findings provide a level of detail that has not been previously achieved through broad examinations of gene editing attitude trends, which have previously only noted that support decreases or increases depending on the type of gene editing (For a review, see Delhove et al., 2020).

Future research needs to account for these findings. Differences in predictor variables across studies may be explained by any given study possessing different proportions of the classes that emerged in this study. For example, variables that measure moral concern may find their relationship with gene editing attitudes attenuated if the sample contains a high proportion of individuals that are primarily concerned with the practical issues of gene editing.

One of the classes that emerged expressed marked concern for the social inequality consequences of gene editing. This has been a concern noted in previous research (Robillard et al., 2014; Xiang et al., 2015), but has not been formally examined. Pursuing this line of

research could lead to a variety of socio-political, or worldview variables relating to attitudes towards gene editing. For example, as mentioned previously, those who score higher on measures of social dominance may be more willing to support gene editing if it was restricted to the wealthy, in order to perpetuate the social hierarchy, but oppose gene editing if it was widely available, as this may pose a risk to the existing social hierarchy.

### **Study 5 – COVID-19 and seasonal flu vaccination hesitancy: Links to personality and general intelligence in a large, UK cohort**

I then turned my attention towards one of the long-standing biotechnology issues – vaccination hesitancy, in the novel context of the COVID-19 pandemic. Previous research has found inconsistent associations in the areas of openness, neuroticism (Lin & Wang, 2020; Murphy et al., 2021; Salerno et al., 2021) and COVID-19 vaccination hesitancy. Moreover, little research has examined the role of general intelligence in COVID vaccination hesitancy, with other research only investigating the related variable of cognitive reflection (Martinelli & Veltri, 2021; Murphy et al., 2021). Most vaccination hesitancy studies have also neglected the motivations for individuals to decline vaccines, and how personality and intelligence variables may predict belonging to particular vaccination hesitancy groups. Finally, vaccine attitudes have previously been assumed to be homogeneous - predictors of hesitancy in one vaccination type are the same as another vaccine type. We wished to examine if this was the case, by comparing predictors of vaccination hesitancy across vaccine types – the COVID-19 and seasonal flu vaccines.

Using a large secondary dataset from The United Kingdom (N= 9667), I examined the role of general intelligence and personality variables in COVID-19 vaccination hesitancy. Firstly, I found that higher levels of intelligence and neuroticism predicted support for vaccination, which was independent of potential confounds, such as education, openness or

income. Secondly, intelligence, sex and education as predictors of COVID vaccination hesitancy generalised to seasonal flu vaccination, but personality variables did not. Finally, through multinomial logistic regression I found significant differences between those who would vaccinate, and the different motivations for declining vaccination. For example, those who declined vaccination due to distrust were significantly more extraverted, open, and had more mental health problems. The differences I found in those who choose to decline vaccination and their reasons for doing so may shed light on previous inconsistencies in the literature regarding the role of individual differences.

Those who score lower on cognitive reflection or intelligence may be choosing to decline vaccination due to their susceptibility to misinformation (Pennycook et al., 2020a), be more prone to cognitive biases (Alós-Ferrer et al., 2016; Juanchich et al., 2016; Sobkow et al., 2020; Toplak et al., 2011), or be less than optimal decision-makers in the context of vaccination (i.e. declining vaccines) (Martinelli & Veltri, 2021). In combination these findings suggest that both the way in which an individual thinks, and their ability to do so are associated with being able to navigate the counter-intuitive nature of vaccination decision-making.

Our findings regarding the role of Big 5 personality traits in vaccination hesitancy were mixed. However, when examining the reasons for vaccination, a possible explanation arises. There were significant differences in which personality traits were associated with particular reasons to decline vaccination. These differences may have been obscured when examining overall vaccination hesitancy in this study, and others that examine Big 5 traits in relation to vaccination hesitancy. Previous inconsistent relationships between personality traits and overall vaccination hesitancy may be explained by having larger proportions of individuals with a particular reason to decline vaccination present in their sample, which creates the illusion that a particular trait is associated with general vaccination hesitancy. This has important implications for both theory and policy. For example, the differences between motivations to

decline vaccination may account for the differences arising between studies that examine similar predictors. Policy makers need to account for the differences in motivations to decline vaccination, as particular message frames may be less effective for different types of vaccine hesitant individuals. For example, those who are concerned with the long-term effects of the vaccine may be resistant to message frames that highlight the danger presented by the illness the vaccine is intended to treat.

### **8.3 Limitations**

#### **Study 1 – Understanding Opposition to Human Gene Editing: A Role for Pathogen Disgust Sensitivity?**

This study was conducted at a particular point in time where there has not been a significant amount of public discussion regarding gene editing. It is likely as the reality of gene editing becomes more prominent in society, that opinions will change, as has been the case with other biotechnologies, such as vaccines, which have seen a waxing and waning of support over the years (Funk & Tyson, 2020; Gowda & Dempsey, 2013; Hansen et al., 2020). Therefore, the relationships identified in this study may not hold across time. As it is, this study provides an insightful snapshot of early attitudes towards gene editing.

#### **Study 2 – Opposition to Novel Biotechnologies: Testing An Omission Bias Account**

One of the key limitations of this study is the potential inattentiveness of the sample. Despite our efforts to account for the issues that have been previously identified in the literature, such as anchoring bias, scale length, and explicit mention of a lack of risks (Baron & Ritov, 2004; Connolly & Reb, 2003), a significant proportion of our respondents gave seemingly nonsensical responses, which partially occluded the omission bias effect. This has been explained by Baron and Ritov (2004) as the labile nature of omission bias, which can be sensitive to methodological changes. However, it is possible that the lability of response (at

least in our study) is due to a lack of understanding on the part of participants, rather than methodological issues, which has often been overlooked as a possibility. In future research, it would be advisable to include a greater number of comprehension checks, to ensure that participants understand the risks they are balancing against. This could be achieved by providing multiple ways to interpret the probability information (e.g. 5% of people or 5 in 100 people). Alternatively, participants could be required to complete some basic mathematical problems involving percentages before proceeding with the risk balancing portion of the study, which would allow a more definitive identification of those who may misunderstand the task.

### **Study 3 – The Role of Social Dominance Orientation in Attitudes towards Animal Centred Gene Editing**

One of the issues that arises with this study is the limited number of questions that examined gene editing attitudes, within the niche topic of pest control. Given the wide range of possible applications for gene editing animals (e.g. to increase food production, for longevity, or greater intelligence), it would be more insightful if a wider range of questions were examined in order to differentiate between applications, as has been the case for human centred gene editing. This would also provide an insight into the way that SDO is associated with gene editing when the outcome is a positive one for the animal. Currently, SDO is examined from the perspective of animal exploitation (Dhont & Hodson, 2014; Funk & Hefferon, 2018; Schuppli & Weary, 2010; Zhao et al., 2019) and never from an animal welfare perspective.

Further to the above point, the kind of animal may also influence the relationship between SDO and gene editing. In the context of this study, the animals were identified as pests, which is already placing them on the lowest point of a social hierarchy. It is conceivable that even participants that are low in SDO may be willing to use gene editing on animals portrayed as pests, especially given New Zealand's proactive approach to dealing with



invasive, non-native species (e.g. Predator free 2050). Individuals believe that different types of non-human animals have differing capacities for emotion (e.g. mammals are perceived to have a greater capacity for emotion compared to fish) (Wilkins et al., 2015), and that the ability to feel emotions is associated with being more or less human (Demoulin et al., 2004). From these findings it is possible that some types of animals (e.g. mammals) are less acceptable targets for gene editing than others, as they are perceived as closer to human, and placed higher on the social hierarchy.

#### **Study 4 – Heterogeneous Attitudinal Profiles Towards Gene Editing: Evidence From Latent Class Analysis**

Due to the use of secondary data, this study had to rely on questions that we did not design ourselves, which raises issues. In particular, some of the wording on the questions was ambiguous regarding the type of gene editing that was taking place (i.e. an enhancement or treatment), and who the subject of the gene editing was (i.e. an adult or baby). This made several of the questions difficult to interpret. While we elected to remove several questions due to their ambiguity, a number of important questions that we retained could have been worded more clearly (e.g. the enhancement and treatment items). Given the type of gene editing and the target of the gene editing are consistent themes that arise in the literature (For a comprehensive review, see Delhove et al., 2020), it is important to make these distinctions clear to participants.

#### **Study 5 – COVID-19 and seasonal flu vaccination hesitancy: Links to personality and general intelligence in a large, UK cohort**

One of the issues in this study is that it was conducted before vaccines were made available to the public. It is conceivable that many of those who expressed a positive or negative attitude towards vaccination may ultimately change their position when the vaccine is offered to them. While it is suggested that intention and behaviour are often highly associated ( $r = .70$ )

(Ajzen, 1985), even over long periods of time (Randall & Wolff, 1994), given the significant amount of negative discourse surrounding the COVID-19 vaccine, it is conceivable this discourse may distort the relationship between intention and behaviour. A study that examines this would make for a useful insight into the differences between vaccination intention and behaviour during the COVID-19 pandemic.

#### **8.4 Potential Applications**

In combination, these studies help to build a picture of the kinds of people who are likely to oppose biotechnologies and their reasons for doing so. Due to my findings that opposition to biotechnologies may be heterogeneous, I will discuss the several different forms of opposition. Firstly, there are people who have negative attitudes towards biotechnology, they fear the negative consequences of it (e.g. the societal changes associated with gene editing), or the (im)moral aspects of the technology. Secondly, there are people who oppose biotechnology due to a lack of trust in those that research or administer it. Given this mistrust, they may be more aligned with those who possess conspiratorial beliefs surrounding biotechnology, or received misinformation, which undermines trust in a given technology. Thirdly, there appears to be a group of people that are more naïve in their opposition to biotechnology, in that they do not oppose it due to assumed knowledge of the technology, but due to being unable to balance the risks of the biotechnology against the risk of the disease it is intended to treat, or a desire for a significant risk premium from the biotechnology.

These different kinds of opposition may differ in their responsiveness to different message frames or methods of delivering messages, which may lead to increased support for a biotechnology. For example, individuals that desire a risk premium before they are willing to use a biotechnology may respond positively to information that highlights the significant risk disparity between a biotechnology procedure and the illness it is intended to treat. Similarly,

those who are unable to balance risks may benefit from alternative ways to present risk information, such as more visual representations of risk, rather than purely numerical. Those who oppose biotechnologies on moral or trust grounds may be receptive to messages from figures they trust or consider to be moral individuals. For example, the results of the latent class analysis suggest that those who harbour moral concerns were more likely to be religious and conservative. Therefore, they may trust in the morality of religious or political figures who have similar beliefs to themselves.

However, these real-world suggestions are reliant upon being able to show that attitudes can lead to uptake of a given biotechnology. One way of doing this in a real-world setting would be to examine COVID-19 vaccination hesitancy longitudinally, specifically by measuring an individual's attitudes towards the COVID-19 vaccination at one time point, and then following up several months later by asking them whether they had chosen to vaccinate. However, some biotechnologies have yet to be introduced to the public, so this approach may not be viable for techniques such as gene editing. Instead, in cross-sectional and experimental work participants could be given an amount of money and be given the choice to donate it to a charity or cause associated with the technology (e.g. a fictitious charity that researches, or aims to administer, gene editing in the future). This may serve as a proxy for real-world behavioural intentions.

### **8.5 Conclusion**

To summarise, this thesis has provided a broad range of novel insights into the way the public perceive biotechnologies, with a special focus on the unexplored area of gene editing attitudes. I have identified several psychological constructs that are associated with gene editing attitudes, such as pathogen disgust sensitivity, SDO, omission bias, and Synthetic Aversion. These findings are intended to serve as a foundation for future research into the

psychological constructs that are associated with gene editing, to provide a greater depth of insight beyond the previous demographic variable centred approaches.

I have also sought to examine the commonalities in predictors of gene editing attitudes and identified common predictors such as omission bias and pathogen disgust sensitivity across gene editing, nanotechnology, cultured meat, GM crops, and vaccination, within the same sample. This serves to provide more conclusive evidence for a common biotechnology attitude latent factor that needs to be explored in future research if researchers are to fully understand how individuals will react to novel biotechnologies in the future.

Despite the many commonalities identified between biotechnologies, there are highly heterogeneous attitudes within biotechnologies. This was shown by examining gene editing attitudes using LCA to explore how individual beliefs about gene editing coalesce within individuals to form different classes of attitude. The findings of this study improve upon the approach taken by previous gene editing researchers that examine attitudes towards it as a simple support and oppose paradigm. While the finding that gene editing attitudes are highly heterogeneous does not undermine the credibility of previous findings, it serves as an important point to consider when examining attitudes in the future.

Finally, this thesis provided a novel insight into the predictors of attitudes towards vaccination, in the real-world context of the COVID-19 pandemic. I found that intelligence and neuroticism were significant predictors of vaccination hesitancy. I then examined the reasons why people choose to decline vaccination and their psychological predictors and found that personality traits differentially predicted reasons to decline vaccination. This provides a useful insight into variation between vaccine hesitant individuals and may allow more targeted interventions to address this significant public health issue.

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## Appendices

### Appendix A. Items used in Chapter 3.

#### *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)

### Appendix B. Supplementary materials for Chapter 3.

This document contains full details of tests that are summarised in the main text.

*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.*

*Vaccination and pathogen disgust sensitivity model:* Knowledge, educational attainment, resistance to change, and trust in science were independent, significant predictors of opposition to vaccines. The adjusted  $R^2$  of the model for vaccination opposition was 0.16. Those who were less resistant to change ( $\beta=.13$ ,  $p=.026$ ), less educated ( $\beta=-.23$ ,  $p<.001$ ), less trusting in science ( $\beta=-.30$ ,  $p<.001$ ), were more likely to oppose vaccination. Pathogen disgust sensitivity was not a significant predictor of vaccination opposition ( $p>.05$ ). See full model results in Table S1.

Table S1. Pathogen disgust sensitivity regression model results with opposition to vaccination as dependent variable.

Variable	<b>Vaccination opposition</b>	
	$\beta$	p
Age	-.04	.464
Sex	-.06	.223
Knowledge	-.14	<b>.006</b>
Educational attainment	-.23	<b>&lt;.001</b>
Resistance to change	-.13	<b>.026</b>
Risk taking	.07	.231
Trust in science	-.30	<b>&lt;.001</b>
Neuroticism	.01	.911
Pathogen disgust sensitivity	.05	.300
F	8.386 ( $p<.001$ )	
$R^2$ /Adjusted $R^2$	0.18/0.16	

Note. Bold indicates  $p<.05$ . *I = 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.*

*Vaccination mediation model.* Although the predicted association between vaccination opposition and pathogen disgust sensitivity was non-significant (for both pathogen and core disgust sensitivity), we still examined whether these associations were mediated by political ideology or religiosity. To this end, we fitted a model with political ideology and religiosity mediating the path from pathogen disgust sensitivity to vaccination opposition. In the model with pathogen disgust sensitivity, the direct effect was non-significant ( $p = .510$ ), as well as the indirect effects of political ideology and religiosity, (both  $\beta < .09$  and  $p > .121$ ).

*Cultured meat mediation model.* Although the predicted association between cultured meat opposition and pathogen disgust sensitivity was non-significant (for both pathogen and core disgust sensitivity), we still examined whether these associations were mediated by political ideology or religiosity. To this end, we fitted a model with political ideology and religiosity mediating the path from pathogen disgust sensitivity to cultured meat opposition. In the model with pathogen disgust sensitivity, the direct effects and indirect effects in all models were non-significant (all  $\beta > .11$ , all  $p < .052$ ).

### ***Sensitivity checks***

*Vaccination and core disgust sensitivity model:* Knowledge, educational attainment, resistance to change, and trust in science were independent, significant predictors of opposition to vaccines. The adjusted  $R^2$  of the model for vaccination opposition was 0.17. Those who were less resistant to change ( $\beta = .13$ ,  $p = .023$ ), less educated ( $\beta = -.22$ ,  $p < .001$ ), less trusting in science ( $\beta = -.30$ ,  $p < .001$ ), were more likely to oppose vaccination. Pathogen disgust sensitivity was not a significant predictor of vaccination opposition ( $p > .05$ ). See full model results in Table S2.



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Table S2. Core disgust sensitivity regression model results with opposition to vaccination as dependent variable.

Variable	<b>Vaccination opposition</b>	
	$\beta$	p
Age	-.05	.373
Sex	-.07	.152
Knowledge	-.13	<b>.008</b>
Educational attainment	-.22	<b>&lt;.001</b>
Resistance to change	-.13	<b>.023</b>
Risk taking	.06	.306
Trust in science	-.30	<b>&lt;.001</b>
Neuroticism	.00	.997
Core disgust sensitivity	.10	.069
F	8.691 (p<.001)	
R <sup>2</sup> /Adjusted R <sup>2</sup>	0.19/0.17	

Note. Bold indicates p<.05. *I* = Female.

**Appendix C. Risk balancing vignette information for Chapter 4****Vaccination basic**

It is the year 2025, and another new strain of coronavirus disease (“COVID-23”) is now fairly common in the USA. People who contract COVID-23 experience a high fever, coughing and muscle aches. Unlike COVID-19, this new illness can be fatal in children as well as in older adults. Imagine that a proportion of people in your city contract COVID-23 each year. Now consider that a vaccine becomes available that – when successful – will prevent your child from catching COVID-23. However, the risk of the vaccine is that a small number of people will become more vulnerable to catching COVID-23 due to the vaccine itself. There are no costs associated with this vaccine (i.e. the procedure is administered completely painlessly and at no cost in a matter of seconds) and no risks beyond the chance of becoming more vulnerable to the disease. Imagine that the proportion of unvaccinated people in your city who contract COVID-23 naturally each year is 10%.

What percentage chance of contracting COVID-23 due to the vaccine would you be willing to accept in order to have your child vaccinated? Please click on the slider below to indicate your response.

**Vaccination reverse**

It is the year 2025, and another new strain of coronavirus disease (“COVID-23”) is now fairly common in the USA. People who contract COVID-23 experience a high fever, coughing and muscle aches. Unlike COVID-19, this new illness can be fatal in children as well as in older adults. Imagine that a proportion of people in your city contract COVID-23 each year. Now consider that a vaccine becomes available that – when successful – will prevent your child from catching COVID-23. However, the risk of the vaccine is that a small number of people will

become more vulnerable to catching COVID-23 due to the vaccine itself. There are no costs associated with this vaccine (i.e. the procedure is administered completely painlessly and at no cost in a matter of seconds) and no risks beyond the chance of becoming more vulnerable to the disease. Imagine that the proportion of vaccinated people in your city who contract COVID-23 each year due to the vaccine is 10%.

What percentage chance of contracting COVID-23 naturally would you be willing to accept, before having your child vaccinated? Please click on the slider below to indicate your response.

### **Gene editing basic**

It is the year 2025, and another new strain of coronavirus disease (“COVID-23”) is now fairly common in the USA. People who contract COVID-23 experience a high fever, coughing and muscle aches. Unlike COVID-19, this new illness can be fatal in children as well as in older adults. Imagine that a proportion of people in your city contract COVID-23 each year. Now consider that gene editing becomes available that – when successful – will prevent your child from catching COVID-23. However, the risk of the gene editing is that a small number of people will become more vulnerable to catching COVID-23 due to the gene editing itself. There are no costs associated with this gene editing (i.e. the procedure is administered completely painlessly and at no cost in a matter of seconds) and no risks beyond the chance of becoming more vulnerable to the disease. Imagine that the proportion of non-gene edited people in your city who contract COVID-23 naturally each year is 10%.

What percentage chance of contracting COVID-23 due to the gene editing would you be willing to accept, in order to have your child gene edited? Please click on the slider below to indicate your response.

**Gene editing reverse**

It is the year 2025, and another new strain of coronavirus disease (“COVID-23”) is now fairly common in the USA. People who contract COVID-23 experience a high fever, coughing and muscle aches. Unlike COVID-19, this new illness can be fatal in children as well as in older adults. Imagine that a proportion of people in your city contract COVID-23 each year. Now consider that gene editing becomes available that – when successful – will prevent your child from catching COVID-23. However, the risk of the gene editing is that a small number of people will become more vulnerable to catching COVID-23 due to the gene editing itself. There are no costs associated with this gene editing (i.e. the procedure is administered completely painlessly and at no cost in a matter of seconds) and no risks beyond the chance of becoming more vulnerable to the disease. Imagine that the proportion of gene edited people in your city who contract COVID-23 each year due to the gene editing is 10%.

What percentage chance of contracting COVID-23 naturally would you be willing to accept, before having your child gene edited? Please click on the slider below to indicate your response.

**Nanotechnology basic**

It is the year 2025, and another new strain of coronavirus disease (“COVID-23”) is now fairly common in the USA. People who contract COVID-23 experience a high fever, coughing and muscle aches. Unlike COVID-19, this new illness can be fatal in children as well as in older adults. Imagine that a proportion of people in your city contract COVID-23 each year. Now consider that a nanotechnology procedure becomes available that – when successful – will prevent your child from catching COVID-23. However, the risk of the nanotechnology procedure is that a small number of people will become more vulnerable to catching COVID-

23 due to the nanotechnology procedure itself. There are no costs associated with this nanotechnology procedure (i.e. the procedure is administered completely painlessly and at no cost in a matter of seconds) and no risks beyond the chance of becoming more vulnerable to the disease. Imagine that the proportion of people who do not receive the nanotechnology procedure in your city who contract COVID-23 naturally each year is 10%.

What percentage chance of contracting COVID-23 due to the nanotechnology procedure would you be willing to accept, in order to have your child treated with nanotechnology? Please click on the slider below to indicate your response.

### **Nanotechnology reverse**

It is the year 2025, and another new strain of coronavirus disease (“COVID-23”) is now fairly common in the USA. People who contract COVID-23 experience a high fever, coughing and muscle aches. Unlike COVID-19, this new illness can be fatal in children as well as in older adults. Imagine that a proportion of people in your city contract COVID-23 each year. Now consider that a nanotechnology procedure becomes available that – when successful – will prevent your child from catching COVID-23. However, the risk of the nanotechnology procedure is that a small number of people will become more vulnerable to catching COVID-23 due to the nanotechnology procedure itself. There are no costs associated with this nanotechnology procedure (i.e. the procedure is administered completely painlessly and at no cost in a matter of seconds) and no risks beyond the chance of becoming more vulnerable to the disease. Imagine that the proportion of people who receive the nanotechnology procedure in your city who contract COVID-23 each year due to the nanotechnology procedure is 10%.

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What percentage chance of contracting COVID-23 naturally would you be willing to accept, before having your child treated with nanotechnology? Please click on the slider below to indicate your response.

## **Appendix D. Biotechnology attitude items for Chapter 4**

\* Indicates where items will be reverse scored

### ***Vaccination attitude items***

1. I think vaccination is safe
2. I trust those who administer vaccinations
3. I think vaccination is immoral\*
4. I think the risks of vaccination outweigh the benefits\*
5. I think vaccination has a positive impact on society

### ***Gene editing items***

1. I think gene editing is safe
2. I trust those who implement gene editing
3. I think gene editing is immoral\*
4. I think the risks of gene editing outweigh the benefits\*
5. I think gene editing will have a positive impact on society

### ***Nanotechnology items***

1. I think nanotechnology is safe
2. I trust those who implement nanotechnology
3. I think nanotechnology is immoral\*
4. I think the risks of nanotechnology outweigh the benefits\*
5. I think nanotechnology will have a positive impact on society

## Appendix E. Supplementary materials for Chapter 4

### Preregistered analyses

#### *T-tests*

**H1:** The mean risk choice indicated the presence of commission bias (in the basic condition this is indicated by risk responses significantly higher than 10%) in the vaccination ( $M = 19.83$ ;  $p < .001$ ), gene editing ( $M = 19.95$ ;  $p < .001$ ), and nanotechnology ( $M = 20.31$ ;  $p < .001$ ) basic conditions. The mean risk choice indicated the presence of omission bias (in the reverse condition this is indicated by risk responses significantly higher than 10%) in the vaccination ( $M = 32.96$ ;  $p < .001$ ), gene editing ( $M = 35.20$ ;  $p < .001$ ), and nanotechnology ( $M = 35.85$ ;  $p < .001$ ) reversed conditions.

#### *Pearson correlations*

**H2:** There were significant positive associations between opposition to their respective biotechnology and tendency to exhibit omission bias in the vaccination ( $r = .36$ ,  $p < .001$ ), gene editing ( $r = .21$ ,  $p = .033$ ), and nanotechnology ( $r = .38$ ,  $p < .001$ ) reverse conditions. Biotechnology attitudes were non-significantly associated ( $p > .05$ ) in all three basic conditions.

**H3:** There was a significant negative association between cognitive reflection scores and absolute deviation from the optimal risk choice in the gene editing basic condition ( $r = -.23$ ,  $p = .023$ ). The rest of the hypothesised relationships were non-significant (all  $ps > .05$ ). See Table S1 for full details.

**H4:** Higher intuitive decision-making scores were significantly positively associated with absolute deviation from the optimal risk choice in the vaccination basic and gene editing reversed conditions ( $r = .23$ ,  $p = .018$ ,  $r = .20$ ,  $p = .039$ , respectively). There was also a positive correlation between higher avoidant decision making scores and absolute deviation from the optimal risk choice in the gene editing reverse condition ( $r = .20$ ,  $p = .044$ ). The rest of the hypothesised relationships were non-significant (all  $ps > .05$ ). See Table S1 for full details.



**H5:** Higher vigilant decision-making scores were negatively associated with absolute deviation from the optimal risk choice in the nanotechnology basic condition ( $r = -.20$ ,  $p = .049$ ). The rest of the hypothesised relationships were non-significant (all  $ps > .05$ ). See Table S1 for full details.

**Table S1.** Pearson correlations for decision making style, cognitive reflection, and absolute deviation from optimal risk choice.

	Avoidant	Anxious	Vigilant	Intuitive	Cognitive reflection
Avoidant					
Anxious	0.79**				
Vigilant	0.01	0.16**			
Intuitive	0.12*	0.08	0.10*		
Cognitive reflection	0.05	0.01	0.16**	-0.20**	
Vaccination basic	0.16	0.11	-0.11	0.23*	-0.05
Vaccination reverse	-0.04	-0.04	-0.07	0.13	0.04
Gene editing basic	-0.02	-0.04	-0.12	0.10	-0.23*
Gene editing reverse	0.20*	0.07	0.02	0.20*	0.14
Nanotechnology basic	0.17	0.00	-0.20*	0.11	-0.17
Nanotechnology reverse	0.03	0.05	-0.16	0.18	-0.09

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

## Truncated results

### Sign tests

**H1:** The median risk choice indicated the presence of omission bias (in the basic condition this is indicated by risk responses significantly lower than 10%) in the vaccination (Median = 5;  $p < .001$ ), gene editing (Median = 2;  $p < .001$ ), and nanotechnology (Median = 5;  $p < .001$ ) basic conditions. There was no significant difference from 10% in the vaccination, and nanotechnology reverse conditions. In the gene editing reverse condition there was evidence

for the presence of commission bias (in the reverse condition this is indicated by risk responses significantly lower than 10%) (Median = 5;  $p = .024$ ).

### *Spearman Correlations*

**H2:** In the gene editing basic condition, there was a significant positive association between opposition to gene editing, and a greater tendency to exhibit omission bias ( $r_s = .35$ ;  $p = .003$ ).

The rest of the hypothesised relationships were non-significant (all  $ps > .05$ ).

**H3:** None of the predicted relationships for this hypothesis were significant ( $p > .05$ ). See Table S2 for full details.

**H4:** Higher intuitive decision-making scores were positively associated with absolute deviation from the optimal risk choice in the gene editing and nanotechnology basic conditions ( $r_s = .27$ ,  $p = .024$ ,  $r_s = .34$ ,  $p = .003$ , respectively). This pattern was also found between the gene editing reverse condition, avoidant decision-making ( $r_s = .41$ ,  $p = .008$ ), and anxious decision-making scores ( $r_s = .45$ ,  $p = .003$ ). The rest of the hypothesised relationships were non-significant (all  $ps > .05$ ). See Table S2 for full details.

**H5:** None of the predicted relationships for this hypothesis were significant ( $p > .05$ ). See Table S2 for full details.

**Table S2.** Spearman correlations for decision making style, cognitive reflection, and absolute deviation from optimal risk choice.

	Avoidant	Anxious	Vigilant	Intuitive	Cognitive reflection
Avoidant					
Anxious	0.78**				
Vigilant	-0.01	0.16**			
Intuitive	0.13*	0.10*	0.01		
Cognitive reflection	0.05	0.02	0.11*	-0.20**	
Vaccination basic	0.00	0.11	-0.09	-0.07	0.01
Vaccination reverse	-0.23	-0.16	0.02	-0.18	-0.09

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Gene editing basic	0.00	0.01	0.02	0.27*	-0.14
Gene editing reverse	0.41*	0.45*	0.05	-0.08	-0.04
Nanotechnology basic	-0.01	0.00	0.03	0.34*	-0.20
Nanotechnology reverse	-0.05	0.01	0.31	0.13	-0.24

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

### Truncated and combined results

#### *Spearman Correlations*

**H2:** Opposition towards their respective biotechnology was significantly positively associated with a tendency to exhibit omission bias in gene editing combined condition ( $r_s = .25, p = .008$ ).

The rest of the hypothesised relationships were non-significant (all  $ps > .05$ ).

**H3:** None of the predicted relationships for this hypothesis were significant ( $p > .05$ ). See Table S3 for full details.

**H4:** Higher intuitive decision-making scores were positively associated with absolute deviation from the optimal risk choice in the gene editing combined condition ( $r_s = .20, p = .037$ ). See Table S3 for full details.

**H5:** None of the predicted relationships for this hypothesis were significant ( $p > .05$ ). See Table S3 for full details.

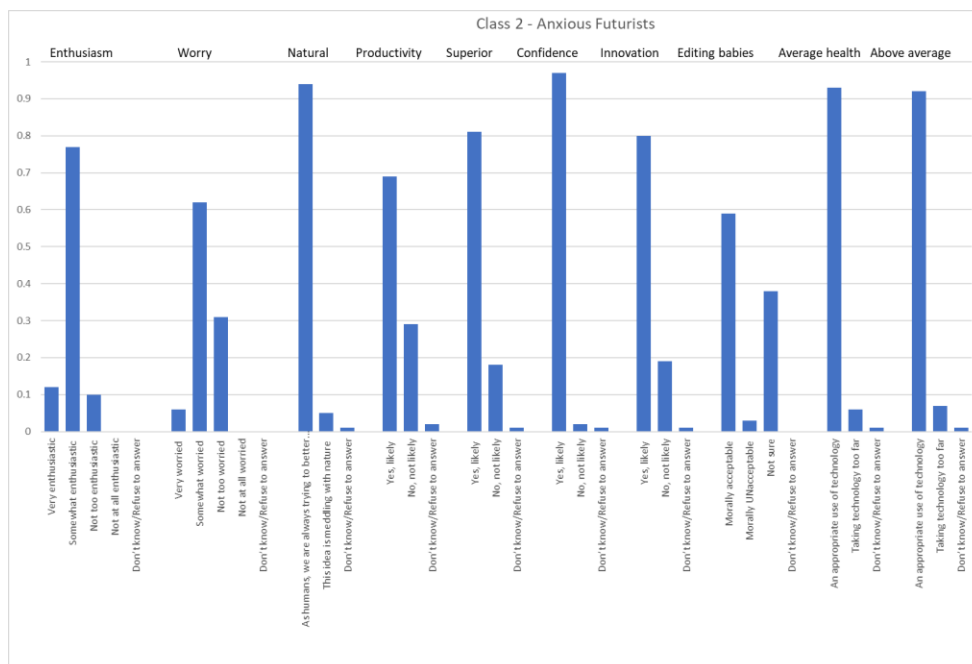
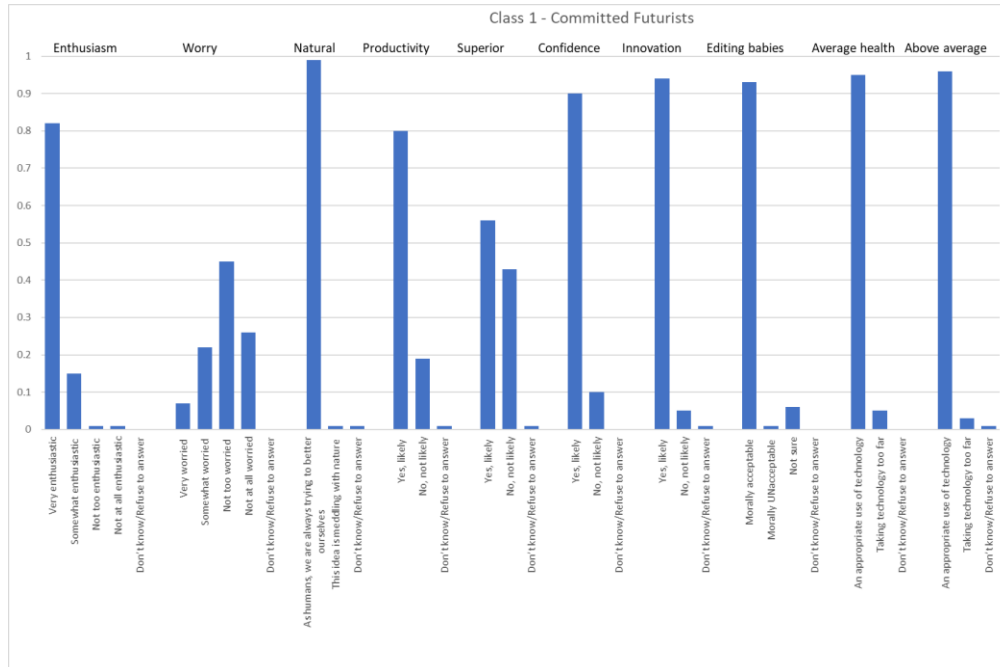
**Table S3.** Spearman correlations for decision making style, cognitive reflection, and absolute deviation from optimal risk choice.

	Avoidant	Anxious	Vigilant	Intuitive	Cognitive reflection
Avoidant					
Anxious	0.78**				
Vigilant	-0.01	0.16**			
Intuitive	0.13*	0.10*	0.01		
Cognitive reflection	0.05	0.02	0.11*	-0.20**	
Vaccination combined	-0.01	0.07	0.15	-0.11	0.08
Gene editing combined	0.03	-0.03	0.08	0.20*	-0.10
Nanotechnology combined	-0.13	-0.03	0.02	0.06	0.10

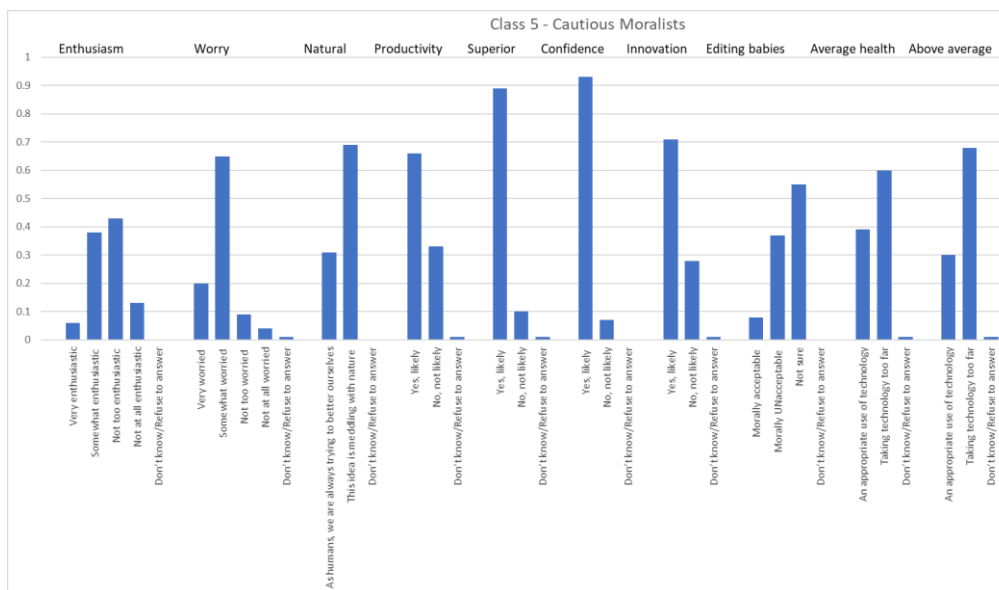
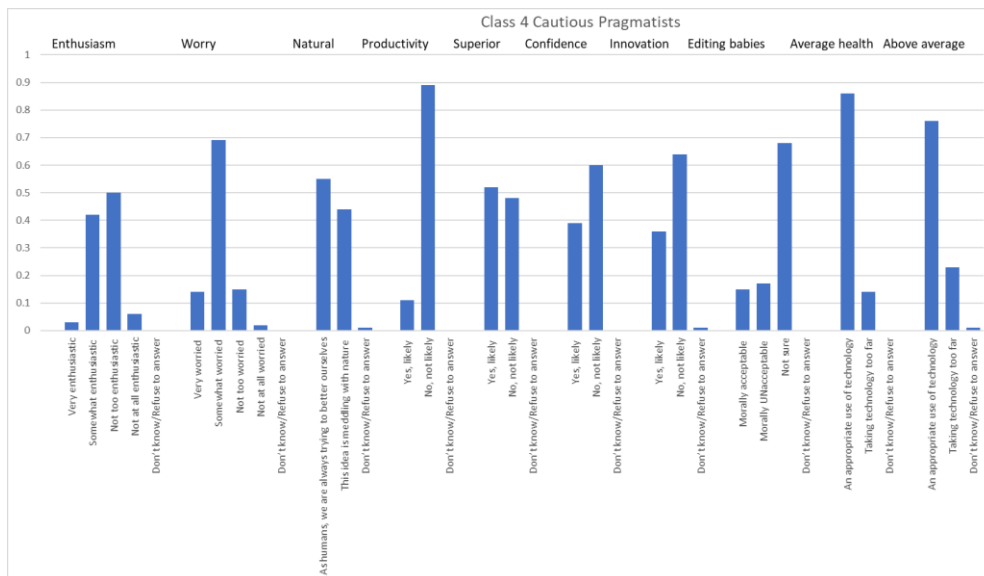
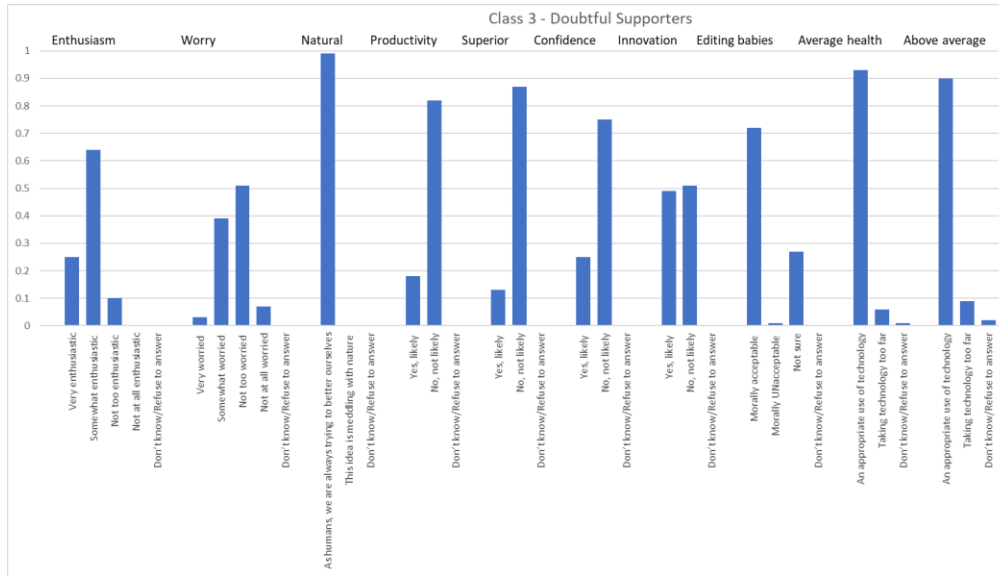
Note. \* =  $p < .05$ ; \*\* =  $p < .001$ .

## Appendix F. Graphical representation of conditional probabilities in Chapter

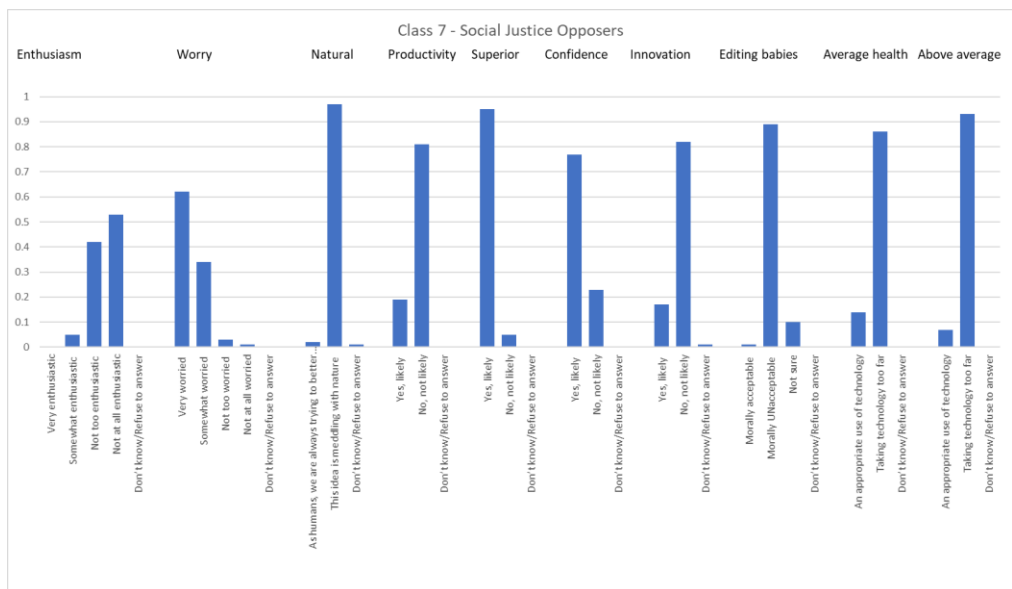
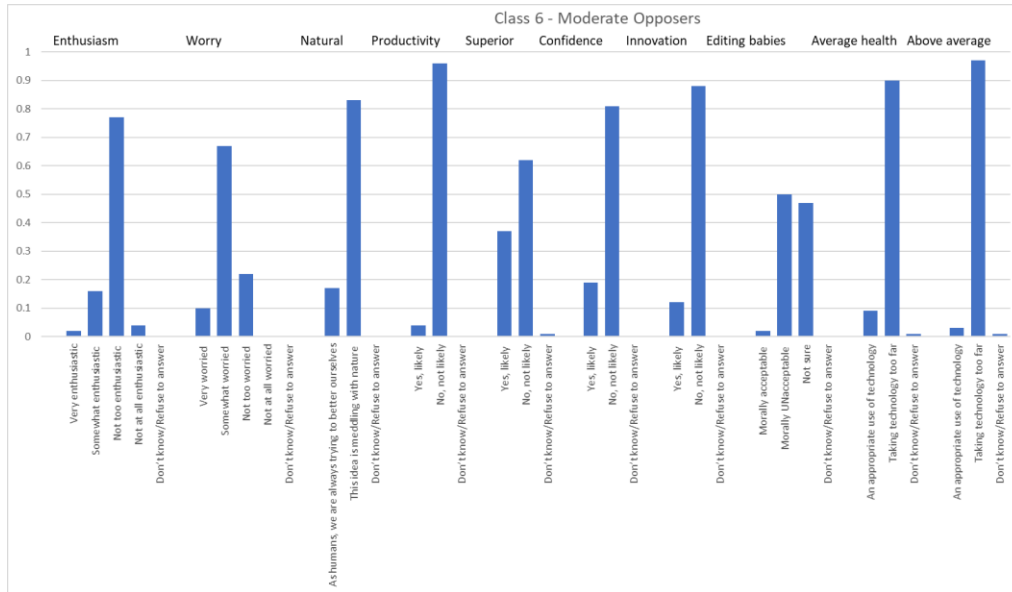
6



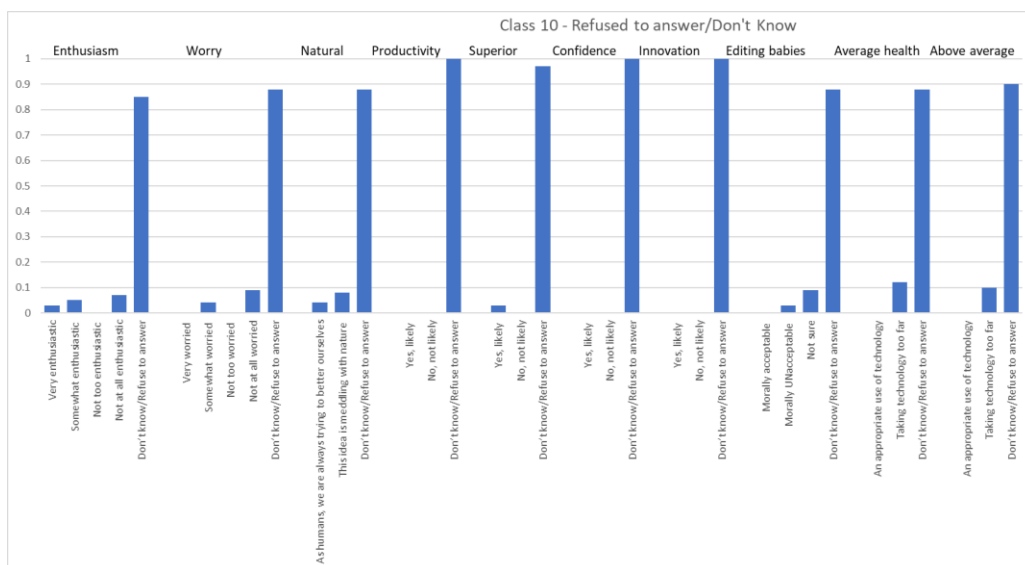
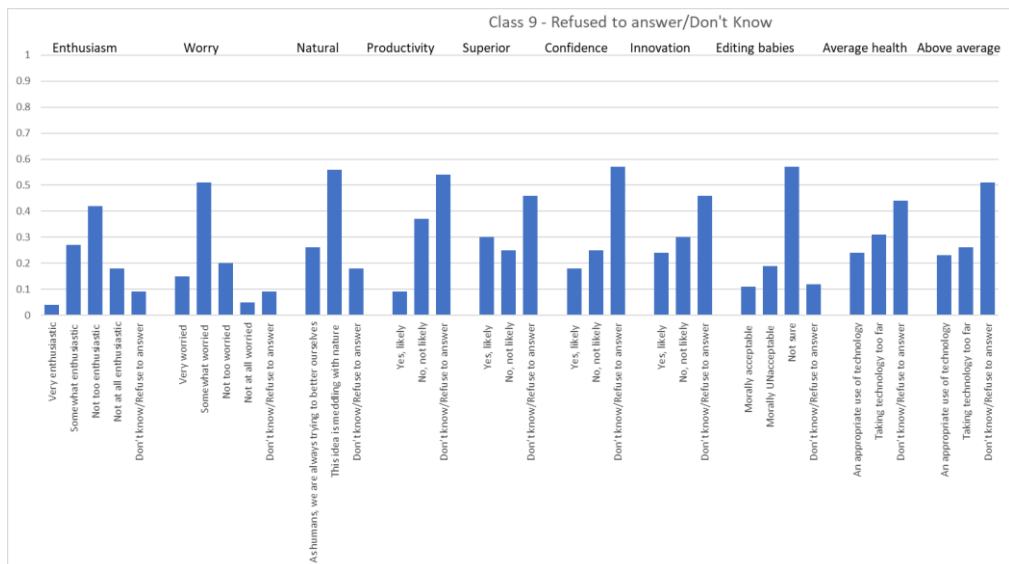
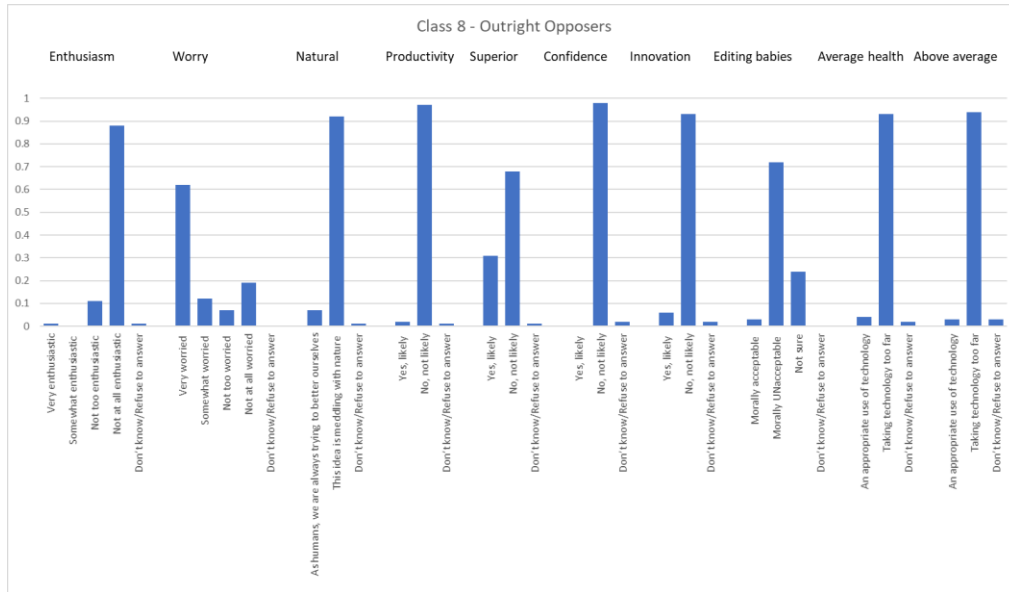
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## APPENDICES

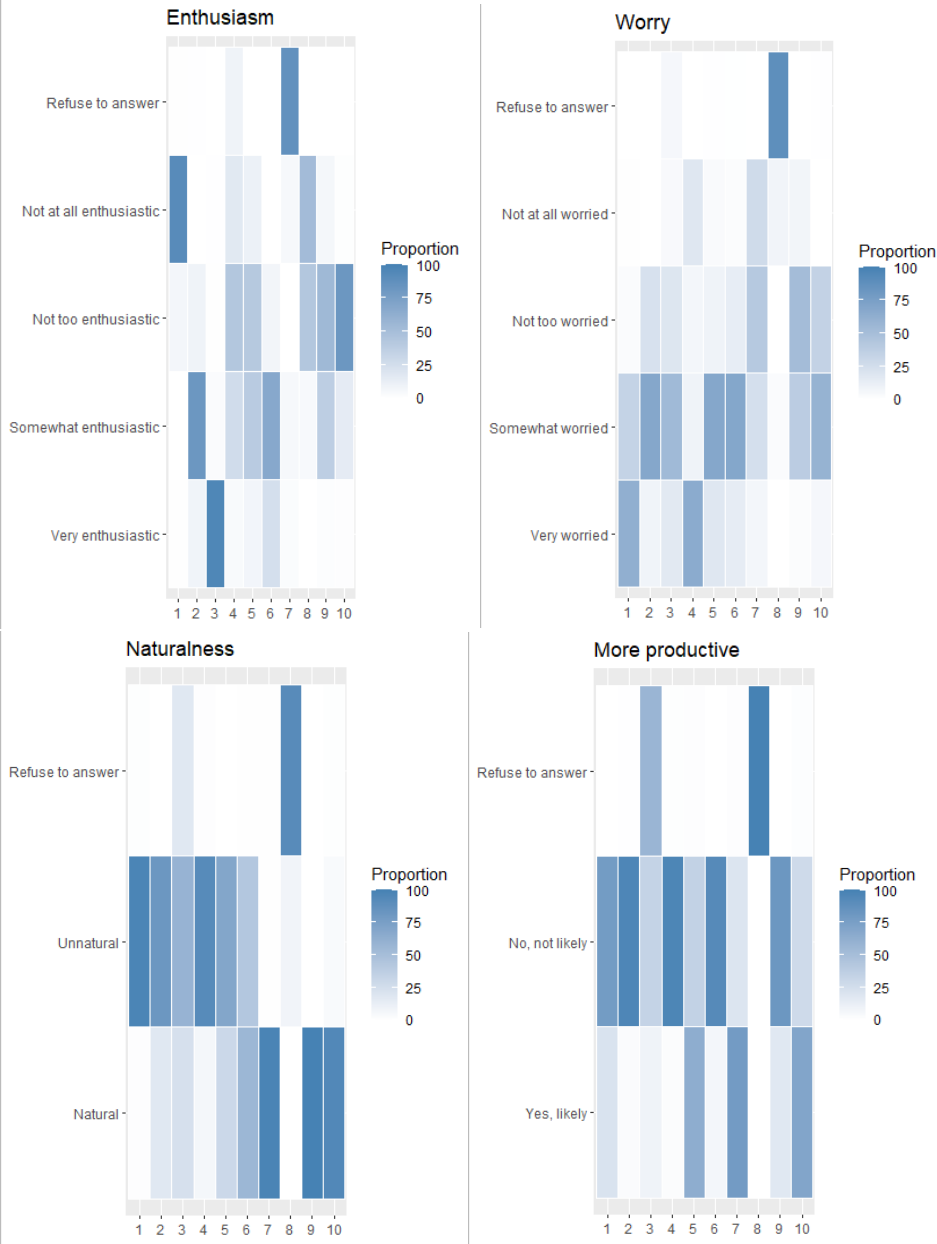


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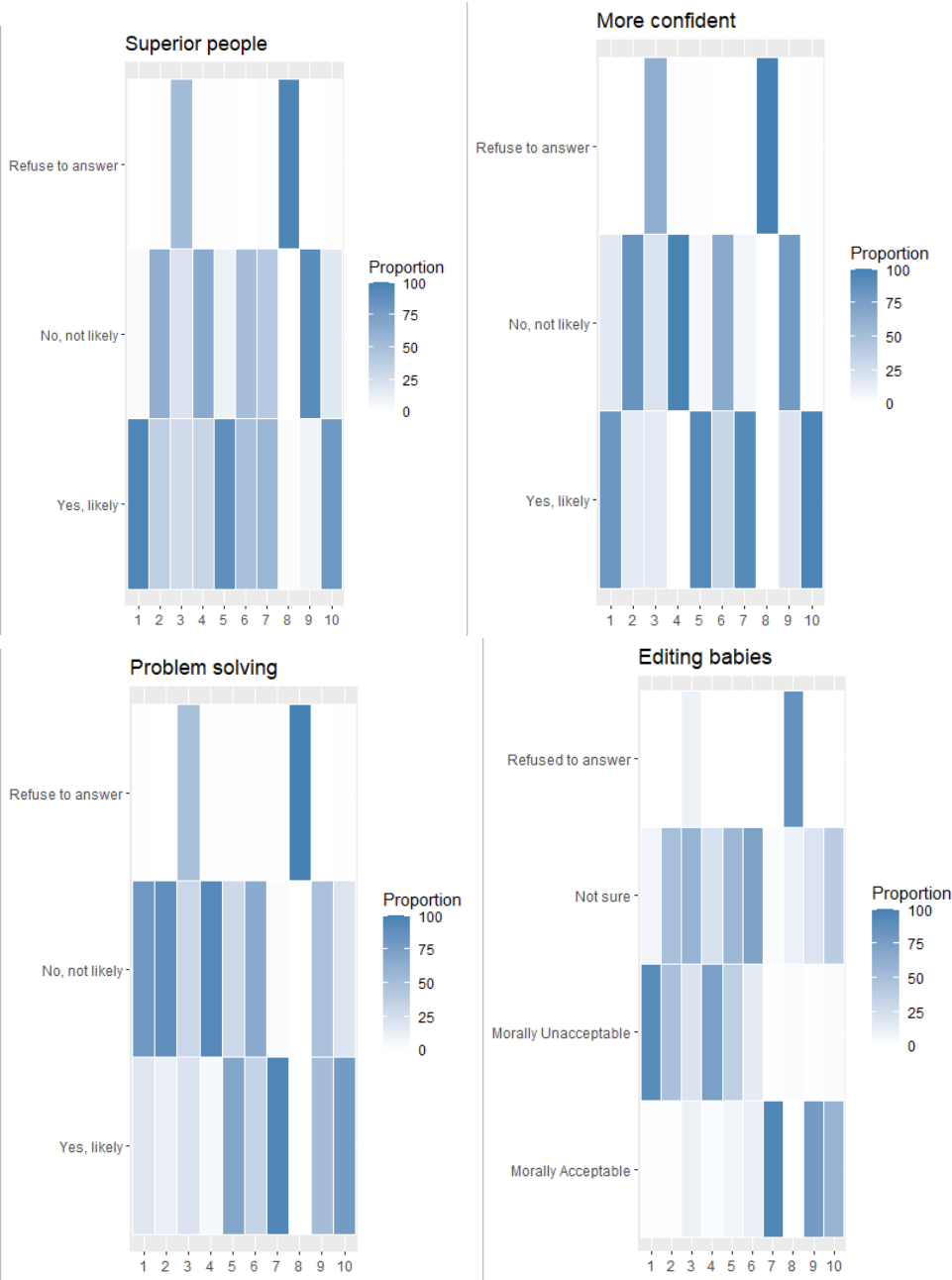
APPENDICES

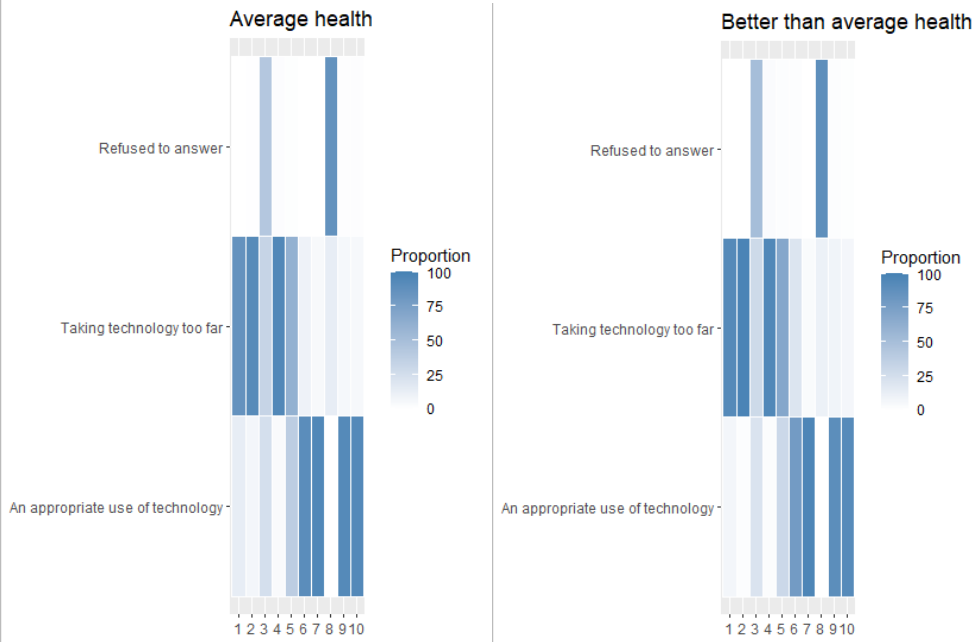
**Figure 1.** The panels present the conditional response probabilities (y-axis) for each of the items (x-axis) used in the latent class analyses by class.





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**Figure 2.** Heatmaps of the conditional response probabilities for the individual categories of the items used in the latent class analysis (y-axis) per class (x-axis); each panel presents one of the questions.

**Appendix G. Full list of questions from Chapter 6**

Item	Response
GEN2 : If you had a baby, do you think this gene-editing -- giving a much reduced risk of serious diseases and conditions over his or her lifetime - is something that you, personally, would want for your baby or not something you would want for your baby?	1: Yes, I would definitely want this for my baby 2: Yes, I would probably want this for my baby 3: No, I would probably NOT want this for my baby 4: No, I would definitely NOT want this for my baby
GEN4. Thinking about the possibility of this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions...	
a. How ENTHUSIASTIC are you, if at all, about this possibility for society as a whole?	1: Very enthusiastic 2: Somewhat enthusiastic 3: Not too enthusiastic 4: Not at all enthusiastic
b. How WORRIED are you, if at all, about this possibility for society as a whole?	1: Very worried 2: Somewhat worried 3: Not too worried 4: Not at all worried
Thinking about the possibility of this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions...	
GEN5. Which of these statements comes closer to your view, even if neither is exactly right?	1: As humans, we are always trying to better ourselves and this idea is no different 2: This idea is meddling with nature and crosses a line we should not cross
GEN6 If this gene-editing become available, giving HEALTHY babies a much reduced risk of serious diseases and conditions, do you think the following are likely or not likely to happen as a result?	
a. People who have this gene-editing will be more productive at their jobs	1: Yes, likely 2: No, not likely
b. People who have this gene-editing will feel superior to people who do not	1: Yes, likely 2: No, not likely
c. This option will be used before we fully understand how it affects people's health	1: Yes, likely 2: No, not likely
d. People who have this gene-editing will feel more confident and better about themselves	1: Yes, likely 2: No, not likely
e. Inequality will increase because this option will be available only for the wealthy	1: Yes, likely 2: No, not likely

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f.Widespread use of this option will lead to new innovation and problem-solving in society	1:Yes, likely 2:No, not likely
GEN7. Do you think using this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions is...	1:Morally acceptable 2:Morally UNacceptable 3:Not sure
GEN8. Would this gene-editing giving HEALTHY babies a much reduced risk of serious diseases and conditions be more acceptable, less acceptable, or would it make no difference in each of these circumstances?	
b.If the effects were permanent and could not be reversed	1:More acceptable 2:Less acceptable 3:No difference
c.If the effects were limited to that person and NOT passed on to future generations	1:More acceptable 2:Less acceptable 3:No difference
d.If it changed the genetic make-up of the whole population for the foreseeable future	1:More acceptable 2:Less acceptable 3:No difference
GEN9. Would you say this is an appropriate use of technology or taking technology too far if the effects were such that those who had this gene-editing were...	
a.Always EQUALLY HEALTHY as the average person today	1:An appropriate use of technology 2:Taking technology too far
b.MUCH HEALTHIER than the average person today	1:An appropriate use of technology 2:Taking technology too far
c.FAR HEALTHIER than any human known-to-date	1:An appropriate use of technology 2:Taking technology too far
GEN10 If this gene-editing becomes available, giving HEALTHY babies a much reduced risk of serious diseases and conditions, how much, if at all, do you think society as a whole would change?	1:A great deal 2:Some 3:Not too much 4:Not at all
GEN11 If this gene-editing becomes available giving HEALTHY babies a much reduced risk of serious diseases and conditions, do you think there would be...	1:More benefits for society than downsides 2:More downsides for society than benefits 3:About equal benefits and downsides for society