Using signal detection theory to understand people's antibiotic expectations

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Abstract

Antibiotic resistance is currently one of the biggest global health threats. Patients' antibiotic expectations have been found among the strongest predictors of clinicians' decisions to prescribe antibiotics. However, the factors underlying these expectations still remain unclear. To better understand the drivers behind people's antibiotic expectations, we used a utility-based signal detection theory framework to provide causal evidence and exact cognitive and computationally testable model predictions behind people's antibiotic expectations by disentangling the two distinct aspects underlying behaviour: sensitivity and bias. In a series of six experiments (N = 1,360), we designed different decision environments by manipulating and eliciting three important drivers of people's antibiotic expectations that map into the main environmental model parameters - payoffs, diagnostic uncertainty, and disease base rate - and presented participants with hypothetical medical scenarios for symptoms of respiratory tract infections. We found that the public's high inappropriate antibiotic expectations can be seen as manifestations of diagnostic uncertainty in environments with high base rates of viral infections, such as the real-world environment we all live in. The findings provide novel causal and computationally testable evidence for the effects of uncertainty and base rate on people's antibiotic expectations and advance our understanding of the factors that drive people to expect antibiotics. The findings also have significant practical implications as they can help tailor effective communication interventions for reducing diagnostic uncertainty and people's antibiotic expectations, and consequently the spread of antibiotic resistance.

Note. All the pre-registrations, data, power calculations, and analysis scripts are available on the Open Science Framework:

https://osf.io/xsrqc/?view_only=b0ad76203d1f4b3f8fe444515a18ec4a

CHAPTER 1

Introduction

Overview

Antibiotic resistance is one of the biggest global health threats. The inappropriate prescribing of antibiotics in healthcare fuels the spread of antibiotic resistance, while people's antibiotic expectations have been found among the strongest predictors of clinicians' decisions to prescribe antibiotics. However, the factors underlying these expectations still remain unclear and a theoretical understanding is lacking. Thus, the main focus of this thesis was to test a psychological theory to better understand the drivers behind people's antibiotic expectations. Specifically, we used a utility-based signal detection theory framework to advance the current literature and provide novel causal evidence and exact cognitive and computationally testable model predictions behind people's antibiotic expectations. A better understanding of what drives people to inappropriately expect antibiotics will enable us to reduce inappropriate antibiotic expectations and consequently antibiotic over-prescribing.

The impact of antibiotic resistance

Antimicrobial resistance is one of the greatest global health risks of modern times and one of the leading causes of death (Centers for Disease Control and Prevention, 2019; Donald, 2016; World Health Organization, 2014, 2021). In 2019, antimicrobial resistance is estimated to have been directly responsible for approximately 1.27 million deaths and associated with 4.95 million deaths (Murray et al., 2022). Antibiotic-resistant infections currently claim at least 50,000 lives each year across Europe and the US alone (O'Neill, 2014), with the estimated number of global infections standing at 700,000 (Department of

Health and Social Care, 2019; O'Neill, 2014); nearly one-third of these deaths are caused by multi-drug resistant tuberculosis (The Review on Antimicrobial Resistance, 2016). The recent COVID-19 pandemic (World Health Organization, 2014, 2021, 2023; Wang et al., 2020) has further exacerbated the crisis with findings pointing to an increase in antibiotic resistance during the pandemic (Sulayyim et al., 2022).

If no action is taken, it is predicted that rising antibiotic resistance will result in 10 million deaths per annum by 2050, alongside a reduction of 2% to 3.5% in Gross Domestic Product (GDP) resulting in a cumulative cost of $100 trillion (The Review on Antimicrobial Resistance, 2016). Further indirect costs to society are expected through loss of life and quality of life with areas such as global health, food sustainability and security, environmental wellbeing, and socio-economic development already at risk (Courtenay et al., 2019; Department of Health and Social Care, 2019; Murray et al., 2022). In Europe, healthcare costs and lost productivity as a result of drug-resistant infections already cost an estimated €1.5 billion per year (The Review on Antimicrobial Resistance, 2016). Moreover, growing antibiotic resistance threatens many of the Sustainable Development Goals (SDGs) with the World Bank estimating that an extra 28 million people will be forced into extreme poverty by 2050 if antibiotic resistance is not contained (Department of Health and Social Care, 2019).

The current cost of resistance is substantial, yet the potential cost of health care in a world where antibiotics are rendered ineffective is catastrophic and potentially unquantifiable (Smith & Coast, 2013). Antibiotic resistance already threatens our ability to cure common infections resulting in longer duration of illness and treatment as patients remain infectious for longer (Neu, 1992; Public Health England, 2015), increased risk of resistant infections spreading to other individuals (Angulo & Mølbak, 2005; Holmes et al., 2016), and higher mortality rates for patients with infections caused by resistant bacteria (The Review on

Antimicrobial Resistance, 2016). Moreover, resistance to first-line antibiotics necessitates the use of broader-spectrum antibiotics, along with the use of alternative, more expensive, and potentially toxic treatments increasing the economic burden on individuals, their families, and communities (Angulo & Mølbak, 2005; Cuevas et al., 2021; Holmes et al., 2016; Paladino et al., 2002), and on healthcare systems already struggling with resource shortages (Arnold & Straus, 2009; The Review on Antimicrobial Resistance, 2016).

A post-antibiotic world in which common infections, minor injuries and routine surgical procedures become lethal, as well as the potential for entire areas of practice (such as surgery or oncology) to be rendered obsolete, may be realised if new antibiotics and other approaches are not taken forward (Andersson & Hughes, 2010; Public Health England, 2015). Already, a growing list of infections – such as pneumonia, tuberculosis, blood poisoning, gonorrhoea, urinary tract infections and foodborne diseases – are becoming harder, and sometimes impossible, to treat as antibiotics become less effective (Public Health England, 2015; World Health Organization, 2021). For instance, mycobacterium tuberculosis remains a major public health across the globe with a disproportionate burden of strains resistant to two key antibiotics, isoniazid and rifampicin, known as multi-drug resistant tuberculosis (MDR-TB) with less than 60% of those treated for MDR-TB being successfully cured (Abubakar et al., 2012; World Health Organization, 2023). We are already seeing in parts of Europe a growing number of patients in intensive care units, haematology and transplant units who have pan-resistant infections with no effective treatment available (The Review on Antimicrobial Resistance, 2016). Moreover, the threat and cost of increasingly drug-resistant infections is even more severe in lower-income settings, where emerging resistance to treatments for diseases, such as tuberculosis, malaria and human immunodeficiency virus (HIV) has devastating and enormous consequences (The Review on Antimicrobial Resistance, 2016).

Antibiotic resistance is a political and financial priory, as evidenced by numerous reports and statements from global bodies, governments, and health organizations that highlight the severity of the threat posed by antibiotic resistance and commit to action to tackle its spread (Khan et al., 2019). In 2015, Member States of the World Health Organization (WHO), Food and Agriculture Organization (FAO) and World Organisation for Animal Health (OIE) endorsed a Global Action Plan on Antimicrobial Resistance (GAP), which includes five strategic objectives that offer a framework to combat antibiotic resistance over the following decade (World Health Organization, 2015). A year later, in 2016, the GAP was reaffirmed as the world's blueprint for tackling antibiotic resistance during the 71st session of the United Nations General Assembly, where all 193 Heads of State publicly committed to tackling the increase of antibiotic resistance at national, regional, and global levels (World Health Organization, 2016). Since then, the global Ad-hoc Interagency Coordination Group on AMR has put it in the wider context of the Sustainable Development Goals (SDGs), (World Bank, 2017). Along with this, an estimated US$40 billion has also been mobilized to fund strategies to address the rise of antibiotic resistance (The Review on Antimicrobial Resistance, 2016).

In the United Kingdom (UK), five-year national strategies were released by the Department of Health and Social Care in 2013 and 2019 (Department of Health and Social Care, 2013, 2019) outlining the aims of the UK government to tackle the spread of antimicrobial resistance. Similarly, in March 2015 in the United States, the President released The National Action Plan for Combating Antibiotic-Resistant Bacteria: a 5-year action plan to coordinate and strengthen prevention efforts and response to antibiotic-resistant infections, and increase federal funding directed toward combating antibiotic resistance (Centers for Disease Control and Prevention, 2015). The World Health Organization (WHO) also launched the Global Antimicrobial Resistance and Use Surveillance System (GLASS) to provide a standardized approach to the global collection, analysis, interpretation and sharing of data (World Health Organisation, 2015). Moreover, a tripartite joint secretariat has been established and is hosted by the World Health Organisation to drive multi-stakeholder engagement in Antimicrobial Resistance (World Health Organization, 2020, 2021).

The mechanisms of antibiotic resistance

Antibiotics were introduced into clinical practice only in the middle of the last century, however, the use of microorganisms for the management of microbial infections in ancient Egypt, Greece, China, and some other places of the world is well-documented (Sengupta et al., 2013; Ventola, 2015). The modern era of antibiotics started with the chance discovery of penicillin by Sir Alexander Fleming in 1928 (Fleming, 1929; Sengupta et al., 2013; Ventola, 2015). Since then, antibiotics have been at the forefront of modern medicine and saved millions of lives (Gould & Bal, 2013; Ventola, 2015).

Antibiotics are chemicals that either kill bacteria (i.e., bactericidal) or inhibit bacterial growth (i.e., bacteriostatic; Bowater, 2016; Sengupta et al., 2013). Different classes of antibiotics possess specific modes of action by which they inhibit the growth or kill bacteria. There are four main modes of antibiotic action that lead to inhibition of one of the following: 1) cell wall or membrane synthesis; 2) protein synthesis; 3) nucleic acid synthesis; and 4) metabolic reactions (Department of Health and Social Care, 2016; Sengupta et al., 2013).

Antibiotic resistance is the ability of pathogenic bacteria to resist the action of antibiotics so that they survive exposure to antibiotics that would normally kill them or stop their growth (Centers for Disease Control and Prevention, 2017; Public Health England, 2015). The three main mechanisms by which bacteria achieve this are: 1) destroying or modifying the antibiotic; 2) modifying the antibiotic target site; and 3) preventing the antibiotic from reaching the target (Bowater, 2016; Department of Health and Social Care, 2016). There is a range of mechanisms by which an organism can acquire resistance, the simplest being genetic mutation through permanent changes in the deoxyribonucleic acid (DNA) sequence that makes up a gene (Department of Health and Social Care, 2016; Read & Woods, 2014; Ventola, 2015). Resistance can also occur via horizontal gene transfer (HGT) that allows bacteria to spread antibiotic resistance genes rapidly between different species of bacteria (Read & Woods, 2014; Ventola, 2015). In the presence of antibiotics, the resistant bacteria have a survival advantage as a result of natural selection, allowing them to survive and proliferate while the sensitive bacteria are killed (Department of Health and Social Care, 2011; Read & Woods, 2014; Ventola, 2015). Since bacteria reproduce so quickly, overtime resistant bacteria come to dominate the population and treatments are lost (Department of Health and Social Care, 2011).

Antibiotic resistance has existed for millennia as a consequence of the natural process of spontaneous genetic mutation, lateral gene transfer, and natural selection (Bowater, 2016; D'Costa et al., 2011; Ventola, 2015). However, even though the evolution of resistance in bacteria does occur as a natural process, human misuse and overuse have accelerated this process (Public Health England, 2015). Any use of antibiotics, however appropriate and conservative, contributes to the development of resistance, but widespread unnecessary and excessive use makes it worse (The Review on Antimicrobial Resistance, 2016). The main drivers of antibiotic resistance include the inappropriate use of antibiotics within healthcare; the extensive use of antibiotics in agriculture as growth supplements; lack of access to clean water, sanitation and hygiene for both humans and animals; poor hygiene, infection and disease prevention and control in health-care facilities and farms; the antibiotic discovery void (i.e., lack of economic incentive for pharmaceutical companies and regulatory barriers impeding the development of new antibiotics); poor access to quality, affordable medicines, vaccines and diagnostics; lack of awareness and knowledge; and lack of enforcement of legislation (Levy & Marshall, 2004; Sirota et al., 2023; Ventola, 2015; World Health Organisation, 2021). Antimicrobial use is fundamentally a human behaviour shaped by human attitudes, norm perceptions, biases, choices, and policies embedded in social, structural, and cultural contexts (Sirota et al., 2023). Advancing our understanding of the behavioural and cognitive factors that relate to the antibiotic resistance drivers and contribute to the spread of antibiotic resistance, as well as identifying mitigating factors to prevent and curtail its spread is, therefore, crucial (Sirota et al., 2023).

The inappropriate use of antibiotics in healthcare

The inappropriate prescription, dispensing, consumption and use of antibiotics is a key driver of antibiotic resistance (Cuevas et al., 2021; Franco et al., 2009). Inappropriate use of antibiotics includes treatment of conditions for which antibiotics are not clinically warranted (i.e., for uncomplicated viral infections such as upper respiratory tract infections), antibiotic overuse, suboptimal dosage regimens, premature cessation of antibiotic treatment, non-adherence to appropriate or recommended treatment, purchasing antibiotics without prescription, self-medicating and sharing antibiotics with others (Atif et al., 2019; Ayukekbong et al., 2017; Ayukekbong et al., 2017; Chan et al., 2012; Cuevas et al., 2021; Levy-Hara et al., 2011; Owens et al., 2004; Radyowijati & Haak, 2003; Smith et al., 2018).

Antibiotic overuse fuels the evolution of resistance, as evidenced by numerous epidemiological studies that demonstrate a direct relationship between antibiotic use and the emergence of antibiotic-resistant bacteria strains (Bartlett et al., 2013; Centers for Disease Control and Prevention, 2013; Read & Woods, 2014; Spellberg &, Gilbert, 2014; Ventola, 2015). In many countries, antibiotics are unregulated and available over the counter without a prescription (Michael et al., 2014; Ventola, 2015). This results in antibiotics that are easily accessible, plentiful, and cheap, which allows people to self-medicate and promotes overuse

(Michael et al., 2014; Ventola, 2015). Moreover, the ability to purchase antibiotics online has also made them accessible in countries where antibiotics *are* regulated, which further fuels the spread of antibiotic resistance (Ventola, 2015).

Self-medication in particular is very common. It accounts for over 30% of antibiotic use in low and middle-income countries (Ocan et al., 2015). For instance, 77%–93% of participants from low and middle-income countries reported self-medicating with antibiotics in the previous 3–12 months for mostly self-limiting infections (Torres et al., 2019). In the case of self-medication, there is also a higher risk that the disease is non-bacterial. For example, between 6.0 and 15.9% of upper respiratory tract infection patients reported self-medicating using purchased antibiotics without a prescription (Duan et al., 2022; Ivanovska et al., 2013; Lin et al., 2020; You et al., 2008), while two studies found that between 5.2 and 28.0% of parents purchased antibiotics without a prescription to treat their children's upper respiratory tract infection (El Khoury et al., 2018; Parimi et al., 2014). Consuming antibiotics in this case has only harmful consequences for the individual and contributes to the overall spread of antibiotic resistance (Public Health England, 2015). The use of leftover antibiotics is also a problem (Medina-Perucha et al., 2020; Mortazhejri et al., 2020; Rutebemberwa et al., 2009). Several studies have found that between 6.7 and 24.5% of parents or caregivers store antibiotics at home (Hernandez-Diaz et al., 2019; Parimi et al., 2014), while between 0.4 and 13.1% of upper respiratory tract infection patients reported self-medicating with leftover antibiotics (Chai et al., 2019; Freidoony et al., 2017; Ivanovska et al., 2013; McNulty et al., 2013; You et al., 2008).

Similarly, electing to terminate a prescription early also contributes to the overall rise of antibiotic resistance. This is currently a highly contentious issue as there is considerable evidence showing no difference in treatment efficacy of short-course versus traditional, longer courses of antibiotic therapy for the treatment of several illnesses (Dawson-Hahn et al., 2017; Spellberg & Rice, 2019), while there is also evidence advocating for the use of longer antibiotic courses for the treatment of more serious bacterial infections (Lee et al., 2023; Rubinstein, 2007). Nevertheless, it is important to adhere to the recommended antibiotic course length prescribed by a physician since terminating an antibiotic treatment earlier than prescribed is likely to only have harmful consequences. Patients may decide to terminate antibiotic use earlier once the symptoms disappear due to concerns about potential side effects (Halfvarsson et al., 2000; Kandeel et al., 2014; Medina-Perucha et al., 2020; Simon et al., 2008; Wun et al., 2012) or simply because of an aversion toward medications in general (Halfvarsson et al., 2000). Overall patient adherence to antibiotic treatment has been reported to be between 67.3 and 78.5% (Freidoony et al., 2017; McNulty et al., 2013; Parimi et al., 2004; Pechere et al., 2001; You et al., 2008). An inappropriately short exposure to antibiotics may injure, but not eliminate, the pathogen, thus allowing the resistant bacteria to proliferate and reproduce their resistance for future bacterial generation as a result of natural selection (Public Health England, 2015).

Incorrect antibiotic prescription also promotes the propagation of antibiotic-resistant bacteria (Centers for Disease Control and Prevention, 2013). Several studies demonstrate that treatment indication, choice of antibiotic agent and dosage, or duration of antibiotic treatment are incorrect in 30% to 50% of cases (Centers for Disease Control and Prevention, 2013; Luyt et al., 2014; Ventola, 2015). Moreover, in intensive care units, a significant number (30% to 60%) of antibiotic prescriptions are found to be inappropriate, unnecessary, or suboptimal (Luyt et al., 2014; Ventola, 2015). As a result, people are exposed to subinhibitory and subtherapeutic doses of antibiotics that do not kill or impede bacterial growth efficiently, which in turn fuels the spread of antibiotic resistance (Ventola, 2015). Specifically, subinhibitory concentrations of antibiotics support changes in gene expression (genetic mutations) and horizontal gene transfer, which promotes the development of antibiotic-resistant bacteria, allowing them to survive and proliferate as a result of selective pressure, while the sensitive bacteria are killed (Davies et al., 2006; Department of Health and Social Care, 2011; Read & Woods, 2014; Ventola, 2015; Viswanathan, 2014). As a result, even though the patient might start to feel better, the surviving resistant bacteria will soon multiply, symptoms will return, and the antibiotic will no longer be effective at the original dose used (Public Health England, 2015; Ventola, 2015). Furthermore, inappropriate prescribing is also a problem for uncomplicated infections which might clear up without antibiotic treatment, such as pharyngitis (Krockow et al., 2019). Finally, the use of broad-spectrum antibiotics, which are effective against a wider range of pathogens compared with more narrow-spectrum antibiotics, also constitutes inappropriate antibiotic prescribing and is a strong driver of the spread of antibiotic resistance (Gopal Rao, 1998; Krockow et al., 2019).

Inappropriate antibiotic prescribing can also have significant adverse effects on individuals. Individuals prescribed with an antibiotic develop resistance to that antibiotic, which can spread across the body via the respiratory and urinary tracts and the skin. The effect is greatest in the month immediately after treatment but may persist for up to 12 months (Costelloe et al., 2010; Gisselsson-Solen et al., 2016). Moreover, any antibiotic prescription can cause side effects to patients either directly through gastrointestinal side effects (i.e., nausea, diarrhoea, vomiting) and allergic reactions (i.e., rashes) or indirectly by changing the nature of the gut flora, while inappropriate antibiotic prescribing can unnecessarily increase the incident of those side effects (Carabotti et al., 2015; Fischer et al., 2010; Smith et al., 2014).

It is worth acknowledging here that defining and measuring inappropriate antibiotic prescribing is often challenging in real practice, which is further complicated by the often conflicting aims of reducing antibiotic prescribing to curb the spread of antibiotic resistance, and the risk of failing to prescribe antibiotics to patients who might need them, especially when there are potential risks of mortality and morbidity (Fitzpatrick et al., 2019, Tarrant et al., 2020). Clinicians often have to make initial treatment decisions under conditions of uncertainty, guided by their own clinical judgments about indicative signs and symptoms presenting in patients, rather than on a definitive diagnosis, while at the same time, they need to balance potential risks to their patients. This is especially the case for acute medical patients presenting with several symptoms that could indicate bacterial infection, and so a definition of inappropriate prescribing, in this case, might differ from physical to physician (Tarrant et al., 2020). Nevertheless, there is no denying that the prescription of antibiotics in the absence of any bacterial infection is clearly inappropriate (Tarrant et al., 2020).

The majority of antibiotic prescriptions in primary care are inappropriately offered to patients consulting for symptoms of respiratory tract infections (Davies, 2018; Fleming-Dutra et al., 2016; Gill et al., 2006; Hansen et al., 2015; Petersen & Hayward, 2007; Pouwels et al., 2018; van den Broek d'Obrenan, et al., 2014; Wigton et al., 2008). Respiratory tract infections are highly recognizable and typical symptoms include cough, nasal discharge, sore throat, fever, fatigue, and loss of appetite (Ingram et al., 2013; Morgan et al., 2009; Neill et al., 2010). Most respiratory tract infections, such as the common cold or flu, are viral and self-limiting in nature, and therefore do not require antibiotic treatment (Gonzales et al., 2001; Young et al., 2008). Although respiratory tract infections are commonly considered to be a minor condition (Jónsson et al., 2002; McNulty et al., 2013, 2019; Morgan et al., 2009), some might develop bacterial complications and thus require an antibiotic prescription, but only a very small proportion of them will do so (Little et al., 1997; Mortazhejri et al., 2020; Tillekeratne et al., 2017). For example, only 0.5% to 2.2% of acute viral sinusitis becomes complicated by a bacterial infection and thus requires antibiotic treatment (Orlandi et al., 2016).

Moreover, there is overwhelming evidence that antibiotics are not an effective treatment option for the majority of respiratory tract infections, as demonstrated in numerous clinical trial studies and meta-analyses showing that antibiotics do not have any significant beneficial effects on symptom reduction, illness duration or complication prevention (Ahovuo-Saloranta et al., 2014; Falagas et al., 2008; Kaiser et al., 1996; Little et al., 2013; Moore et al., 2014; Rosenfeld et al., 2007; Venekamp et al., 2015). As such, the current clinical guidelines and recommendations from the Centers for Disease Control and Prevention (CDC), the National Institute for Health and Care Excellence (NICE) and the National Health Service (NHS) specifically state that antibiotics should not be prescribed to patients in primary care consulting for symptoms of a respiratory tract infection (Gonzales et al., 2001; NICE, 2008, 2017; Snow et al., 2001a, 2001b).

However, despite the official clinical guidelines and substantial clinical evidence, an alarmingly high number of antibiotics are still offered to patients with respiratory tract infections. Approximately 80% of all antibiotics in the UK and the US are prescribed in primary care, and the rest in hospital settings (Goossens et al., 2005; Public Health England, 2015). Nearly one-third of antibiotics prescribed in the United States are to treat non-bacterial infections, meaning around 47 million prescriptions are unnecessary each year (Centers for Disease Control and Prevention, 2016). In the UK, around 37% and 51% of antibiotic prescriptions were offered to primary care patients consulting for cough and cold symptoms in the years between 1995 and 2011 (Hawker et al., 2014). Moreover, antibiotics were prescribed for 60% of sore throat diagnoses despite the fact that 90% of cases are caused by viruses (The Pew Charitable Trusts, 2016). Despite recent efforts, government, and health recommendations and strategies to tackle the spread of antibiotic resistance and reduce antibiotic prescribing, current evidence indicates that inappropriate antibiotic prescriptions continue to be given in primary care with an estimated 20% of all prescriptions (approximately 6.3 million) being offered unnecessarily each year in the UK (Pouwels et al., 2018; Public Health England, 2015; Smieszek et al., 2018). Therefore, reducing the inappropriate prescribing of antibiotics in primary care remains one of the top health priorities in the fight against the growing spread of antibiotic resistance (Davies, 2018).

The effect of patient expectations on inappropriate prescribing

The public's expectations for antibiotics are crucial in this effort as findings consistently indicate that people's antibiotic expectations contribute to antibiotic overuse within healthcare (Public Health England, 2015). Patients consulting their doctor for symptoms of respiratory tract infections usually expect (in around 50% to 90% of cases) to be offered an antibiotic prescription as a treatment (Braun & Fowles, 2000; Haltiwanger et al., 2001; Macfarlane et al., 1997; McNulty et al., 2013; Ranji et al., 2006; Webb & Lloyd, 1994; Welschen et al., 2004). However, patient expectations and their understanding of diseases and treatment are not always aligned with that of health professionals (Eccles et al., 2005; Hull et al., 2013). As a result, patients' antibiotic expectations are seldom associated with the severity of their symptoms or their illness recovery, meaning that in most cases they are inappropriate, and should therefore not guide doctors' prescribing behaviours (Coenen et al., 2013). Despite this, several studies have demonstrated that patients' antibiotic expectations are one of the key drivers of the clinically inappropriate prescribing of antibiotics in primary care and are among the strongest predictors of clinicians' decisions to prescribe antibiotics (Cals et al., 2017; Macfarlane et al., 1997; Sirota et al., 2017; Strumiło et al., 2016; Van Driel et al., 2006; Welschen et al., 2004). Moreover, numerous studies also show that clinicians' perceptions of patients' antibiotic expectations also influence antibiotic prescribing, with clinicians often perceiving patient demand for antibiotics where it does not exist (Coenen et al., 2006, 2013; Courtenay et al., 2017; Kohut et al., 2020; Lucas et al., 2015; Mangione-Smith et al., 2006; Roope et al., 2020).

Many physicians report that they offer antibiotic prescriptions for viral infections because they feel pressured to do so by patients or parents (Bauchner 1999; Palmer 1997; Watson 1999). Webb and Lloyd (1994) found that patients who expected antibiotics were almost five times more likely to receive them as opposed to patients who had no expectations for a prescription. Cockburn and Pit (1997) similarly found that patients who expected antibiotics were around three times more likely to receive them, while Macfarlane et al. (1997) found that antibiotics were prescribed to 85% of patients who expected them, as opposed to 41% of patients who did not expect antibiotics. Welschen et al. (2004) also found that antibiotics were offered to 73% of patients who expected them, compared to 14% of patients who did not expect an antibiotic prescription. According to self-reported patient data, about 97% of patients who asked directly for antibiotics received a prescription (McNulty et al., 2013), while an observational study of family medicine residents observing consultations of patients with respiratory tract infection symptoms found that direct patient requests for antibiotics significantly increased the likelihood of clinicians' antibiotic prescriptions (Strumiło et al., 2016).

Moreover, a qualitative study seeking to identify the drivers of antibiotic prescribing for sore throats, found that patient pressure and expectation were cited among the main reasons for clinicians' decision to prescribe antibiotics (Kumar, Little, & Britten, 2003), while a prospective observational study found that when family physicians believed that a patient expected antibiotics, the number of prescribed antibiotics was 12 times higher (Coenen et al., 2013). More recently, an experimental study provided the first casual evidence on the effect of patients' antibiotic expectations at increasing inappropriate prescribing of antibiotics; family physicians were twice as likely to prescribe antibiotics for a patient who expected them than for a patient without such expectation but with the same clinical symptoms (Sirota et al., 2017).

The prevalence and influence of patients' expectations on clinicians' inappropriate antibiotic prescribing are well supported. However, despite the well-established link between patients' antibiotic expectations and antibiotic overprescribing, the cognitive mechanisms underlying these expectations still remain unclear and a theoretical understanding is lacking (Donald, 2015). Here, to tackle the overuse of antibiotics in healthcare, we aimed to understand the cognitive factors that drive people to expect antibiotics by employing a signal detection theory framework to provide behavioural, cognitive, and computationally testable mechanisms behind their antibiotic expectations. We argue that the mechanisms should be able to account for three important determinants of peoples' antibiotic expectations: diagnostic uncertainty, base rate, and cost-benefit considerations (Sirota et al., 2022).

The drivers behind people's antibiotic expectations

Patients' diagnostic uncertainty about the nature of the illness and the efficacy of antibiotics has gathered strong empirical and theoretical support as the main driver of people's antibiotic expectations. Many studies have reported that people experience conceptual confusion about whether antibiotics are needed or not (Braun & Fowles, 2000; McNulty et al., 2013, 2019; Welschen et al., 2004), while findings also show that people expect antibiotics for conditions that do not require them, such as viral infections (McNulty et al., 2019; Kong et al., 2021). Diagnostic uncertainty can also concern the clinical symptoms and whether they manifest a viral or bacterial infection. For example, uncertainty regarding the nature of their illness predicted people's expectations for antibiotics for their recently experienced symptoms of a cold (Thorpe et al., 2021), while recent robust experimental evidence showed that reducing diagnostic uncertainty by providing a clinician's judgement about the illness aetiology of the symptoms, and in some cases including a diagnostic test, significantly decreased people's antibiotic expectations in hypothetical consultations (Thorpe et al., 2020a, 2020b, 2021).

Another important but understudied determinant of antibiotic expectations is the base rate of viral versus bacteria illnesses. Even though the evidence is limited, an aspect of base rate which has gathered some evidence as a determinant of people's antibiotic expectations is prior experience. Several studies have found that past consultation behaviours and previous antibiotic treatment for viral infections are associated with greater expectations for antibiotics (Thorpe et al., 2021; Vinker et al., 2003), while two studies also showed that between 74.4% and 81.8% of those who have been prescribed with antibiotics for upper respiratory tract infections expect antibiotic treatment for similar infections in the future (Emslie et al., 2003; Osborne et al., 2006). Moreover, people typically encounter and experience many more cases of viral rather than bacterial illnesses in their daily lives (Creer et al., 2016), but no study has yet directly manipulated the base rate to provide evidence for its effect on people's antibiotic expectations.

Furthermore, people consider various subjective benefits and costs associated with their decisions to expect antibiotics or not. For instance, people tend to overestimate the benefits of antibiotics to avoid the cost and the associated negative consequences of missed illness (Spicer et al., 2020; Thorpe et al., 2021). Many studies have reported that people believe that antibiotics can shorten the duration and halt the progress of upper respiratory tract infections, and thus warrant their use for even minor conditions (Cabral et al., 2015; Gaarslev et al., 2016; Jin et al., 2011; Kandeel et al., 2014). Conversely, people tend to underestimate the risks of side effects of antibiotics, with most deeming them common but relatively benign (Halfvarsson et al., 2000; Roberts et al., 2015; Spicer et al., 2020; Szymczak et al., 2018; Thorpe et al., 2021). People also tend to consider the risks associated with the consequences of antimicrobial resistance. Most believe that antibiotic resistance is an individual matter of low response to antibiotics (Finkelstein et al., 2014; Jónsson et al., 2002; Rutebemberwa et al., 2009), and they may consider themselves at low risk of antibiotic resistance simply because they are low users (Bakhit et al., 2019; Gaarslev et al., 2016; Van Hecke et al., 2019). They are less likely to consider the negative consequences associated with it when they believe they are not personally at risk (Fletcher-Miles & Gammon, 2020; Roope et al., 2020). Given that most people have an incomplete knowledge regarding antibiotic resistance (Deschepper et al., 2002; Jin et al., 2011; Rutebemberwa et al., 2009), public health campaigns increasingly include information about the negative consequences of antibiotic overuse (Huttner et al., 2010). Moreover, according to the fuzzy trace theory, people often rely on categorical value-based distinctions between decision options; when they feel sick from an infection, they are more likely to seek antibiotics and subscribe to the categorical gist of "why not take a risk" on the possibility of improvement, even if they understand that probability of improvement is low (Reyna et al., 2021, 2022). Patients can also attach added value to antibiotic treatment which goes beyond the management of their current condition, such as reducing the uncertainty of health events to come (Cabral et al., 2015; Gaarslev et al., 2016; Jin et al., 2011; Kandeel et al., 2014; Medina-Perucha et al., 2020), a reward for patient's efforts (Gaarslev et al., 2016), and a shortcut to returning to normal life (Gaarslev et al., 2016; Roberts et al., 2015).

Moreover, even though several other distinct factors have been identified as driving people's antibiotic expectations, such as fear (Roope et al., 2020), knowledge (Cals et al., 2007; Kong et al., 2019), action bias (Thorpe et al., 2020a), and social information (Bohm et al., 2022; Krockow et al., 2022), the processes underlying them still remain unclear as most studies have relied on approaches that conflate two conceptually distinct aspects in the identification of patients' antibiotic expectations: a) ability to accurately distinguish between clinical situations whether antibiotics are needed or not, and b) response biases to judge certain clinical situations as needing or not antibiotics regardless of whether antibiotics are actually needed or not (Betailler et al., 2022).

Utility-based signal detection theory

In the current thesis, we adopted a utility-based signal detection theory approach (Lynn & Barrett, 2014; Lynn et al., 2015) to integrate the above sets of findings about the drivers and provide behavioural, cognitive, and computationally testable mechanisms behind people's antibiotic expectations by disentangling the two distinct aspects underlying behaviour: sensitivity and bias. Signal detection theory (SDT) characterises how individuals separate meaningful information or "signals" (i.e., clinical situations where antibiotics are needed) from "noise" (i.e., clinical situations where antibiotics are not needed; Green & Swets, 1966; Lynn & Barrett, 2014). This information, however, can be uncertain, as the cases of whether antibiotics are needed or not might be similar to one another, and misclassification might carry some relative cost, called risk (Lynn & Barrett, 2014). To apply SDT to antibiotic expectations, we need to assume that the perceiver is judging a case (i.e., a hypothetical medical scenario) based on a decision variable (i.e., need for antibiotics; Lynn & Barrett, 2014; Kostopoulou et al., 2019; Sirota et al., 2022). Repeated presentations generate a distribution of values of the decision variable for antibiotics in "signal" (antibiotics are needed) and "noise" (antibiotics are not needed) clinical situations (Kostopoulou et al., 2019; Sirota et al., 2022). However, the probability distributions overlap because some values on the decision variable can result from either type of clinical situation (Kostopoulou et al., 2019). Given the information provided, the perceiver must, therefore, make a decision about whether antibiotics are needed or not (Lynn & Barrett, 2014; Kostopoulou et al., 2019; Sirota et al., 2022). There are four possible decision outcomes that represent either correct or incorrect decisions: (i) expecting antibiotics when they are needed (correct detection); (ii) expecting antibiotics when they are not needed (false alarm); (iii) not expecting antibiotics when they are needed (missed detection); and (iv) not expecting antibiotics when they are not needed (correct rejection; Lynn & Barrett, 2014). These can be captured with a 2 × 2 table (see Table 1). Drawing on this conceptualisation, research on why people display inappropriate antibiotic expectations can be understood as being concerned with the causes of false alarms, that is, why do people inappropriately expect antibiotics when they are not clinically needed?

Table 1

The Decision Outcomes

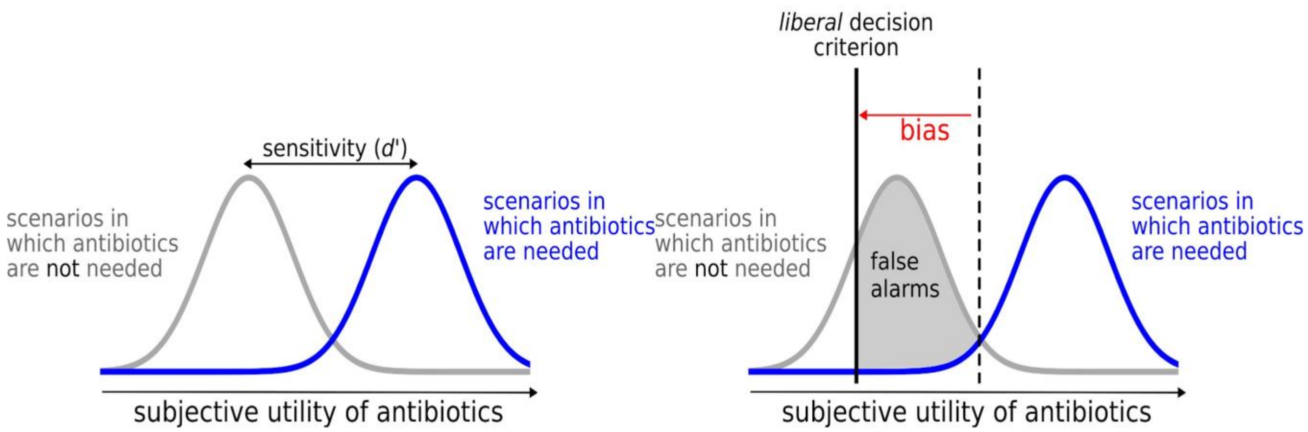
	Antibiotics needed	Antibiotics not needed
Decision (antibiotics needed)	**Correct detection**	**False alarm**
Decision (antibiotics not needed)	**Missed detection**	**Correct rejection**

Note. The four decision outcomes represent correct (correct detection and correct rejection and incorrect (missed detection and false alarm) decisions.

This framework postulates that when a person is experiencing symptoms of a respiratory tract infection, they must decide whether their symptoms warrant an antibiotic treatment. According to SDT, their decision is determined by two distinct components underlying behaviour: sensitivity and bias (Green & Swets, 1966; Lynn & Barrett, 2014). Sensitivity is the ability to discriminate between the clinical situations when antibiotics are needed (i.e., "targets") and when they are not (i.e., "foils"). Sensitivity is typically quantified with the *d'* index, which corresponds to the distance between the target and foil distributions expressed in standard deviations, and it is an estimate of the uncertainty (see Figure 1). Bias (c) reflects the propensity to categorise certain clinical situations as targets (antibiotics are needed) vs foils (antibiotics are not needed) and is described as liberal, neutral or conservative (Lynn & Barrett, 2014). Bias is derived from the location of the decision criterion on the support space of the decision variable. Given a certain sensitivity and prior probabilities of the targets and foils, there is an optimal criterion that maximises the frequency of correct decisions; in this thesis we will define bias as the distance from such an optimal criterion (see Figure 1). For instance, a person with a liberal antibiotic bias will be more likely to classify clinical situations as needing antibiotics even when they are not clinically needed (see Figure 1; Lynn & Barrett, 2014).

Figure 1

The Signal Detection Model Parameters



Note. The figure shows the signal detection model parameters, sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in grey) and bias (c, that is the distance of the decision criterion, shown by vertical black bold line, from the optimal criterion, shown by the vertical dashed black line). The y-axis here shows the probability density of the distributions, while the x-axis shows the location of the response variable.

The utility-based approach combines uncertainty with the economic concept of utility, which is the net benefit expected to accrue from a series of decisions (Lynn & Barrett, 2014). According to the utility-based approach, there are three main parameters that characterise the uncertainty and risk within a specific decision-making environment: 1) The payoff parameter, which describes the value of the four possible decision outcomes; 2) The base rate parameter, which describes the perceiver's probability of encountering targets (clinical situations where antibiotics are needed) vs foils (clinical situations where antibiotics are not needed); and 3) The similarity parameter, which models the perceptual or conceptual uncertainty of the target and foil categories (Lynn & Barrett, 2014). Payoffs and base rate influence bias (i.e., rare targets or costly false alarms each promote a *conservative* bias, a higher criterion for judging that a target is present and that antibiotics are needed) whereas common targets or costly misses each promote a *liberal* bias (i.e., a lower criterion for judging that a target is present and that antibiotics are needed), (Lynn & Barrett, 2014). Conversely, the similarity of the target and foil categories influences sensitivity (i.e., perceivers have reduced sensitivity when targets and foils are more similar to one another), (Green & Swets, 1966; Lynn & Barrett, 2014; Macmillan & Creelman, 1991). The utility-based approach to SDT quantifies and predicts these relationships between environmental parameters and behaviour when the decision-maker optimally adjusts their decision strategy (the placement of the criterion) in a way that maximises the expected value or utility of their choices.

By modelling the three environmental parameters (i.e., payoffs, base rate and similarity) that underlie bias and sensitivity, we can measure participants' optimality of decision-making in terms of their antibiotic expectations and gain behavioural insight into the factors that drive people to inappropriately expect antibiotics when they are not clinically needed (Lynn & Barrett, 2014). Moreover, we can mathematically predict and empirically compare perceivers' optimality within and between experimental conditions (Lynn & Barrett, 2014). Based on the three parameters, the expected utility for every possible criterion location will be calculated. The point of maximum utility will correspond to the optimal criterion location, where inappropriate antibiotic expectations will be minimised (Lynn & Barrett, 2014).

Signal detection theory has been applied to several clinical contexts, ranging from breast and prostate cancer detection (Abbey et al., 2009; Swets et al., 2000) to screening for the virus of AIDS (Swets at al., 2000), and measuring the referral decision making of general practitioners (GPs) in cases of possible lung cancer (Kostopoulou et al., 2019). More recently, a study measuring people's inappropriate antibiotic expectations employed a utility-based signal detection theory framework by testing the qualitative predictions of the model (Sirota et al., 2022).

A utility-based signal detection theory approach predicts that people inappropriately expect antibiotics because they adopt a liberal criterion of what establishes a signal due to diagnostic uncertainty, and/or due to being oblivious to the costs associated with inappropriate use of antibiotics (i.e., antibiotic resistance), and/or due to failing to adjust their decision strategy to the environmental base rate of viral versus bacterial illnesses. In other words, a utility-based signal detection theory approach predicts that people's antibiotic expectations can be explained by the interplay between the three main model parameters – diagnostic uncertainty, cost-benefit considerations, and the disease base rate. This approach has been successfully applied to this context: decreasing diagnostic uncertainty and making people aware of costs associated with antibiotic resistance changed the criterion location, and hence decreased people's expectations and requests for antibiotics in hypothetical consultations (Sirota et al., 2022). However, exact quantitative and computationally testable model predictions are missing, and no study has yet tested the effect of similarity (i.e., uncertainty) in a systematic manner, or the extent to which people adjust their antibiotic expectations to the base rate. Further work is needed to develop a theoretical framework for understanding the main factors underlying people's antibiotic expectations and provide causal evidence and exact cognitive and computationally testable model predictions.

Thesis Overview

Antibiotic resistance is one of the biggest global health threats. The overuse of antibiotics within healthcare is one of the main contributors to the emergence and propagation of antibiotic resistance, while the public's antibiotic expectations drive clinicians' prescribing behaviours. However, despite the well-established link between people's antibiotic expectations and antibiotic overprescribing, little is known about the drivers behind these expectations.

A better understanding of the behavioural and cognitive factors that drive people's antibiotic expectations would extend our theoretical understanding of the psychological reasons of why people expect antibiotics even when these are not clinically appropriate. An even more important objective of this research would be to enable us to identify effective methods to help inform national efforts to reduce antibiotic expectations and consequently antibiotic over-prescription.

To better understand the factors that drive people to expect antibiotics, the current research employs a utility-based signal detection theory framework to provide causal evidence and computationally testable mechanisms behind people's antibiotic expectations. In a series of six pre-registered studies, we design different decision environments by manipulating or eliciting three important drivers of antibiotic expectations that map into the main model parameters - payoffs, diagnostic uncertainty, and disease base rate.

Specifically, Chapter 2 focuses on testing the antibiotic scenarios that we created and the utility-based signal detection theory model., while manipulating and electing the three main model parameters. Chapter 3 reports experimental evidence of three studies focusing on systematically removing some of the potential methodological limitations identified in Chapter 2 by designing different decision environments to test their effect on people's antibiotic expectations. Chapter 4 focuses on testing the base rate parameter to provide causal evidence for its effect on people's antibiotic expectations. Finally, Chapter 5 contains a discussion of the main findings of the research presented in the preceding chapters along with the theoretical and practical implications, as well as consideration of potential limitations and some directions for future research.

CHAPTER 2

Testing signal detection theory of people's antibiotic expectations

Introduction

Patients' antibiotic expectations are one of the key drivers of the clinically inappropriate prescribing of antibiotics in primary care and are among the strongest predictors of clinicians' decisions to prescribe antibiotics; patients who expect and/or request antibiotics are more likely to receive a prescription, thus leading to overuse (McNulty et al., 2013; Sirota et al., 2017; Welschen et al., 2004). However, despite the well-established link between patients' antibiotic expectations and antibiotic overprescribing, the cognitive mechanisms underlying these expectations still remain unclear and a theoretical understanding is lacking (Donald, 2015). A better understanding of the drivers behind people's antibiotic expectations will enable us to reduce people's antibiotic expectations and thus the inappropriate antibiotic prescribing in health care: by decreasing people's expectations, doctors will feel less pressured to prescribe antibiotics, which will in turn reduce antibiotic prescribing.

People's diagnostic uncertainty about the nature of the illness and the efficacy of antibiotics has been identified as one of the key drivers of people's antibiotic expectations (Braun & Fowles, 2000; McNulty et al., 2013, 2019; Welschen et al., 2004). For example, uncertainty regarding the nature of their illness predicted people's expectations for antibiotics for their recently experienced symptoms of a cold (Thorpe et al., 2021), while recent experimental evidence showed that reducing diagnostic uncertainty by providing a clinician's judgement about the illness aetiology of the symptoms, and in some cases including a diagnostic test, significantly decreased people's antibiotic expectations in hypothetical consultations (Sirota et al., 2022; Thorpe et al., 2020a, 2020b, 2021).

Moreover, people consider various subjective benefits and costs associated with their decisions to expect antibiotics or not, such as the negative consequences of missed illnesses and the side effects of antibiotics (Roberts et al., 2015; Simon et al., 1996; Spicer et al., 2020; Thorpe et al., 2021), the risks associated with the consequences of antimicrobial resistance (Finkelstein et al., 2014; Fletcher-Miles & Gammon, 2020; Jónsson et al., 2002; Roope et al., 2020; Rutebemberwa et al., 2009). People also often rely on categorical value-based distinctions between decision options. According to the fuzzy trace theory, when people are sick from an infection, they are more likely to subscribe to the categorical gist of "why not take a risk" and choose the risky option on the possibility of improvement as opposed to preferring the option without an antibiotic treatment even if they understand that probability of improvement is low (Reyna et al., 2021, 2022).

Sirota et al. (2022) employed a utility-based signal detection theory approach (Lynn & Barrett, 2014; Lynn et al., 2015) to explain how people form their antibiotic expectations and found that both the diagnostic uncertainty and the cost-benefit considerations can explain people's antibiotic expectations. Specifically, they found that reducing the diagnostic uncertainty and increasing the saliency of the costs of antibiotic overuse decreased people's antibiotic expectations and requests in hypothetical consultations (Sirota et al., 2022). However, these were only qualitative predictions of the theory and served more as proof-of-the-concept experiments. Quantitative and computationally testable model predictions are still missing, and further work is needed for estimating the individual decision-makers' model parameters – sensitivity and bias - underlying behaviour, extending the scope of the model predictions to accommodate for other findings in the literature, providing exact quantitative and computationally testable model predictions, and developing a theoretical framework for understanding the exact factors underlying people's antibiotic expectations (Sirota et al., 2022).

Moreover, another promising but understudied determinant of antibiotic expectations and the third utility-based signal detection model parameter is the base rate of viral versus bacteria illnesses. People typically encounter many more cases of viral rather than bacterial illnesses in their daily lives (i.e., Creer et al., 2016). However, most studies on antibiotic expectations have typically only used the real-world base rates (i.e., McNulty et al., 2019) without manipulating or controlling for the base rate in any way. Another aspect of base rate which has gathered some evidence as a determinant of people's antibiotic expectations is prior experience. Several studies have found that past consultation behaviours and previous antibiotic treatment for upper respiratory tract infections are associated with greater expectations for antibiotics for similar infections in the future (Emslie et al., 2003; Osborne et al., 2006). However, no study has yet directly manipulated the base rate to provide causal evidence and computationally testable predictions for its effect on people's antibiotic expectations.

Furthermore, even though several other important drivers of antibiotic expectations have been identified (i.e., Bohm et al., 2022; Cals et al., 2007; Kong et al., 2019; Krockow et al., 2022; Roope et al., 2020; Thorpe et al., 2020a), it is difficult to understand which factors, and to what extent, have an effect on people's antibiotic expectations as most studies have typically relied on approaches that conflate two conceptually distinct aspects in the identification of people's antibiotic expectations: sensitivity (the ability to accurately distinguish between clinical situations whether antibiotics are needed or not) and bias (the propensity to judge certain clinical situations as needing or not antibiotics (Betailler et al., 2022).

Here, we adopted a utility-based signal detection theory approach (Lynn & Barrett, 2014; Lynn et al., 2015) to extend the above set of findings and provide exact cognitive and computationally testable model predictions behind people's antibiotic expectations by decomposing the two distinct aspects underlying behaviour: sensitivity (the ability to discriminate between the clinical situations when antibiotics are needed and when they are not) and bias (the propensity to categorize certain clinical situations as needing antibiotics vs not needing antibiotics). A utility-based signal detection theory approach predicts that people inappropriately expect antibiotics because they adopt a liberal criterion of what establishes a signal due to diagnostic uncertainty, and/or due to being oblivious to the costs associated with inappropriate use of antibiotics (i.e., antibiotic resistance), and/or due to failing to adjust their decision strategy to the environmental base rate of viral versus bacterial illnesses. This approach has been successfully applied to this context using qualitative model predictions: decreasing diagnostic uncertainty and making people aware of costs associated with antibiotic resistance changed the criterion location, and hence decreased people's expectations and requests for antibiotics in hypothetical consultations (Sirota et al., 2022). However, exact quantitative and computationally testable model predictions are missing, and no study has yet tested the effect of diagnostic uncertainty in a systematic manner, or the effect of base rate on people's antibiotic expectations to provide causal evidence.

Pre-test

Before manipulating the signal detection model parameters, we first had to create and test the experimental stimuli that we were planning to use in our main studies. Therefore, the overarching aim of this Pre-test was to test the antibiotic scenarios that we created. Specifically, we created 24 hypothetical medical scenarios (see Appendix Pre-test) of both viral and bacterial respiratory tract infections, while we also manipulated the uncertainty in the scenarios resulting in four main conditions: certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed.

The scenarios in the two antibiotics are not needed conditions (certain and uncertain) were both modelled after cases where antibiotics should not be prescribed. Specifically, they were both modelled after a diagnosis of acute bronchitis. Acute bronchitis is a self-limited respiratory tract infection with cough as the primary symptom (Albert, 2010). Approximately 90% of acute bronchitis infections are caused by viruses (Gonzales et al., 2001; Worrall, 2008) and the NICE clinical guidelines recommend that antibiotics should not be prescribed to patients consulting for symptoms associated with bronchitis (National Institute for Health and Care Excellence NICE, 2019a).

Conversely, the scenarios in the two antibiotics are needed conditions (certain and uncertain) were modelled after cases where antibiotics should be prescribed. Specifically, they were modelled after a diagnosis of community-acquired pneumonia. Pneumonia is a lower respiratory tract infection that is most commonly caused (in around 90% of cases) by a bacterial infection (Lim et al., 2009; Jain et al., 2015). However, due to its high mortality rate, the clinical guidelines state that all people exhibiting symptoms of community-acquired pneumonia should be prescribed antibiotics (National Institute for Health and Care Excellence, 2019b).

The scenarios used a symptomatic description, similar to those of past research (i.e., Roope et al., 2020; Sirota et al., 2022l Thorpe et al., 2020a, 2020b, 2021) rather than specifying ‘bronchitis’ or ‘pneumonia’. This is because participants might interpret specific symptoms differently, while it is also possible that people might be aware that antibiotics are not indicated for viral illnesses, but they might not be able to recognise specific respiratory tract infection symptoms as being more indicative of viral, rather than bacterial infection (Roope et al., 2020).

Present study & Aims

The main aim of this Pre-test was to test the antibiotic scenarios that we created and test whether participants are able to discriminate between the different symptom categories. We presented participants with the 24 hypothetical medical scenarios in the four different uncertainty conditions and asked them to indicate their need for antibiotics as a treatment. Participants were also asked to complete a short ranking task of antibiotic decision outcomes, as well as two ranking tasks of antibiotic-related outcomes associated with false alarms (i.e., taking antibiotics when they are not needed) and missed detections (i.e., not taking antibiotics when they are needed).

Specifically, we set up three main aims. First, we aimed to test whether the antibiotic scenarios worked as intended and whether participants would be able to discriminate between the four uncertainty conditions and different symptom categories. Second, we aimed to calculate the signal detection model parameters underlying behaviour – bias and sensitivity - and get a baseline of people's antibiotic expectations. Third, we wanted to explore how participants rank different antibiotic-related outcomes associated with false alarms and missed detections.

Methods

Ethics

The research complied with all relevant ethical regulations. It received ethical approval from the Ethics Committee at the University of Essex (ref: ETH2021-0608). Informed consent was also obtained from all participants prior to starting the study online.

Participants

Participants were recruited via the university's online research participation system (SONA) and through social media (i.e., Facebook). For the pre-test, we were aiming to recruit around 20 participants. In the final sample size of 19 participants, 4 identified as male, 14 as female and 1 as other. The sample age ranged from 19 to 63 years old *(M* = 26.7, *SD* = 12.6 years). Most participants (14) were native English speakers. Participants' occupation varied as follows: management, professional, and related (5.3%), student (89.5%) and other (5.3%). Their level of education varied as follows: high school degree (10.5%), some college (47.4%), undergraduate degree (31.6%) and master's degree (10.5%).

Design

This was a within-subjects design with uncertainty condition being the independent variable and expectations for antibiotics being the dependent variable. Participants read 24 hypothetical medical scenarios (see Appendix Pre-test) in the four within-subjects uncertainty conditions (certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and were asked to report their need for antibiotics as a treatment via a rating on a 4-point discrete scale ranging from 1 (Definitely no) to 4 (Definitely yes) with an explicit cut-off between "yes" and "no" responses (necessary for the analyses based on signal detection theory). From the responses to the antibiotic expectations variable, we calculated the bias and sensitivity with bias being the main dependent variable.

Participants also completed a short ranking task of four antibiotic decision outcomes, as well as two ranking tasks of antibiotic-related outcomes associated with false alarms and missed detections, followed by some sociodemographic questions.

Materials and Procedure

After participants provided informed consent, they were able to start the study, which took around 15 minutes to complete. They then moved on to the introductory page of the antibiotic scenarios task. Importantly, due to the COVID-19 pandemic, all participants were told that COVID-19 cannot account for their symptoms and were asked to indicate "yes" to the following question showing that they have read and understood the above information. All participants were then presented with the 24 antibiotic scenarios (presented in random order but with fixed attention check questions), then with the four antibiotic decision outcomes ranking task, followed by the two ranking tasks of the antibiotic-related outcomes associated with false alarms and missed detections (order of the task was randomised), and finally with the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 24 hypothetical medical scenarios describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines. There were four main conditions: certain antibiotics are not needed (6 scenarios) uncertain antibiotics are needed (6 scenarios), uncertain antibiotics are not needed (6 scenarios), and certain antibiotics are needed (6 scenarios). Participants completed all four conditions and were presented with all 24 scenarios in a randomised order. They were also presented with three attention-check questions embedded in the scenarios. In the scenarios, all participants received a description of the symptoms and illness duration and a description of the physical chest examination. Specifically, all the scenarios had the following set of symptoms that stayed constant: sore throat, runny nose, muscle aches and general fatigue. Moreover, the following pieces of clinical information were present in all scenarios but varied depending on the condition: *illness duration, cough, phlegm, temperature, breathlessness, and physical chest examination*. After each scenario, participants were asked to report their perceived need for antibiotics as a treatment on a four-item Likert scale ranging from 1 to 4 (1 = *Definitely no*, 2 = *Probably no*, 3 = *Probably yes*, 4 = *Definitely yes*) with an explicit cut-off between "yes" and "no" responses.

The scales had an acceptable to excellent internal consistency in the four conditions: certain antibiotics are not needed (Cronbach's Alpha = 0.91), uncertain antibiotics are not needed (Cronbach's Alpha = 0.83), uncertain antibiotics are needed (Cronbach's alpha = .76) and certain antibiotics are needed (Cronbach's alpha = .81). An average score of antibiotics expectations (0-4) was computed for each participant in the four conditions. Higher scores indicate higher antibiotic expectations. The antibiotic expectations responses were also coded in a binary "yes" or "no" response according to the explicit cut-off value between the responses on the scale (necessary for the analyses based on signal detection theory).

Antibiotic decision outcomes. Participants had to rank four decision outcomes associated with taking or not taking antibiotics from 1 (best possible outcome) to 4 (worst possible outcome). The four decision outcomes were as follows: taking antibiotics when they are needed (correct detection), not taking antibiotics when they are needed (missed detection), not taking antibiotics when they are not needed (correct rejection), taking antibiotics when they are not needed (false alarm).

False alarms and missed detection outcomes. Participants had to rank eight antibiotic-related outcomes associated with false alarms (i.e., taking antibiotics when they are not needed) and eight outcomes associated with missed detections (i.e., not taking antibiotics when they are needed) from 1 (best possible outcome) to 8 (worst possible outcome). The eight false alarm outcomes were as follows: 1) Increased risk of hospital admittance and extended hospital stays, 2) Additional follow-up doctor visits, 3) Loss of productivity/income due to ill health and extended time off work, 4) Antibiotics side effects (i.e., nausea, diarrhoea), 5) Increased susceptibility to infections due to the death of your body's good bacteria, 6) Alternative and toxic treatments with serious side effects (i.e., permanent hearing loss), 7) Increased risk of developing diabetes, 8) Getting an antibiotic-resistant infection.

The eight missed detection outcomes were: 1) Increased risk of hospital admittance, 2) Additional follow-up hospital and doctor visits, 3) Unnecessary treatments and medical prescriptions, 4) Higher medical costs (i.e., from unnecessary prescriptions), 5) Deteriorating condition and progressive feelings of unwellness, 6) Longer illness duration, 7) Serious complications due to illness progression, 8) Loss of productivity/income due to ill health and extended time off work.

Lastly, participants were asked to report some socio-demographic information (i.e., age, gender, education, occupation and language) and were debriefed and given the chance to comment on the study.

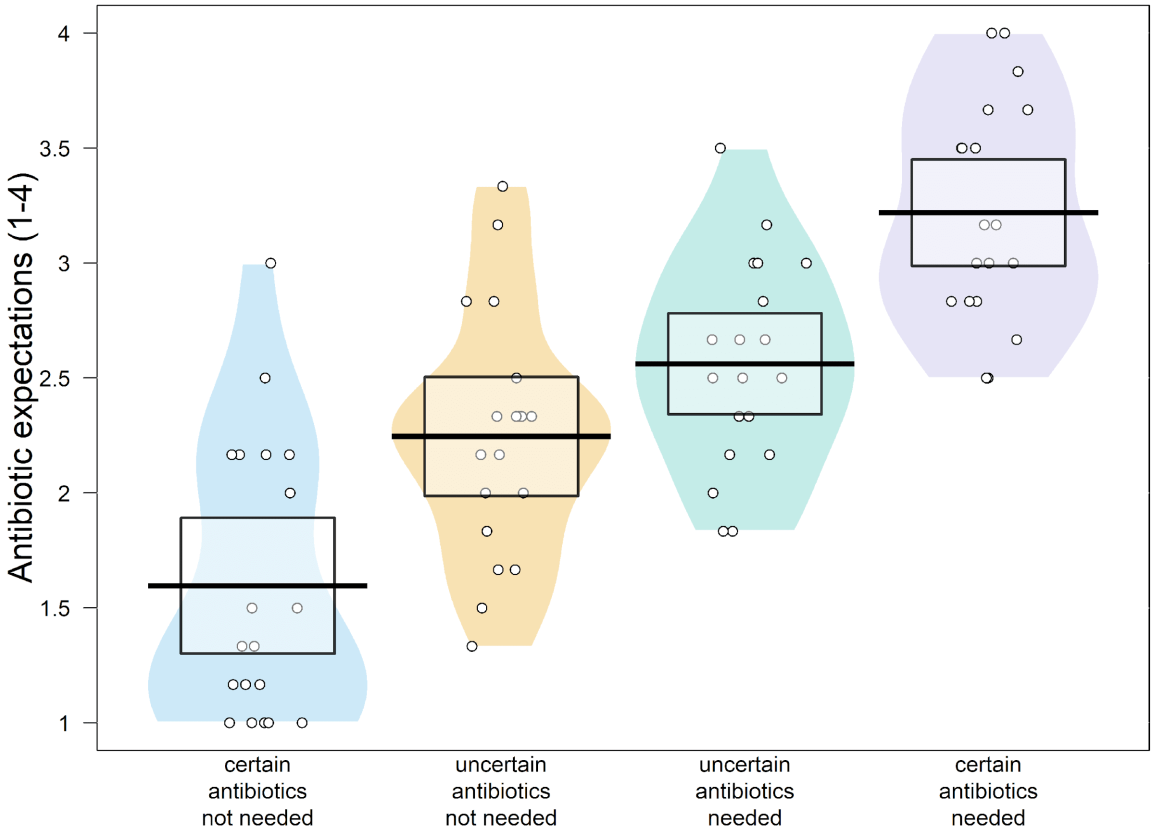
Results and Discussion

Antibiotic expectations

Participants reported the lowest antibiotic expectations in the "certain antibiotics are not needed" condition, whereas they reported the highest expectations in the "certain antibiotics are needed" condition (see Figure 1). In the two uncertain conditions, participants' antibiotic expectations responses fell around the middle of the scale (see Figure 2). Overall, participants' antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories.

Figure 2

Effect of Uncertainty on Antibiotic Expectations

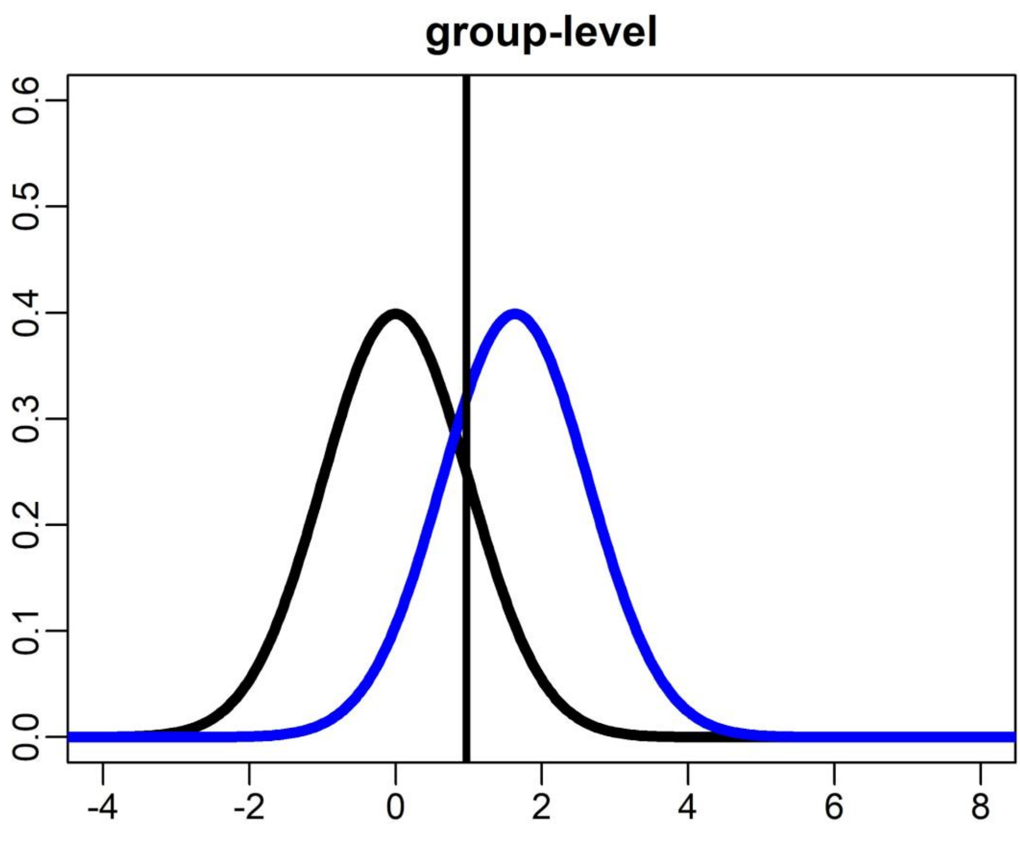


Note. Effect of uncertainty condition (certain antibiotics are not needed vs uncertain antibiotics are not needed vs uncertain antibiotics are needed vs certain antibiotics are needed) on antibiotic expectations. The middle bold line represents the arithmetic mean and the box borders represent 95% confidence intervals.

We also conducted a multilevel Bayesian generalized linear model (with a probit link function, thus equivalent to a signal detection theory model with a Gaussian-distributed latent decision variable comprising both group-level "fixed" effects and subject-specific "random" effects) to estimate the group-level signal detection model parameters: bias (the distance of the decision criterion from the optimal criterion) and sensitivity (the distance between signal and noise distribution, expressed in standard deviations, also referred to as d'). Overall, participants' responses did not deviate systematically from the optimal strategy (as indicated by the mean deviation from the optimal criterion and its associated 95% Bayesian credible interval) and they did not display any liberally biased antibiotic expectations, mean deviation from optimal criterion = 0.16, 95%CI [-0.24,0.59], (see Figure 3).

Figure 3

The Signal Detection Model Parameters



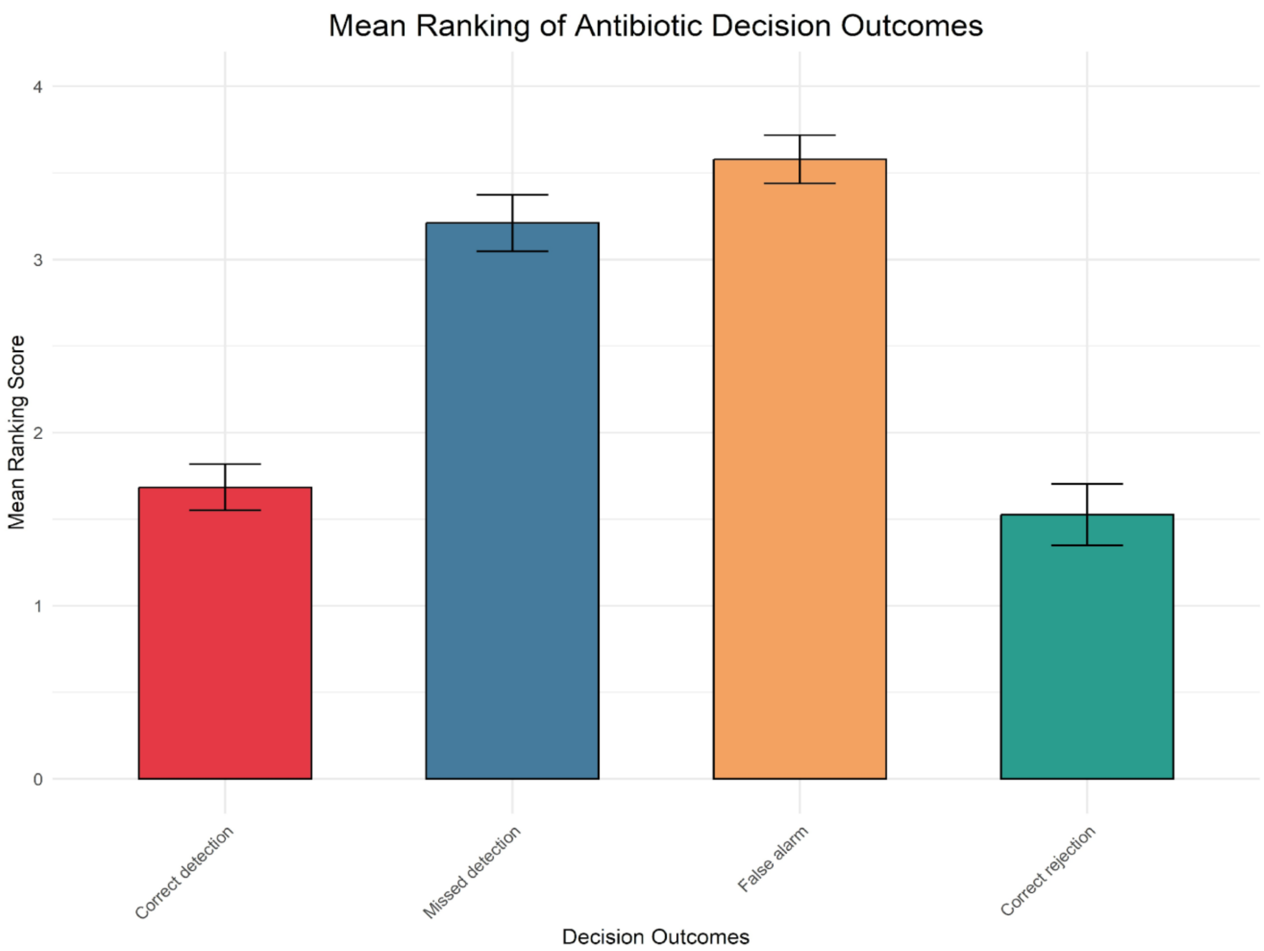
Note. The figure shows the signal detection model parameters, bias (c) and sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in black), calculated by people's antibiotic expectations in the scenarios. The vertical black bold line represents the criterion location.

Antibiotic decision outcomes

Participants ranked the four antibiotic decision outcomes from best to worst as follows: 1) Not taking antibiotics when they are not needed (correct rejection); 2) Taking antibiotics when they are needed (correct detection); 3) Not taking antibiotics when they are needed (missed detection); and 4) Taking antibiotics when they are not needed (false alarm), (see Figure 4).

Figure 4

The Mean Rankings of the Antibiotic Decision Outcomes



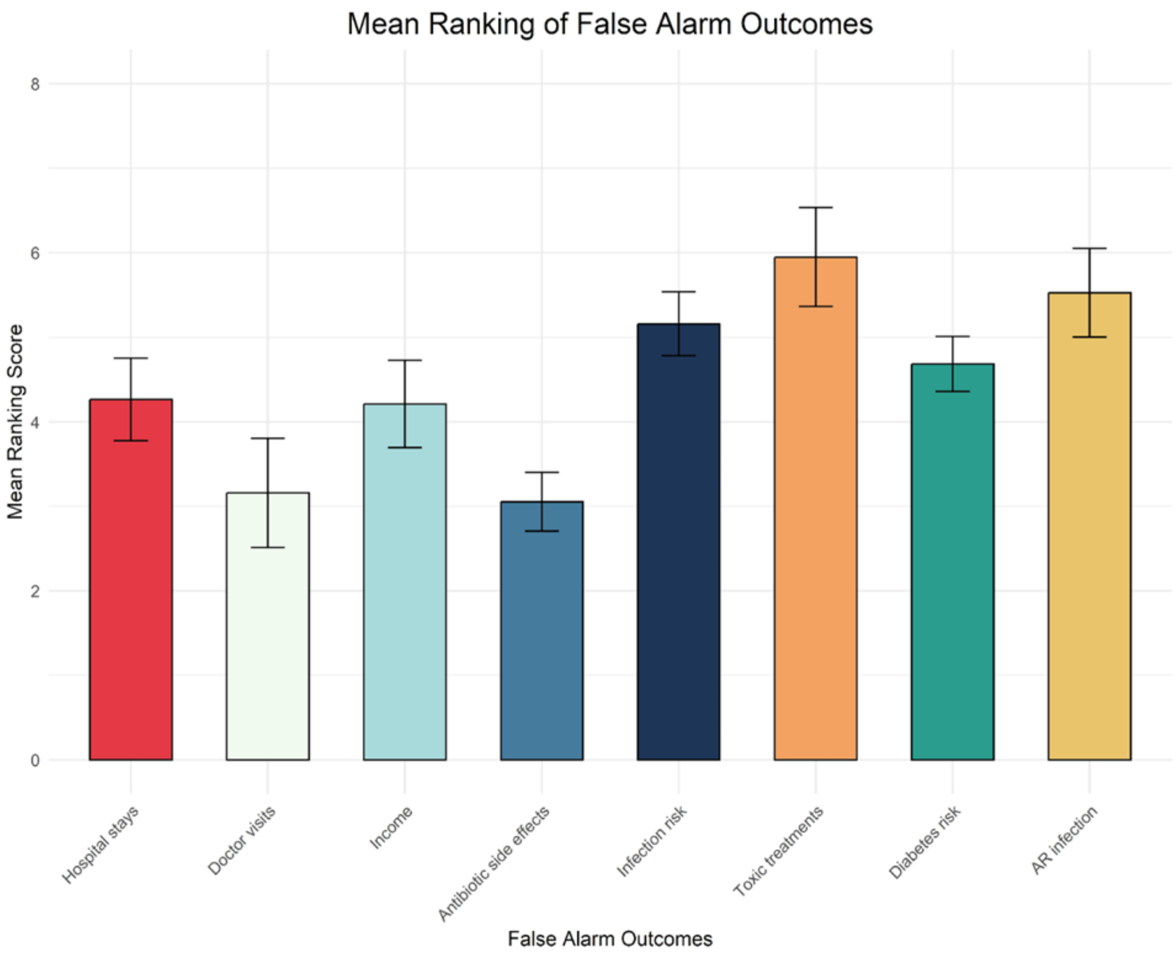
Note. The figure shows the mean rankings of the four antibiotic decision outcomes: correct detection, missed detection, false alarm, and correct rejection. The error bars represent the standard error of the mean.

False alarms and missed detection outcomes

Participants ranked the eight outcomes associated with false alarms (taking antibiotics when they are not needed) from best to worst as follows: 1) Antibiotics side effects (i.e., nausea, diarrhoea); 2) Additional follow-up doctor visits; 3) Loss of productivity/income due to ill health and extended time off work; 4) Increased risk of hospital admittance and extended hospital stays; 5) Increased risk of developing diabetes; 6) Increased susceptibility to infections due to the death of your body's good bacteria; 7) Getting an antibiotic resistant infection; and 8) Alternative and toxic treatments with serious side effects (i.e., permanent hearing loss), (see Figure 5).

Figure 5

The Mean Rankings of the False Alarm Outcomes

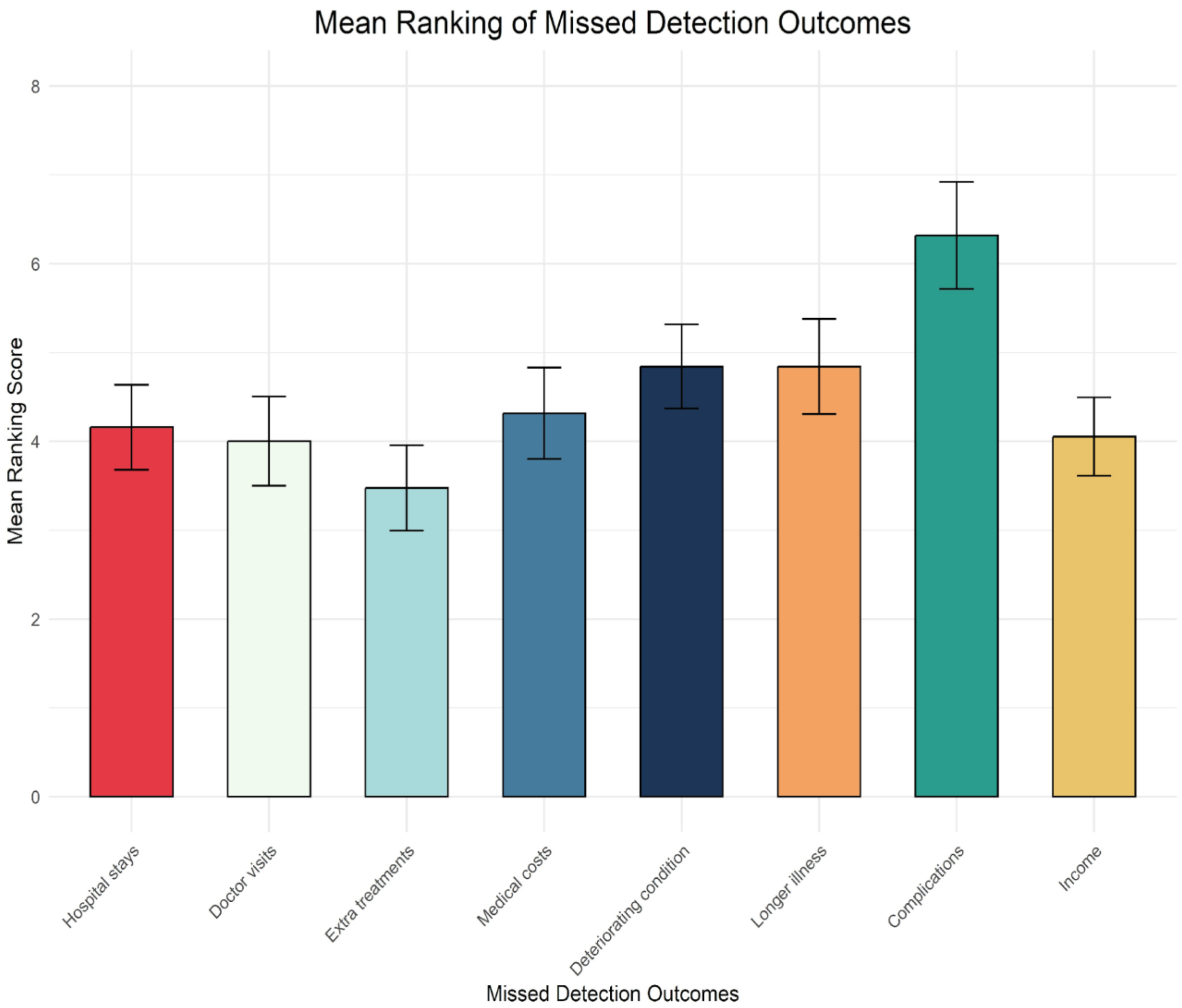


Note. The figure shows the mean rankings of the eight false alarm outcomes from left to right: hospital stays, doctor visits, income, antibiotic side effects, infection risk, toxic treatments, diabetes risk, AR infection. The error bars represent the standard error of the mean.

Finally, participants ranked the eight outcomes associated with missed detections (not taking antibiotics when they are needed) from best to worst as follows: 1) Unnecessary treatments and medical prescriptions; 2) Additional follow-up hospital and doctor visits; 3) Loss of productivity/income due to ill health and extended time off work; 4) Increased risk of hospital admittance; 5) Higher medical costs (i.e., from unnecessary prescriptions), 6) Longer illness duration; 7) Deteriorating condition and progressive feelings of unwellness; and 8) Serious complications due to illness progression (see Figure 6).

Figure 6

The Mean Rankings of the Missed Detection Outcomes



Note. The figure shows the mean rankings of the eight missed detection outcomes from left to right: hospital stays, doctor visits, extra treatments, medical costs, deteriorating condition, longer illness, complications, and income. The error bars represent the standard error of the mean.

Summary

Overall, participants were able to discriminate between the different symptom categories and they did not display any liberally biased antibiotic expectations. However, given the small sample size, more work is needed to provide more robust and conclusive evidence and further test the model and the antibiotic scenarios.

Study 1

The Present Research

The present study aimed to test the scenarios more broadly with a bigger sample size to get a more accurate understanding of people's biases regarding antibiotics. We presented participants with the hypothetical medical antibiotic scenarios used in the Pre-test of varying uncertainty (4 conditions: certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and asked them to report their antibiotic expectations. Participants were also asked to complete a set of rating questions of the four antibiotic decision outcomes to elicit their utility, as well as a task involving the ranking of antibiotic-related outcomes associated with false alarms and missed detections.

Specifically, we set up five aims. First, we aimed to test the scenarios more broadly by including a bigger sample size sensitive enough to detect a small effect. Second, we aimed to test participants' biases towards antibiotics by calculating the signal detection model parameters: bias and sensitivity. Third, we aimed to test participants' ability to discriminate between the different uncertainty conditions and symptom categories. Moreover, we were also interested in exploring how participants' antibiotic responses will vary depending on the uncertainty condition. Fourth, we aimed to test how participants' responses to the perceived base rate and payoff questions that tap into utility related to their antibiotic expectations (i.e., how liberal is their bias). Finally, we aimed to explore how participants rank the different antibiotic-related outcomes associated with false alarms and missed detections.

We derived three main hypotheses. First, we hypothesise that participants will display a liberal bias for judging whether antibiotics are needed or not (i.e., resulting in increased antibiotic expectations relative to the statistical optimum criterion location that maximises accuracy), (Hypothesis 1). Second, we expect participants to display a more liberal bias in the uncertain conditions relative to the certain conditions (Hypothesis 2). Third, we hypothesise that participants' perceived base rate and payoffs will be associated with their antibiotic expectations (Hypothesis 3).

Methods

Ethics

The research complied with all relevant ethical regulations. It received ethical approval from the Ethics Committee at the University of Essex (ref: ETH2021-0608). Informed consent was also obtained from all participants prior to starting the study online. Participants were also remunerated for their time at a standard Academic Prolific rate.

Participants

Participants were recruited online via the participant research platform Prolific. Based on a-priori power calculations for detecting a small-to-medium correlation ($\rho = .25$) assuming $\alpha = .05$ and $1 - \beta = .80$, we aimed to recruit a minimum of 123 valid responses. A total of 137 responses was recorded initially. Based on pre-registered exclusion criteria, 9 responses were excluded from the final sample size: 6 were incomplete responses, 2 failed the 2 (out of 3) attention check questions, and 1 participant completed the study in less than one-third of the median completion time.

In the final sample size of 128 participants, 45 identified as male, 80 as female and 3 as other. The sample age ranged from 18 to 73 years old *(M* = 39.1, *SD* = 13.8 years). Most participants (89.1%) were native English speakers. Participants' occupation varied as follows: management, professional, and related (32.8%), service (5.5%), sales and office (5.5%), construction, extraction, and maintenance (3.1%), production, transportation and material moving (0.8%), government (2.3%), retired (6.3%), unemployed (13.3%), student (11.7%) and other (18.8%). Their level of education varied as follows: less than high school (1.6%), high school degree (11.7%), some college (21.9%), undergraduate degree (43.8%), master's degree (14.1%), and doctoral or professional degree (7.0%).

Design

This was a within-subjects design with uncertainty condition being the independent variable and expectations for antibiotics being the dependent variable. Participants read 24 hypothetical medical scenarios in the four within-subjects uncertainty conditions and were asked to report their need for antibiotics as a treatment via a rating on a 4-point discrete scale ranging from 1 (Definitely no) to 4 (Definitely yes) with an explicit cut-off between "yes" and "no" responses (necessary for the analyses based on signal detection theory). From the responses to the antibiotic expectations variable, we calculated the bias and sensitivity with bias being the main dependent variable.

Participants also completed a set of rating questions of the four antibiotic decision outcomes to elicit their utility (see Appendix Study 1), as well as two ranking tasks of antibiotic-related outcomes associated with false alarms and missed detections, followed by some socio-demographic questions.

Materials and Procedure

After participants provided informed consent, they were able to start the study, which took around 15 minutes to complete. All participants were presented with the 24 antibiotic scenarios (presented in random order but with fixed attention check questions), then with the rating questions of the four antibiotic decision outcomes (presented in a random order), followed by the two ranking tasks of the antibiotic-related outcomes associated with false alarms and missed detections (order of the task was randomised), and finally with the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 24 hypothetical medical scenarios describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines. There were four main conditions: certain antibiotics are not needed (6 scenarios) uncertain antibiotics are needed (6 scenarios), uncertain antibiotics are not needed (6 scenarios), and certain antibiotics are needed (6 scenarios). Participants completed all four conditions and were presented with all 24 scenarios in a randomised order and three attention check questions embedded in the scenarios. In the scenarios, all participants received a description of the symptoms and illness duration and a description of the physical chest examination (see Pre-test Antibiotic scenarios for exact details). After each scenario, participants were asked to report their perceived need for antibiotics as a treatment (i.e., “I need antibiotics”) on a four-item Likert scale ranging from 1 to 4 with an explicit cut-off between “yes” and “no” responses. The scales had an acceptable to good internal consistency in the four conditions: certain antibiotics are not needed (Cronbach’s Alpha = 0.82), uncertain antibiotics are not needed (Cronbach’s Alpha = 0.80), uncertain antibiotics are needed (Cronbach’s alpha = .78) and certain antibiotics are needed (Cronbach’s alpha = .79). An average score of antibiotics expectations (0-4) was computed for each participant in the four conditions. Higher scores indicate higher antibiotic expectations. The antibiotic expectations responses were also coded in a binary "yes" or "no" response according to the explicit cut-off value between the responses on the scale (necessary for the analyses based on signal detection theory).

Antibiotic decision outcomes. Participants also completed a set of three rating questions of the four antibiotic decision outcomes (taking antibiotics when they are not needed, taking antibiotics when they are needed, not taking antibiotics when they are needed, not taking antibiotics when they are not needed) to elicit their utility (see Appendix Study 1). First, they had to rate how good or bad they perceive the potential consequences of the four decision outcomes (i.e., "How good or bad are the consequences of not taking antibiotics when they are needed?" on a Likert scale ranging from 0 (extremely bad) to 100 (extremely good). Second, they had to rate the perceived likelihood of the four decision outcomes happening to them (i.e., "How likely is the situation of taking antibiotics when they are not needed to happen to you?") on a Likert scale ranging from 0 (absolutely certain it will not happen) to 100 (absolutely certain it will happen). Third, they had to rate the likelihood of the consequences of the four decision outcomes happening (i.e., When antibiotics are not needed, how likely are the consequences of taking antibiotics to happen?") on a Likert scale ranging from 0 (absolutely certain they will not happen) to 100 (absolutely certain they will happen). Finally, participants had to answer an open-ended question asking them to report the possible consequences of the four decision outcomes (i.e., What do you think are the consequences of taking antibiotics when they are needed?").

False alarms and missed detection outcomes. Participants had to rank eight antibiotic-related outcomes associated with costly false alarms (i.e., taking antibiotics when they are not needed) and eight outcomes associated with costly missed detections (i.e., not taking antibiotics when they are needed) from 1 (best possible outcome) to 8 (worst possible outcome). The eight costly false alarm outcomes were as follows: 1) Increased risk of hospital admittance and extended hospital stays, 2) Additional follow-up doctor visits, 3) Loss of productivity/income due to ill health and extended time off work, 4) Antibiotics side effects (i.e., nausea, diarrhoea), 5) Increased susceptibility to infections, 6) Alternative and toxic treatments with serious side effects (i.e., permanent hearing loss), 7) Increased risk of developing diabetes, 8) Getting an antibiotic-resistant infection.

The eight costly missed detection outcomes were: 1) Increased risk of hospital admittance, 2) Additional follow-up hospital and doctor visits, 3) Unnecessary treatments and medical prescriptions, 4) Higher medical costs (i.e., from unnecessary prescriptions), 5) Deteriorating condition and progressive feelings of unwellness, 6) Longer illness duration, 7) Serious complications due to illness progression, 8) Loss of productivity/income due to ill health and extended time off work.

Lastly, participants were given the chance to comment on the study prior to being asked to answer some socio-demographic questions (i.e., age, gender, education, occupation and language) and were finally debriefed.

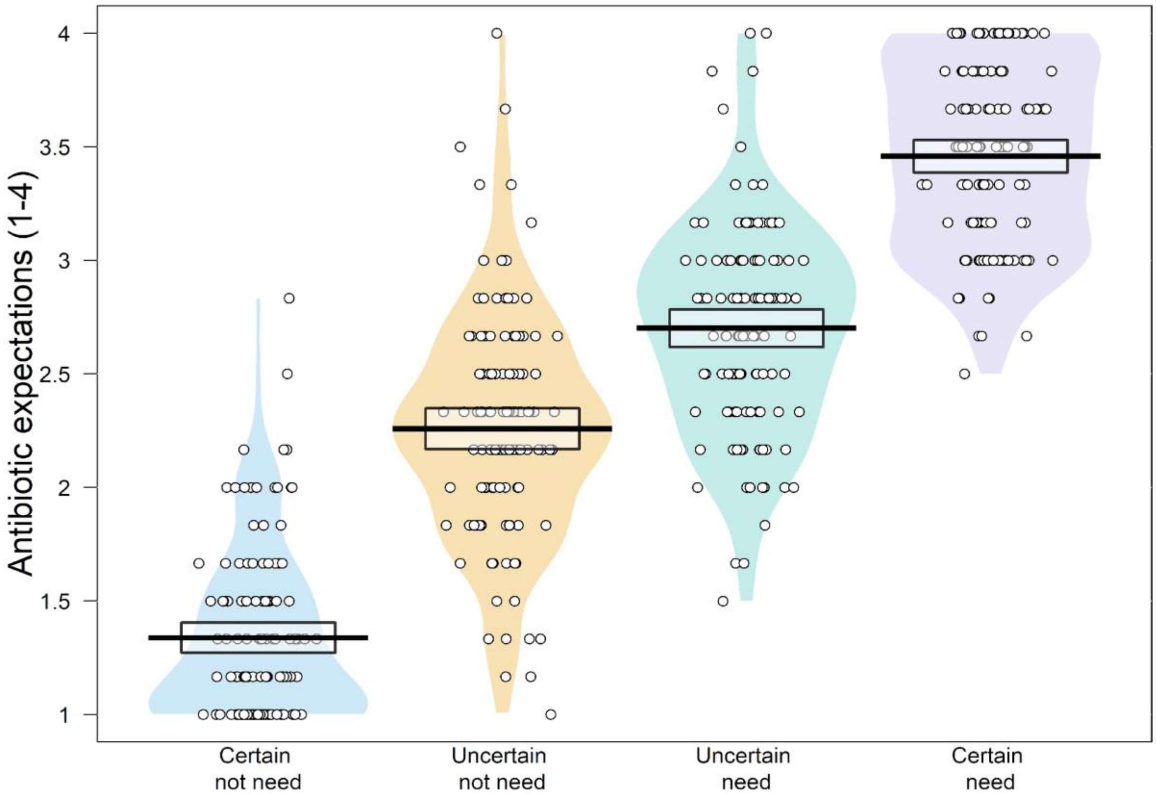
Results

The role of bias on antibiotic expectations

Participants reported the lowest antibiotic expectations in the "certain antibiotics are not needed" condition, whereas they reported the highest expectations in the "certain antibiotics are needed" condition (see Figure 7). In the two uncertain conditions, participants' antibiotic expectations fell around the middle of the scale but there was much greater response variation compared to the two certain conditions (see Figure 7). Overall, participants' antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories.

Figure 7

Effect of Uncertainty on Antibiotic Expectations

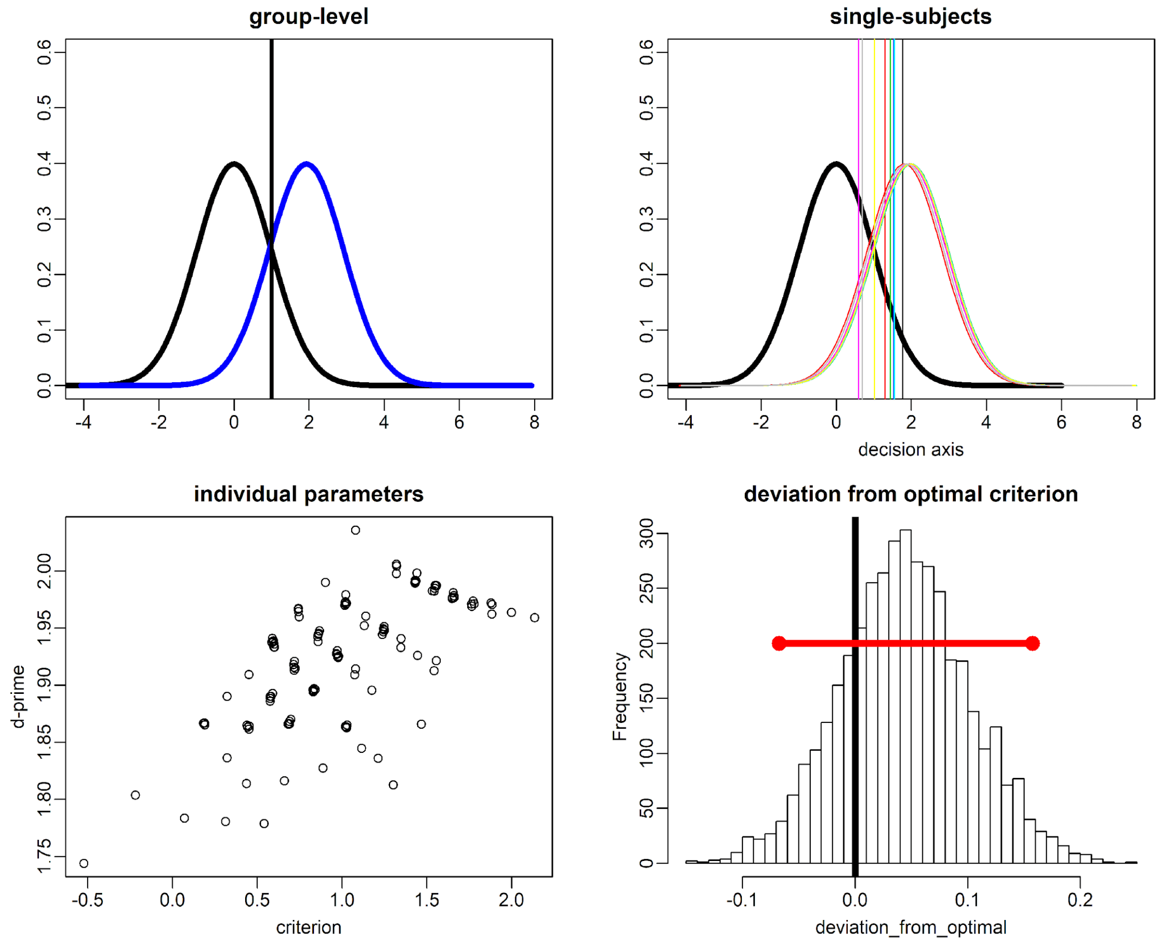


Note. The figure shows the effect of uncertainty condition (certain antibiotics are not needed vs uncertain antibiotics are not needed vs uncertain antibiotics are needed vs certain antibiotics are needed) on antibiotic expectations. The middle bold line represents the arithmetic mean and the box borders represent 95% confidence intervals.

We conducted a pre-registered multilevel Bayesian generalized linear model (with a probit link function, thus equivalent to a signal detection theory model with a Gaussian-distributed latent decision variable comprising both group-level “fixed” effects and subject-specific “random” effects) to estimate the group-level signal detection model parameters: bias (the distance of the decision criterion from the optimal criterion) and sensitivity (the distance between signal and noise distribution, expressed in standard deviations, also referred to as d'). Overall, participants’ responses did not deviate systematically from the optimal strategy (as indicated by the mean deviation from the optimal criterion and its associated 95% Bayesian credible interval) and they did not display any liberally biased antibiotic expectations, mean deviation from optimal criterion = 0.04, 95%CI [-0.07,0.17], (see Figure 8). Participants, therefore, tended to err on both sides: they expected antibiotics for uncertain conditions where antibiotics are not needed but also did not expect antibiotics for uncertain conditions where antibiotics were clinically appropriate. Thus, Hypothesis 1, which predicted that participants would display a liberal antibiotic bias, was not confirmed.

Figure 8

The Signal Detection Model Parameters



Note. The group-level plot shows the signal detection model parameters, bias (c) and sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in black), calculated by people's antibiotic expectations in the scenarios. The vertical black bold line represents the criterion location. The single-subjects plot shows participants' individual responses. The individual parameters plot shows participants' fitted responses. The deviation from the optimal criterion plot shows the mean deviation from the optimal criterion. The vertical black bold line shows the mean deviation from the optimal criterion while the horizontal red line shows its associated 95% credible interval.

The role of bias on antibiotic expectations in the certain vs uncertain conditions

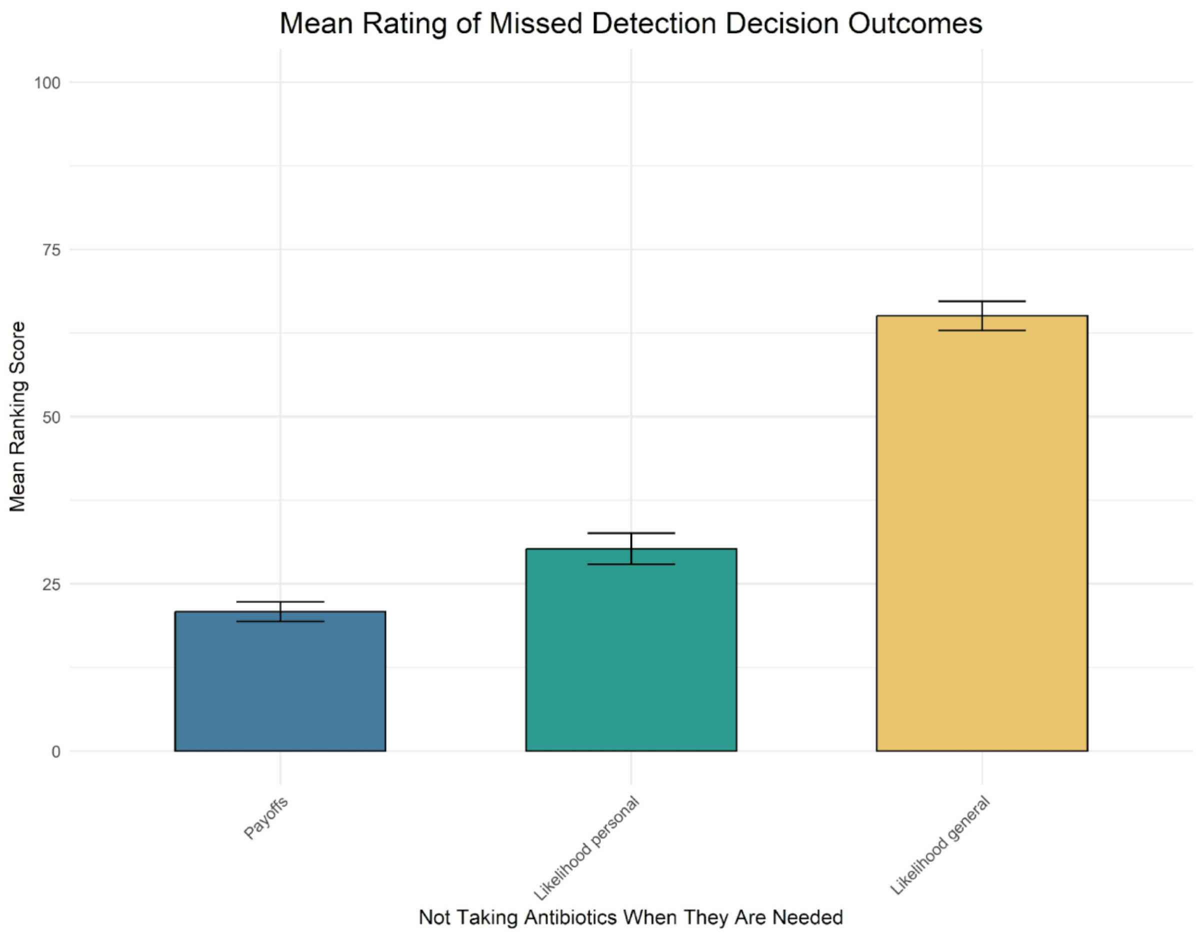
We created a new binary variable to code the uncertainty conditions. We then estimated the signal detection model parameters for certain and uncertain conditions to understand whether antibiotics expectations (i.e., the criterion location of the bias) change as a function of the uncertainty. We thus run a similar hierarchical Bayesian model as above while including the uncertainty as an interaction term to both the random and the fixed effects and estimated the 95% credible interval of the difference in the criterion between the certain and uncertain conditions. Overall, we found that there was no significant difference in the criterion location in the uncertain compared to the certain conditions as shown in the highest density interval, 95%HDI(-0.57, 0.04). Thus, Hypothesis 2, that participants would display a more liberal bias in the uncertain conditions relative to the certain conditions was not confirmed.

Antibiotic decision outcomes: perceived payoffs and base rate

Not taking antibiotics when they are needed (missed detection). In the perceived payoffs question, participants rated the consequences of not taking antibiotics when they are needed as quite bad overall (*M* = 20.8, *SD* = 16.6). In the two perceived base rate questions, participants first rated the likelihood of the situation of not taking antibiotics when they are needed happening to them (personal likelihood) as quite unlikely to happen to them (*M* = 30.3, *SD* = 26.4). Furthermore, they rated the likelihood of the consequences of not taking antibiotics when they are needed happening in general (general likelihood) as quite likely to happen overall (*M* = 65.1, *SD* = 24.4), (see Figure 9).

Figure 9

The Mean Ratings of the Missed Detection Decision Outcomes

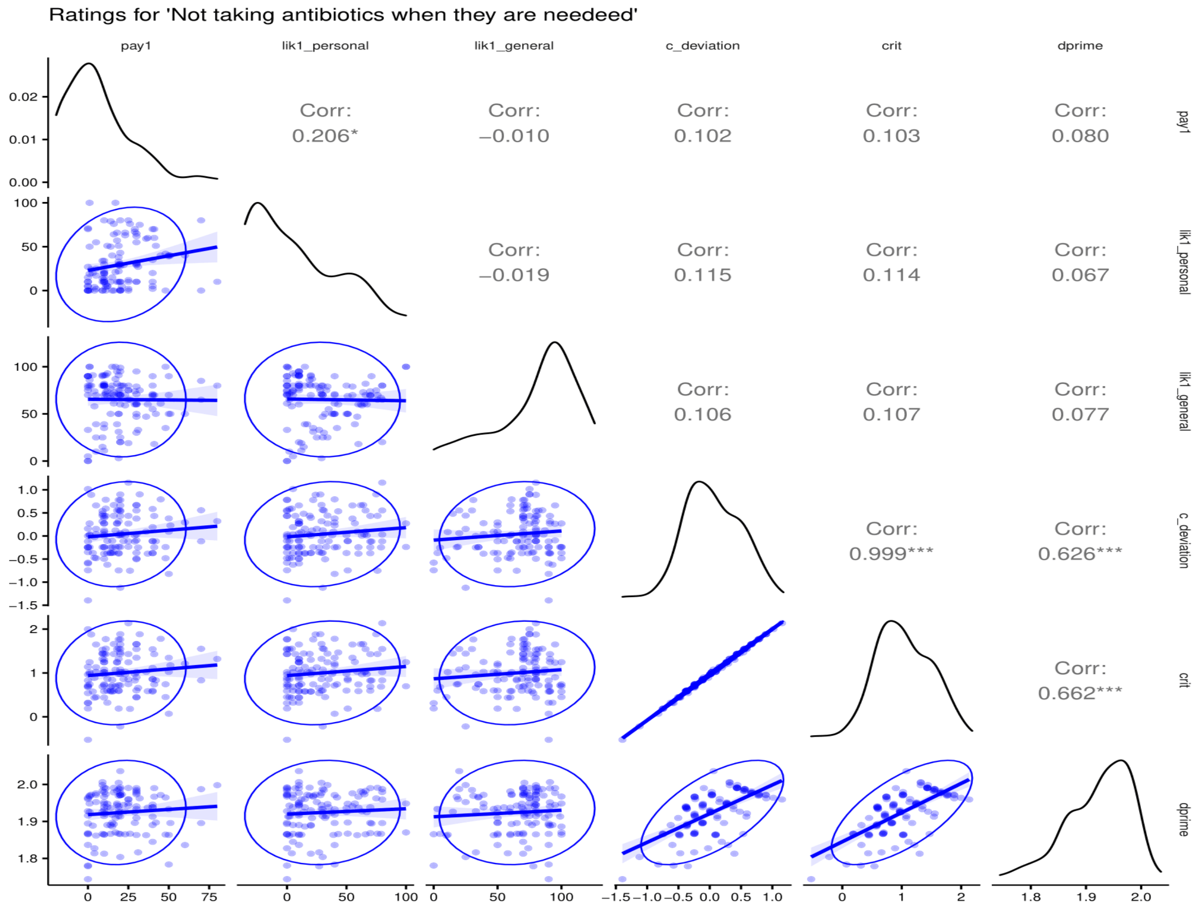


Note. The figure shows the mean ratings of the three missed detection decision outcomes (payoffs, personal likelihood, general likelihood). The error bars represent the standard error of the mean.

We then run three zero-order correlations between the three questions that tap into the utility (perceived payoffs and base rate) of the "not taking antibiotics when they are needed" decision outcome and participants' bias and sensitivity (see Figure 10). We found no significant correlations between participants' bias and sensitivity and the three utility rating questions.

Figure 10

Correlations between Participants' Utility and the Signal Detection Model Parameters.



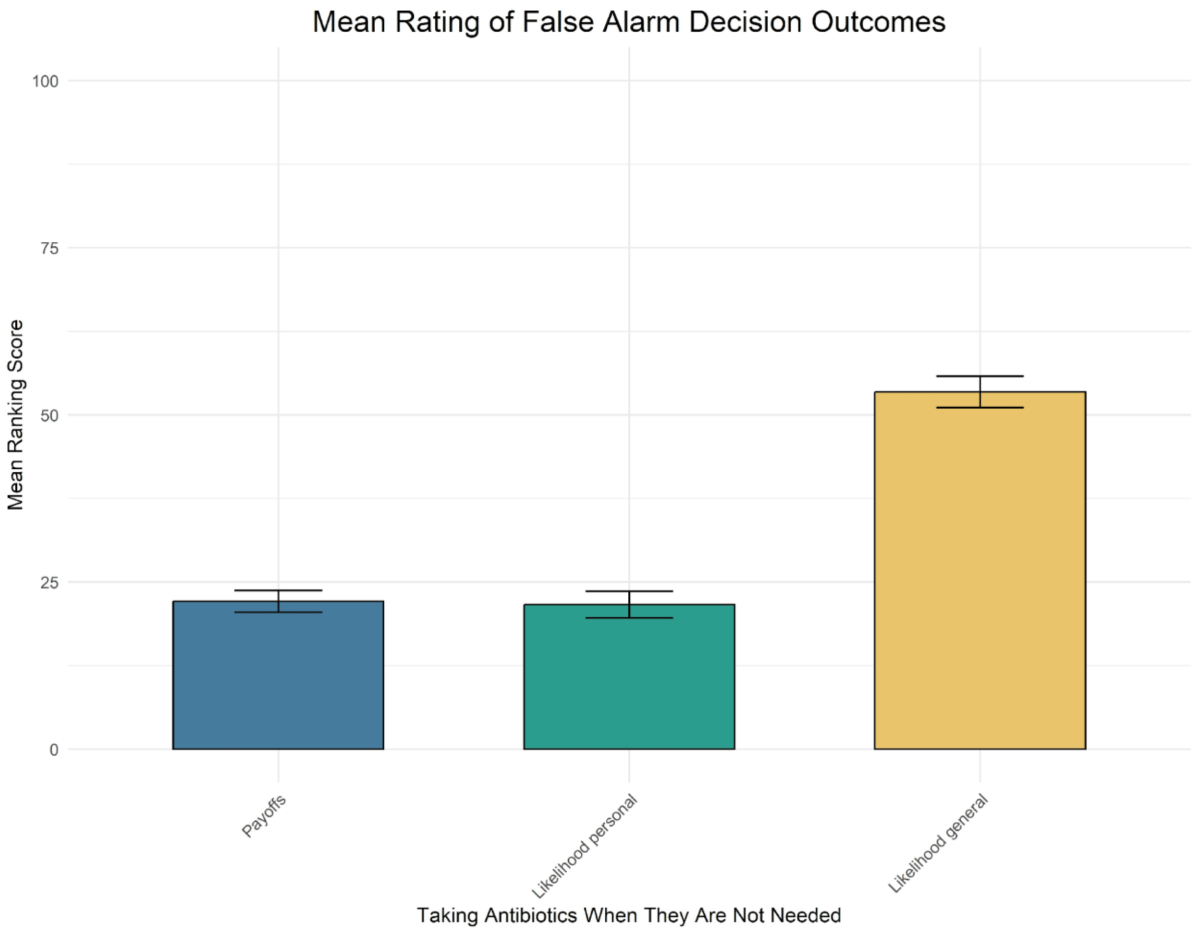
Note. The figure shows zero-order correlations between participants' perceived payoffs (pay1), perceived base rates (lik1_personal and lik1_general), participants' bias (crit), sensitivity (dprime) and deviation from the optimal criterion (c_deviation) in the missed detection (not taking antibiotics when they are needed) decision outcome.

Taking antibiotics when they are not needed (false alarm). In the perceived payoffs question, participants rated the consequences of taking antibiotics when they are not needed as quite bad overall (*M* = 22.1, *SD* = 18.5). In the two perceived base rates questions, participants first rated the likelihood of the situation of taking antibiotics when they are not needed happening to them (personal likelihood) as quite unlikely to happen to them (*M* =

21.6, *SD* = 22.4). Furthermore, they rated the likelihood of the consequences of taking antibiotics when they are not needed happening in general (general likelihood) as neither likely nor unlikely to happen overall (*M* = 53.4, *SD* = 26.6), (see Figure 11).

Figure 11

The Mean Ratings of the False Alarm Decision Outcomes

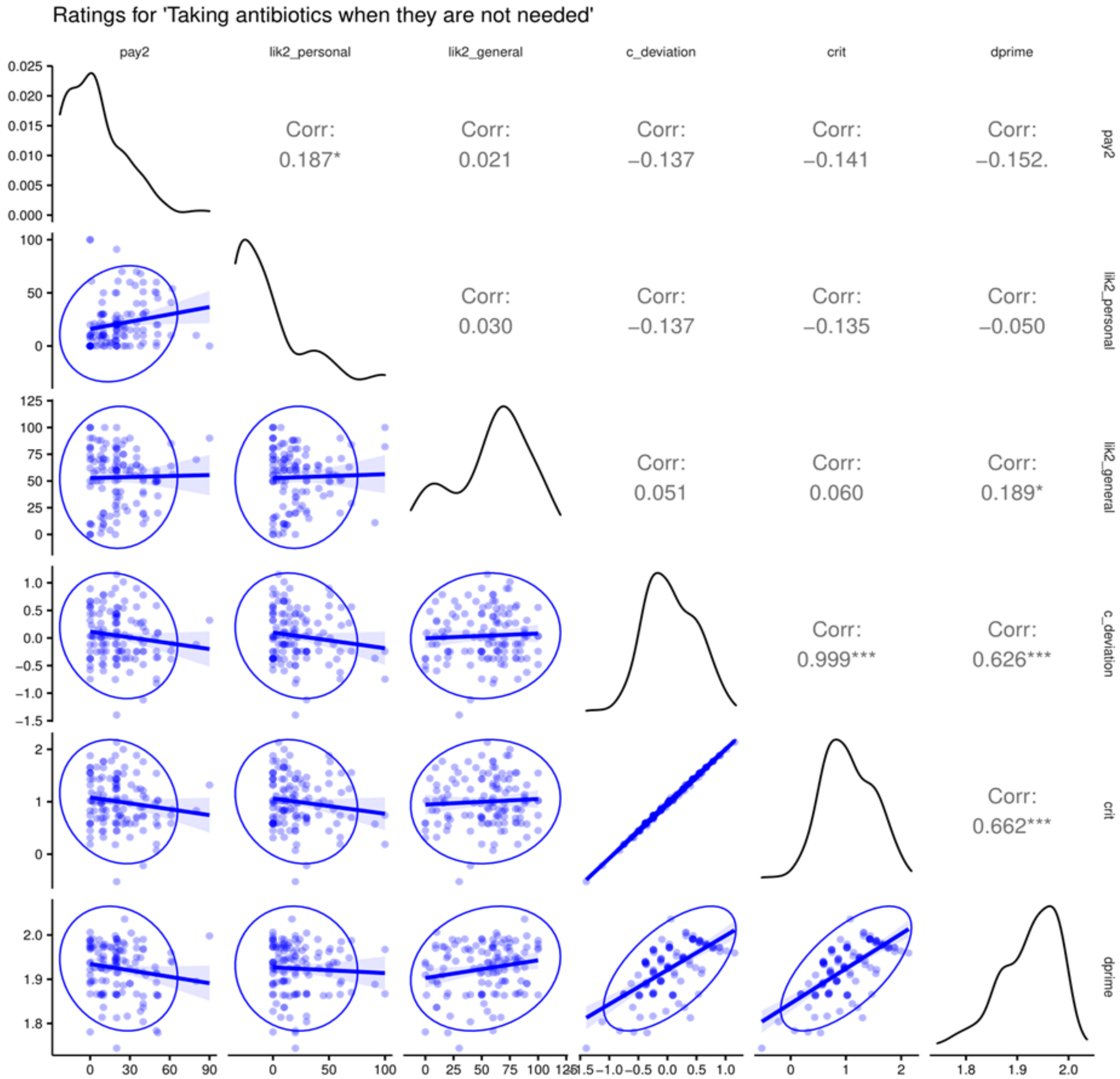


Note. The figure shoes the mean ratings of the three false alarm decision outcomes (payoffs, personal likelihood, general likelihood). The error bars represent the standard error of the mean.

We then run three zero-order correlations between the three questions that tap into the utility (perceived payoffs and base rate) of the "taking antibiotics when they are not needed" decision outcome and participants' bias and sensitivity (see Figure 12). A weak but statistically significant correlation was observed between the sensitivity and the perceived general likelihood ($r = .19$), indicating that participants with higher sensitivity tended to rate the consequences of taking antibiotics when they are not needed happening in general as higher. No other statistically significant correlations were observed between the bias, sensitivity and the utility questions.

Figure 12

Correlations between Participants' Utility and the Signal Detection Model Parameters

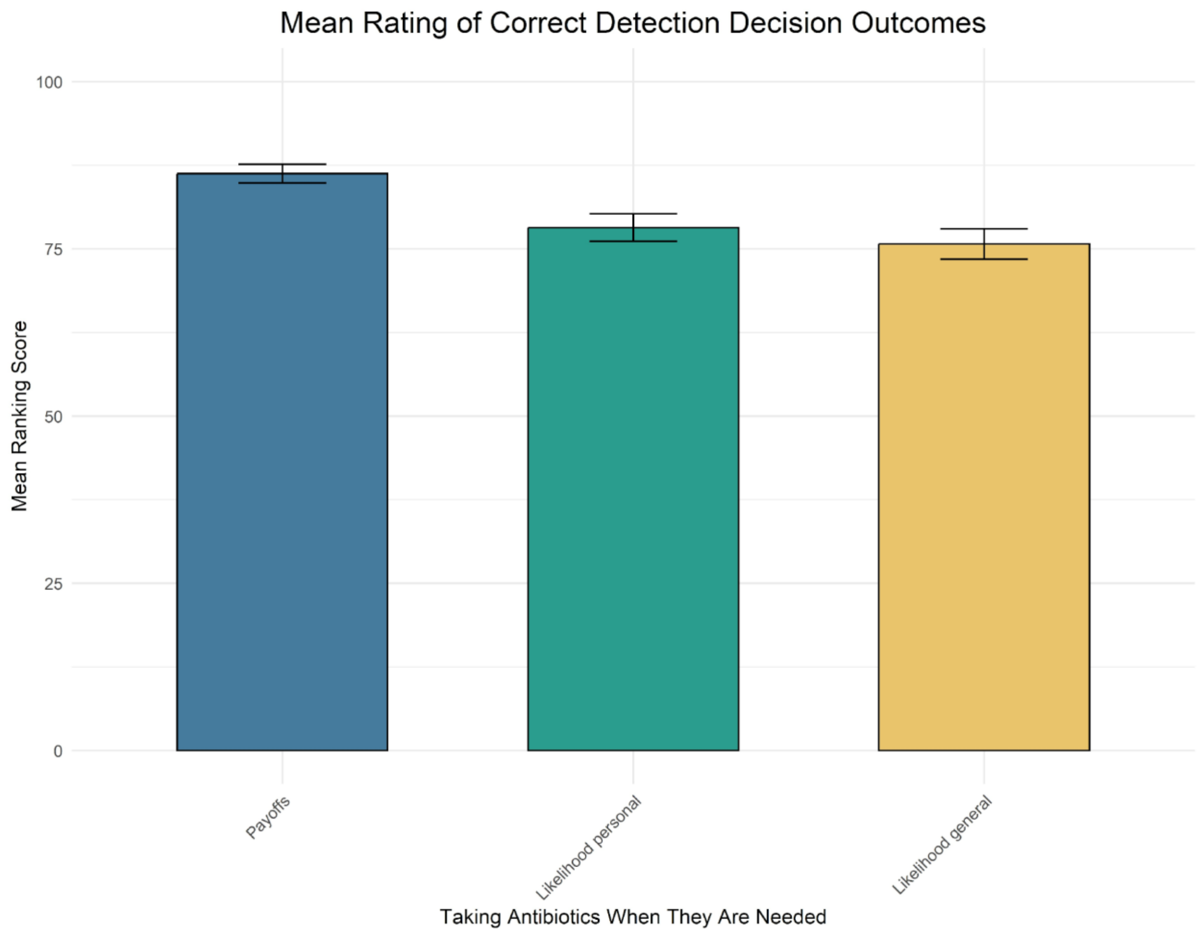


Note. The figure shows zero-order correlations between participants' perceived payoffs (pay1), perceived base rates (lik1_personal and lik1_general), participants' bias (crit), sensitivity (dprime) and deviation from the optimal criterion (c_deviation) in the false alarm (taking antibiotics when they are not needed) decision outcome.

Taking antibiotics when they are needed (correct detection). In the perceived payoffs question, participants rated the consequences of taking antibiotics when they are needed as very good overall (*M* = 86.2, *SD* = 15.9). In the two perceived base rates questions, participants first rated the likelihood of the situation of taking antibiotics when they are needed happening to them (personal likelihood) as very likely to happen to them (*M* = 78.2, *SD* = 23.2). Furthermore, they rated the likelihood of the consequences of taking antibiotics when they are needed happening in general (general likelihood) as quite likely to happen overall (*M* = 75.7, *SD* = 25.5), (see Figure 13).

Figure 13

The Mean Ratings of the Correct Detection Decision Outcomes

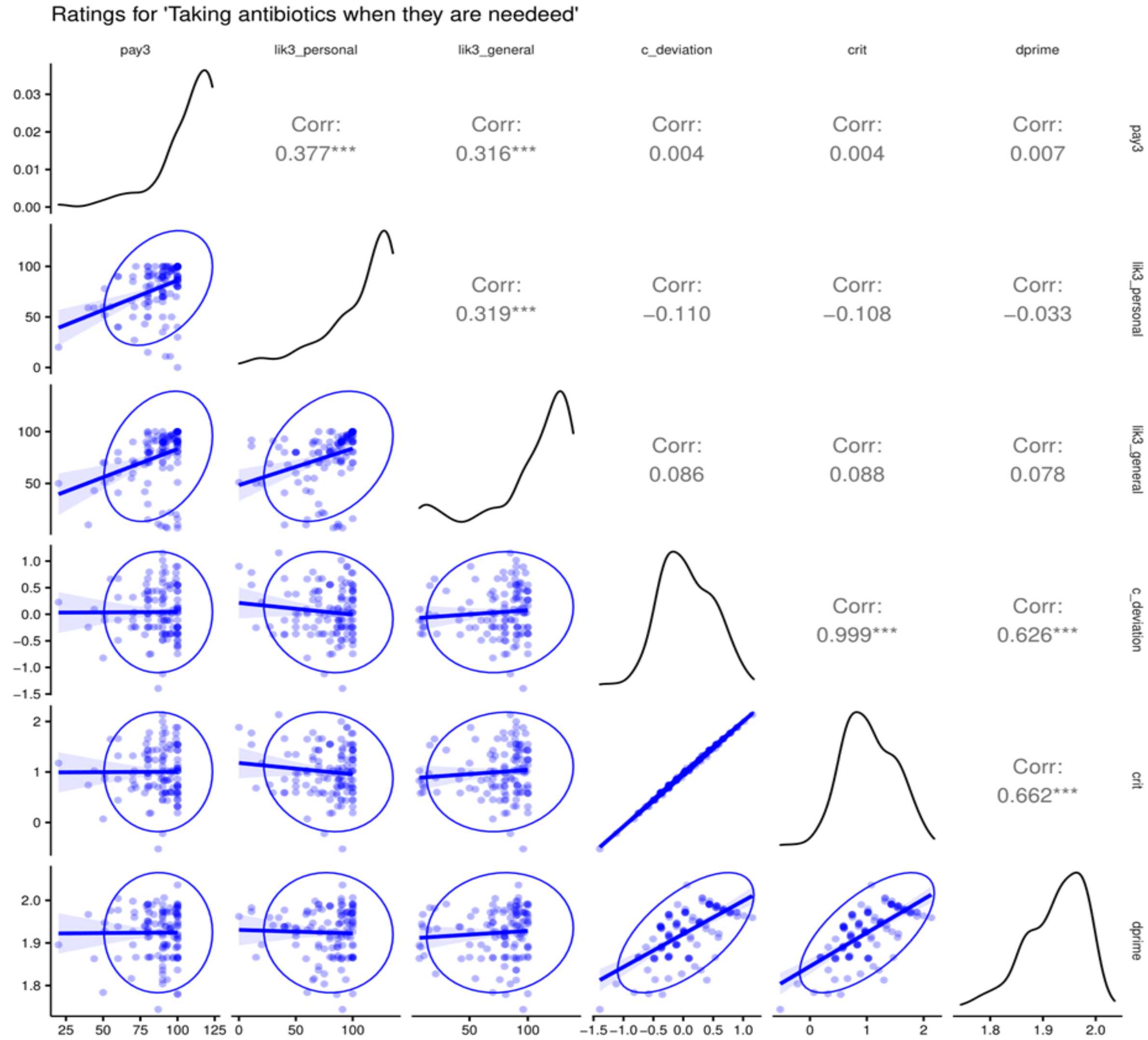


Note. The figure shows the mean ratings of the three correct detection decision outcomes (payoffs, personal likelihood, general likelihood). The error bars represent the standard error of the mean.

We then run three zero-order correlations between the three questions that tap into the utility (perceived payoffs and base rate) of the “taking antibiotics when they are needed” decision outcome and participants’ bias and sensitivity (see Figure 14). No significant correlations were observed between the three utility questions and participants’ bias and sensitivity.

Figure 14

Correlations between Participants' Utility and the Signal Detection Model Parameters

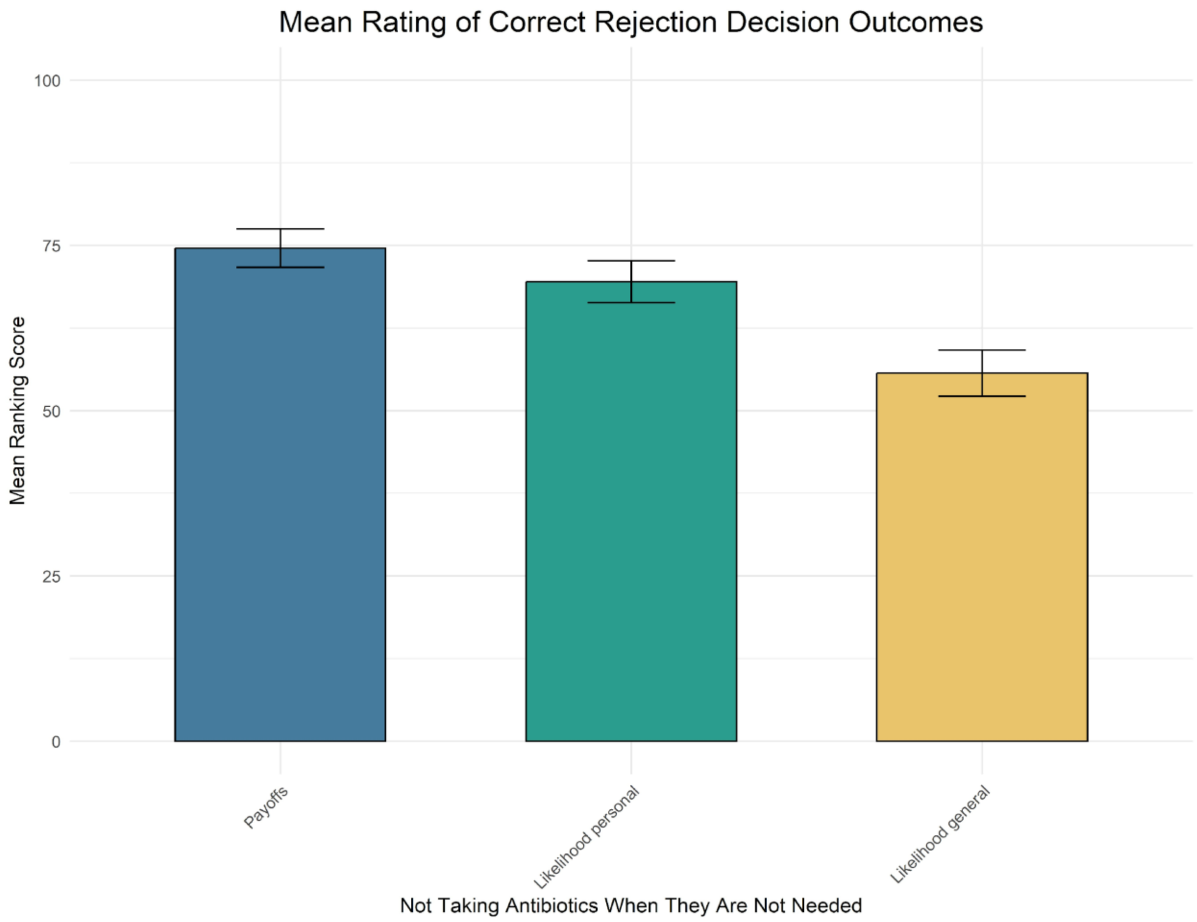


Note. The figure shows zero-order correlations between participants' perceived payoffs (pay1), perceived base rates (lik1_personal and lik1_general), participants' bias (crit), sensitivity (dprime) and deviation from the optimal criterion (c_deviation) in the correct detection (taking antibiotics when they are needed) decision outcome.

Not taking antibiotics when they are not needed (correct rejection). In the perceived payoffs question, participants rated the consequences of not taking antibiotics when they are not needed as very good overall (*M* = 74.6, *SD* = 32.8). In the two perceived base rates questions, participants first rated the likelihood of the situation of not taking antibiotics when they are not needed happening to them (personal likelihood) as quite likely to happen to them (*M* = 69.5, *SD* = 36.0). Furthermore, they rated the likelihood of the consequences of not taking antibiotics when they are not needed happening in general (general likelihood) as neither too likely nor unlikely to happen overall (*M* = 55.7, *SD* = 39.4), (see Figure 15).

Figure 15

The Mean Ratings of the Correct Detection Decision Outcomes

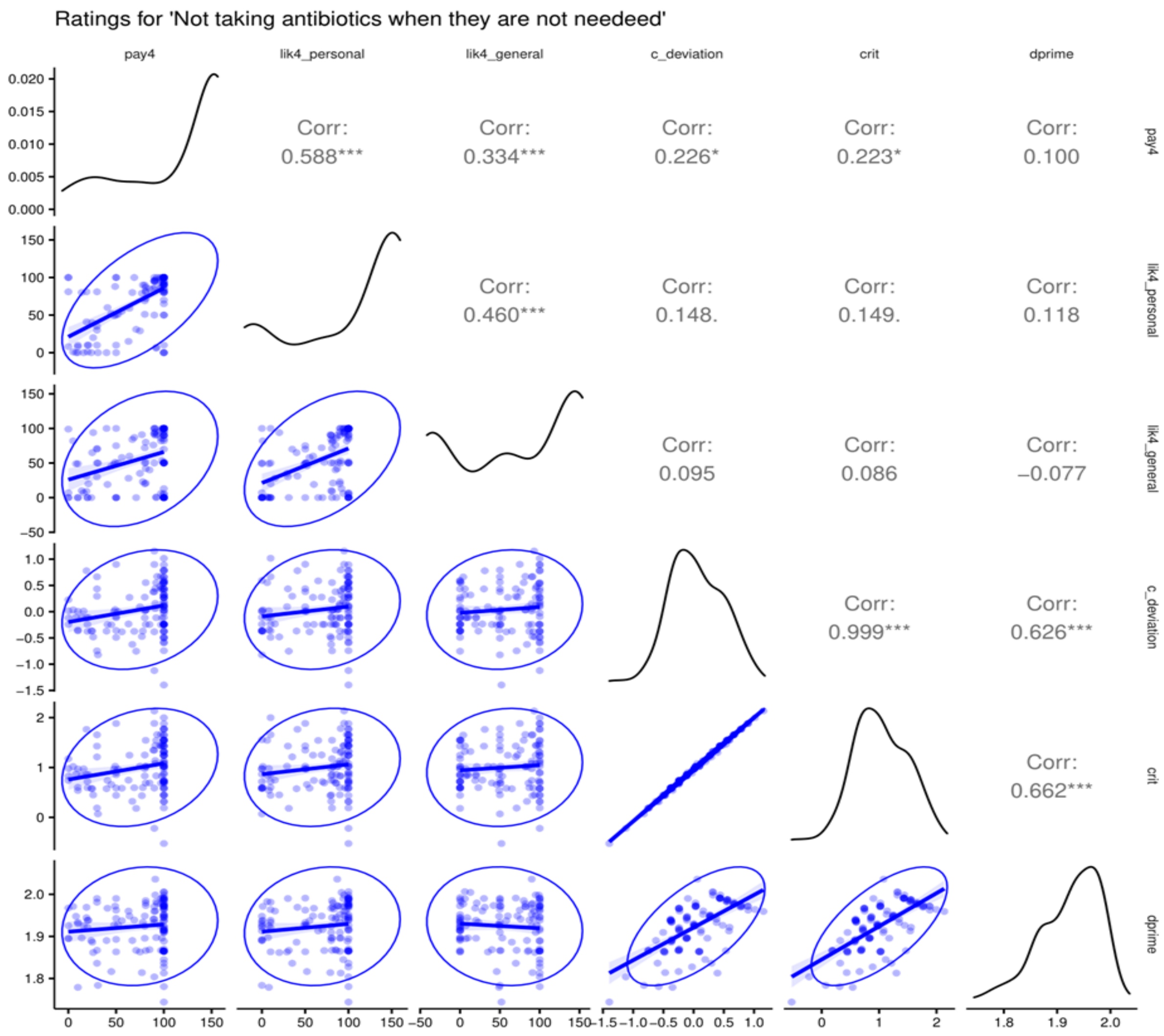


Note. The figure shows the mean ratings of the three correct detection decision outcomes (payoffs, personal likelihood, general likelihood). The error bars represent the standard error of the mean.

We then run three zero-order correlations between the three questions that tap into the utility (perceived payoffs and base rate) of the “not taking antibiotics when they are not needed” decision outcome and participants’ bias and sensitivity (see Figure 16). A weak but statistically significant correlation was observed between participants’ perceived payoffs and bias (r = .22), indicating that partitions with a more liberal bias tended to rate the consequences of taking antibiotics when they are needed as better overall. No other significant correlations were observed.

Figure 16

Correlations between Participants' Utility and the Signal Detection Model Parameters



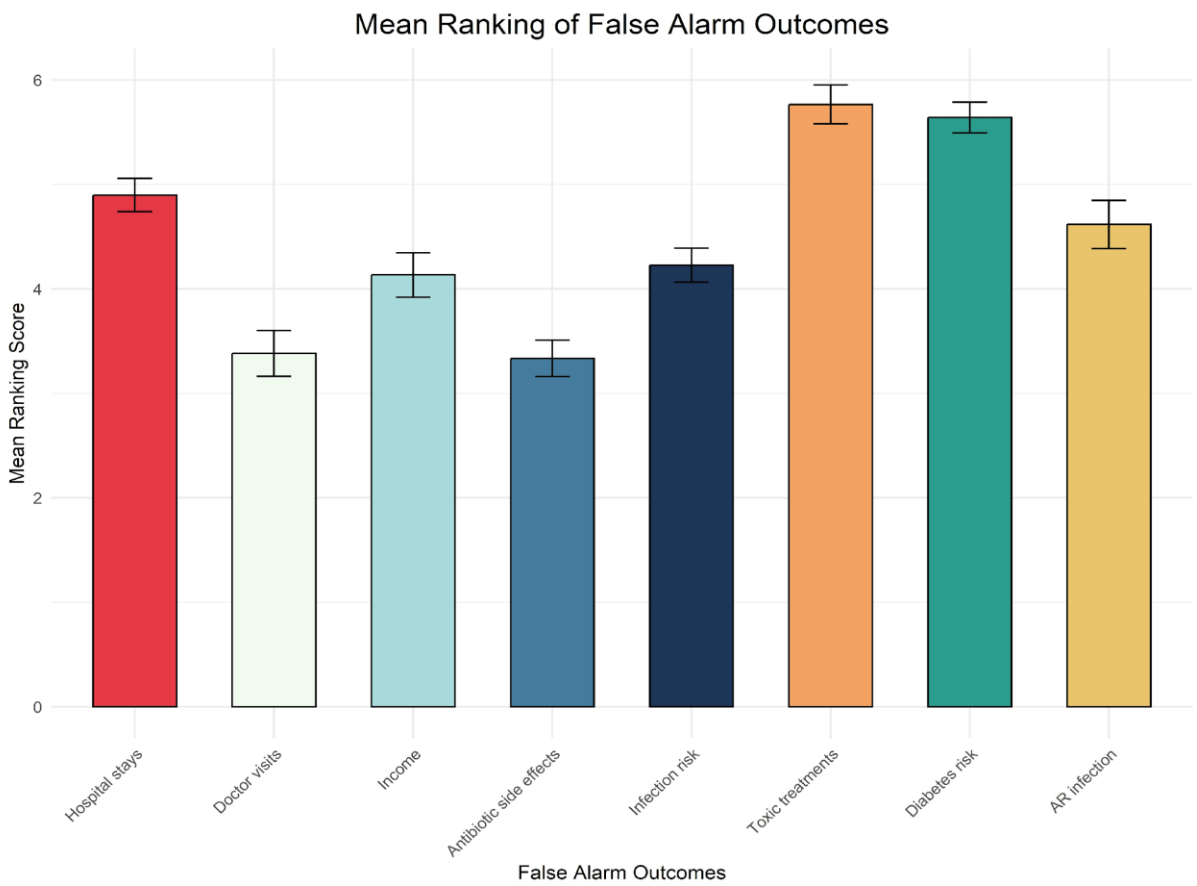
Note. The figure shows zero-order correlations between participants' perceived payoffs (pay1), perceived base rates (lik1_personal and lik1_general), participants' bias (crit), sensitivity (dprime) and deviation from the optimal criterion (c_deviation) in the correct rejection (not taking antibiotics when they are not needed) decision outcome.

Antibiotic-related outcomes associated with false alarms and missed detections

Regarding the antibiotic-related outcomes associated with costly false alarms (taking antibiotics when they are not needed), participants ranked the outcomes overall from best to worst as follows: 1) Antibiotics side effects (i.e., nausea, diarrhoea); 2) Additional follow-up doctor visits; 3) Loss of productivity/income due to ill health and extended time off work; 4) Increased susceptibility to infections; 5) Getting an antibiotic-resistant infection; 6) Increased risk of hospital admittance and extended hospital stays and, 7) Increased risk of developing diabetes; and 8) Alternative and toxic treatments with serious side effects (i.e., permanent hearing loss), (see Figure 17).

Figure 17

The Mean Rankings of the False Alarm Outcomes

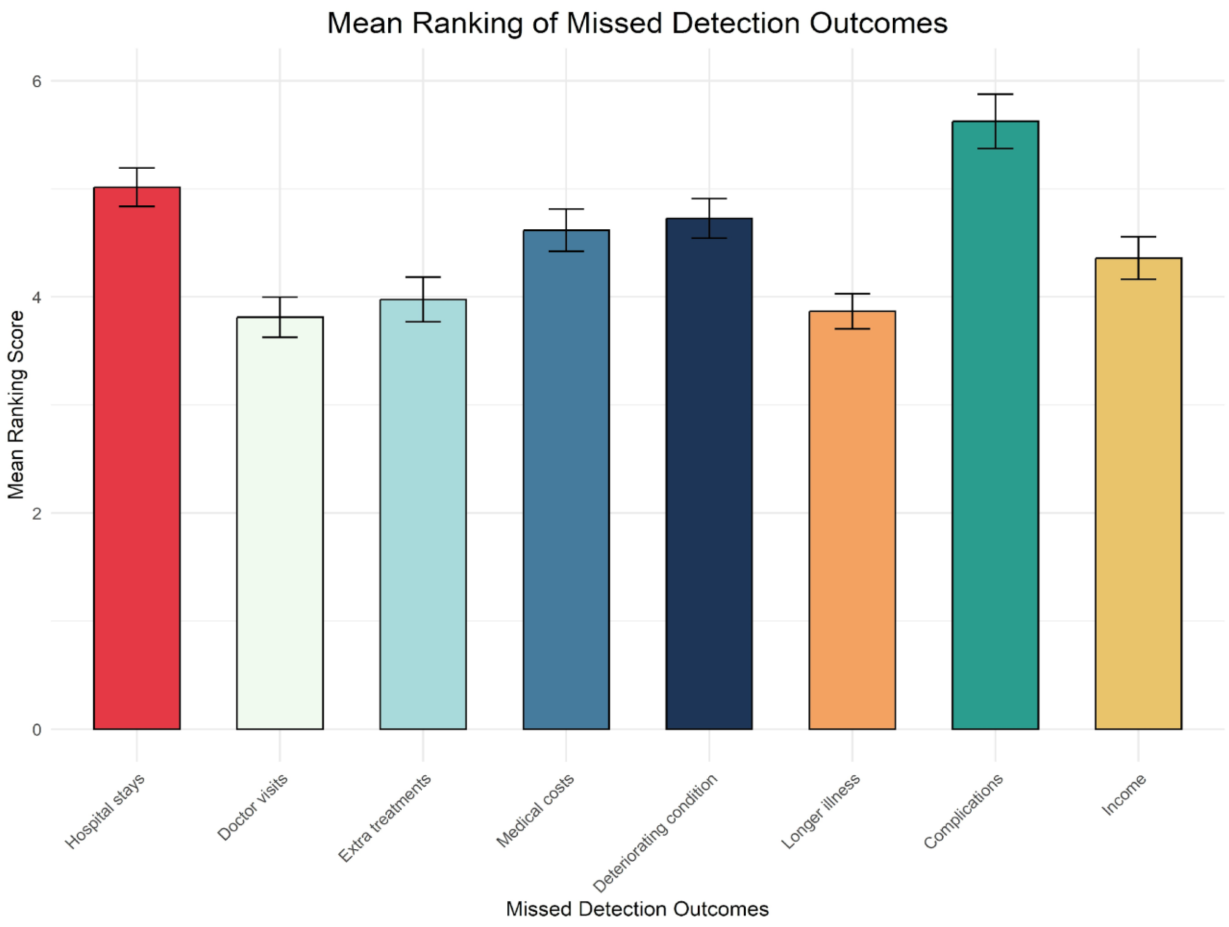


Note. The figure shows the mean rankings of the eight false alarm outcomes from left to right: hospital stays, doctor visits, income, antibiotic side effects, infection risk, toxic treatments, diabetes risk, and AR infection. The error bars represent the standard error of the mean.

Regarding the antibiotic-related outcomes associated with costly missed detections (not taking antibiotics when they are needed), participants ranked the outcomes overall from best to worst as follows: 1) Additional follow-up hospital and doctor visits; 2) Longer illness duration; 3) Unnecessary treatments and medical prescriptions, 4) Loss of productivity/income due to ill health and extended time off work; 5) Higher medical costs (i.e., from unnecessary prescriptions), 6) Deteriorating condition and progressive feelings of unwellness; 7) Increased risk of hospital admittance; and 8) Serious complications due to illness progression, (see Figure 18).

Figure 18

The Mean Rankings of the Missed Detection Outcomes



Note. The figure shows the mean rankings of the eight missed detection outcomes from left to right: hospital stays, doctor visits, extra treatments, medical costs, deteriorating condition, longer illness, complications, and income. The error bars represent the standard error of the mean.

The effect of symptoms (additional exploratory analysis)

We wanted to look at the different symptom categories to see how participants made their decisions and if certain symptoms influenced their decisions more. First, we created different levels for the symptoms: cough (normal, severe), illness duration (<7 days, >14 days), phlegm (no, clear, yellow, green, blood-stained), temperature (low, high), breathlessness (low, high), chest examination (normal, abnormal). We then run a multilevel logistic regression with the antibiotics needed responses as the predicted variable and the different symptom categories as predictors.

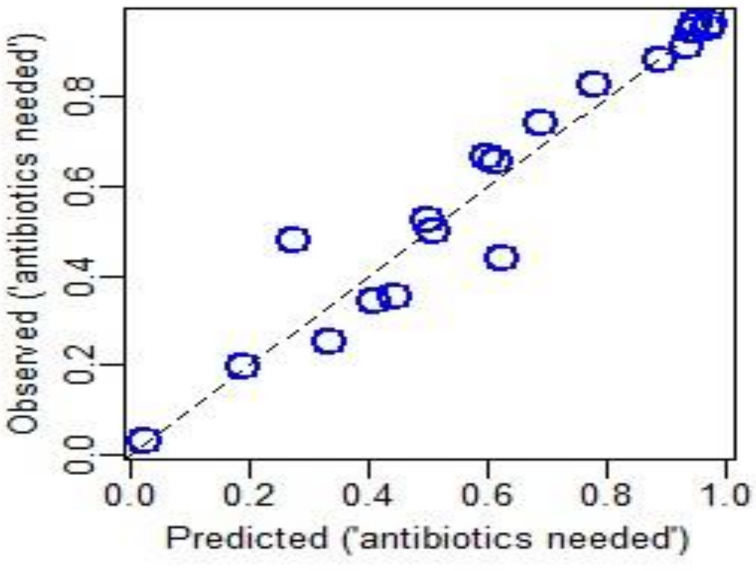
Overall, participants considered all aspects of the scenarios when making their decisions, rather than focusing on just a few symptoms. Severe cough was positively associated with participants' antibiotics-needed responses (b = 1.57, p <.001) compared to the baseline cough normal, meaning that participants' antibiotics-needed responses were higher in the scenarios where the cough was stated as severe rather than normal. Duration of illness longer than 14 days was similarly positively associated with antibiotics-needed responses (b = 2.09, p <.001) compared to the baseline duration of illness lasting fewer than seven days, meaning that participants displayed higher antibiotics-needed responses when the illness duration was stated as more than fourteen days as opposed to lower than seven days in the scenarios. Low breathlessness was negatively associated with antibiotics-needed responses (b = -0.88, p <.001) compared to the baseline high breathlessness, meaning that participants' antibiotics-needed responses were higher when breathlessness was stated as high in the scenarios rather than low. A normal physical chest examination was similarly negatively associated with participants' antibiotics-needed responses (b = -0.95, p <.001) compared to the baseline abnormal physical examination, meaning that participants displayed higher antibiotics-needed responses when the physical examination was stated as abnormal rather than normal. Finally, regarding the phlegm categories, no phlegm (b = 1.27, p = .002), clear phlegm (b = -1.27, p = .040), and yellow phlegm (b = -0.78, p = .032) were all negatively associated with antibiotics needed responses compared to the baseline blood-stained phlegm, while green phlegm, in contrast, was not associated (b = -0.20, p = .598), meaning that participants displayed higher antibiotics needed responses when the phlegm was stated as blood-stained and green in the scenarios compared to when it was stated as yellow, clear, or as no phlegm.

Moreover, to estimate the overall fit of the model, we performed a likelihood ratio test and compared the model to a null model that contains only the intercept. Overall, we found that the model predicts the data better than chance, X^2 (7, N = 128) = 1963.4, p <.001.

Finally, we also looked at how well the different symptoms can predict the antibiotics needed responses for each scenario. Overall, the different symptom categories enabled us to predict quite well the frequency of "antibiotics needed" responses for each scenario (see Figure 19).

Figure 19

The Observed to Predicted Antibiotic Responses



Note. The figure shows the fitted observed to predicted participants' antibiotics needed responses.

General Discussion

Gaining a better understanding of the factors that drive people to expect antibiotics will enable us to reduce the spread of antibiotic resistance. The present chapter aimed to test the utility-based signal detection theory approach and extend our understanding of the factors that drive people to expect antibiotics. In the Pre-test, the main aim was to test the antibiotic scenarios that we created. In Study 1, we wanted to test the scenarios more broadly, as well as test the utility-based signal detection theory approach to provide exact cognitive and computationally testable mechanisms behind people's antibiotic expectations. Participants were presented with 24 hypothetical medical scenarios modelled after the NICE clinical guidelines with varying symptoms and illness duration in four within-subjects uncertainty conditions (certain antibiotics are not needed, uncertain antibiotics are not needed, uncertain antibiotics are needed, certain antibiotics are needed) and were asked to report their need for antibiotics as a treatment. Based on participants' responses, we then calculated the signal detection model parameters underlying behaviour: bias and sensitivity. Participants also completed a set of ranking and rating tasks of the four antibiotic decision outcomes to elicit their utility, as well as two ranking tasks of antibiotics-related outcomes associated with false alarms and missed detections.

Overall, the antibiotic scenarios worked as intended. In both the Pre-test and Study 1, participants' responses in the four uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories. In Study 1, we found no evidence for a liberal bias in people's antibiotic expectations; participants' responses did not deviate systematically from the optimal strategy (Hypothesis 1). We also found no evidence for a more liberal bias in the uncertain versus certain conditions; participants' bias did not increase in the uncertain conditions (Hypothesis 2). Finally, the results provide no evidence for an association between participants' antibiotic expectations and perceived payoffs and base rate (Hypothesis 3). Overall, the findings do not indicate that people are liberally biased towards antibiotics but suggest that expectations for antibiotics can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics.

The role of bias on antibiotic expectations

Participants did not display a liberal bias towards antibiotics; participants' antibiotic expectations were not increased relative to the optimal strategy. Thus, hypothesis 1, that participants would display liberally biased antibiotic expectations, was not confirmed. Moreover, we found no difference in participants' bias in the uncertain compared to the certain condition. Thus, Hypothesis 2, that participants would display a more liberal bias in the uncertain conditions relative to the certain conditions was also not confirmed. There are two main explanations for why this might be the case.

First, the results seem to indicate that expectations for antibiotics can be explained by diagnostic uncertainty rather than a genuine bias towards antibiotics (*uncertainty assumption*). Participants expected antibiotics for uncertain conditions where antibiotics were not needed but also did not expect antibiotics for uncertain conditions where antibiotics *were* clinically appropriate. Past research looking at people's antibiotic expectations and finding evidence for inappropriate expectations has typically only focused on uncertain cases where antibiotics should not be prescribed (i.e., for cold-like symptoms and acute ear infections; Thorpe et al., 2020a, 2020b; Sirota et al., 2022) or on certain cases where antibiotics should be prescribed (i.e., for kidney infection with bacterial aetiology; Sirota et al., 2022) and usually presenting participants with only one antibiotic sicario (i.e., Thorpe et al., 2020a, 2020b) without controlling for or taking into account all the possible uncertainty levels.

For example, Thorpe et al. (2020) presented participants with only one antibiotic scenario of cold-like symptoms and viral aetiology corresponding to the “uncertain antibiotics are not needed” condition where antibiotics should not be prescribed. Similarly, Sirota et al. (2022) only presented participants with two hypothetical medical scenarios: one was modelled after an acute ear infection with viral aetiology corresponding to the “uncertain antibiotics are not needed” condition where antibiotics should not be prescribed, while the other was modelled after a kidney infection with bacterial aetiology corresponding to the “certain antibiotics are needed” condition where antibiotics should be prescribed.

Looking in isolation at the “uncertain antibiotics are not needed” condition in Study 1, we also find evidence for inappropriate antibiotic expectations. Specifically, the false alarm rate is around 36%, meaning that around 36% of people inappropriately expect antibiotics for conditions where antibiotics should not be prescribed, which is aligned with the findings of prior research. However, when taking into context the different uncertainty levels, we no longer observe inappropriate antibiotic expectations as people also seem to not expect antibiotics in the “uncertain antibiotics are needed” condition for cases where antibiotics should be prescribed. In fact, they seem to be displaying an almost equal number of missed detections to false alarms, meaning that around 36% of participants also do not expect antibiotics for cases where antibiotics *should* be prescribed. Specifically, their false alarm rate is counteracted by their almost equal missed detection rate, resulting overall in optimal antibiotic expectations. The findings, therefore, seem to indicate that in cases of diagnostic uncertainty people seem to err on both sides, indicating that they are not actually biased but rather well-calibrated. Participant’s antibiotic expectations then seem to be better explained by uncertainty rather than a genuine bias towards antibiotics. This is also in line with our utility-based signal detection model prediction, positing that people’s antibiotic expectations can be explained by diagnostic uncertainty. Future research should further test the uncertainty account to provide more conclusive and robust evidence behind people's antibiotic expectations.

Second, it is possible that the results observed in our study might be due to methodological limitations (*methodological artefacts assumption*). One of those potential methodological limitations might be the number of scenarios presented and the length of the experiment. Due to the high number of scenarios presented (24 in total), it is possible that people viewed the task as more of a cognitive game and therefore tried to give equal responses in the 4-point discrete response scale. The high number of scenarios might also have contributed to cognitive load which might have similarly affected participants' performance. Future research should further test the methodological artefacts assumption by reducing the number of scenarios and the length of the survey to test whether similar findings will be observed by removing these possible methodological limitations.

Another methodological limitation potentially accounting for the observed findings has to do with the antibiotic scenarios themselves. The results showed that participants were able to discriminate between the different symptom categories and that their antibiotic expectations were in the expected direction in all conditions, indicating that the antibiotic scenarios worked as expected. However, it is possible that some of the wording in the scenarios might have influenced participants' responses. Specifically, looking back at the scenarios, there seem to be some cases of ambiguously worded information (i.e., "You do not have a high temperature") that some people might have interpreted as meaning "You have a raised temperature" while some others might have instead interpreted as meaning "You have a normal temperature." Future research should further test the account by rewording the scenarios to remove any potentially ambiguous information and avoid any negations.

Finally, another possible methodological limitation that could account for the findings is the response scale used. In our study, we used a 4-point discrete scale ranging from 1 to 4 (1 = *Definitely no*, 2 = *Probably no*, 3 = *Probably yes*, 4 = *Definitely yes*) with an explicit cut-off between “yes” and “no” responses necessary for the signal detection analysis. It could be argued that the scale itself has inherent uncertainty as it contains options in probability terms which might influence participants’ responses. For example, a participant might be unsure about whether antibiotics are needed and choose the “probably no” option from the scale which will be treated as a “no” response. However, if the participant only had two response options to choose from (yes or no) it is possible that this “probably no” response could have shifted to “yes”. Future research should further test the account by including a binary response scale instead with a (yes or no) explicit response.

Antibiotic decision outcomes: perceived payoffs and base rate

Participants ranked the false alarm (taking antibiotics when they are not needed) and the missed detection (not taking antibiotics when they are needed) as the worst decision outcomes in the Pre-test, while in Study 1 they rated the consequences of these two outcomes (perceived payoffs) as the worst overall. Moreover, it is worth noting that in the perceived base rate questions of the two negative decision outcomes (false alarm and missed detection), participants rated the likelihood of the two outcomes happening to them (personal likelihood) much lower in both cases compared to the likelihood of the two decision outcomes happening in general (general likelihood). However, the findings provide no evidence for an association between participants’ antibiotic expectations and perceived payoffs and base rate (personal and general likelihood). Only two weak associations were observed in the findings. First, we found that in the case of the false alarm decision outcome, participants’ sensitivity was associated with the perceived general likelihood, indicating that participants with higher sensitivity tended to rate the consequences of taking antibiotics when they are not needed happening in general as higher. Second, we found that in the case of the correct rejection decision outcome, participants' bias was associated with the perceived payoffs, indicating that participants with a more liberal bias tended to rate the consequences of taking antibiotics when they are needed as better overall. Thus, hypothesis 3, that participants' antibiotic expectations (i.e., their bias and sensitivity) would be associated with the perceived payoffs and base rate in the four decision outcomes was not confirmed. This might be due to the methodology employed for eliciting the utility.

The aim of this task was to elicit participants' utility via the three rating questions tapping into the payoffs and base rate parameters of the four antibiotic decision outcomes. However, we believe that this was not the best way to do so and that participants might have found the wording of the task and the questions confusing. Indeed, a number of participants commented at the end of the study about that specific task, citing that they found those questions and the use of double negatives quite confusing at times. Although the current study served more as a pilot study to test the signal detection theory model, as well as to explore some different methods for eliciting participants' utility and their responses to the antibiotic-related outcomes, we now believe there are much better methods for manipulating the payoffs and base rate model parameters. For instance, future research could manipulate the base rate parameter by modelling the base rates of viral versus bacterial illnesses via the number of scenarios presented. Another avenue for going forward would be to manipulate the payoff parameter of the model, such as by creating different cost environments either via the use of monetary incentives or health points (Böhm et al., 2022), or by stressing the cost of taking or not taking antibiotics verbally in the scenarios.

Antibiotic-related outcomes associated with false alarms and missed detections

Participants had to rank eight outcomes associated with false alarms (taking antibiotics when they are not needed) and eight outcomes associated with missed detections (not taking antibiotics when they are needed) from best to worst. The purpose of this task was to explore participants' perceptions regarding the outcomes, as well as to use some of the overall worst-ranked outcomes associated with false alarms and missed detections in another study focusing on manipulating the payoff parameter of the model. Given the time constraints for the thesis, we were not able to conduct such a study in the end as we chose to focus on the other two parameters of the model: similarity and base rate. However, the findings of the two ranking tasks are still important.

Regarding the outcomes associated with false alarms, participants ranked "Alternative and toxic treatments with serious side effects" as the worst outcome in both the Pre-test and Study 1. It is worth noting, however, that the outcome of "Getting an antibiotic-resistant infection" was only rated as the fourth-worst outcome in Study 1. This lower ranking might be explained by participants' incomplete knowledge regarding antibiotic resistance. Indeed, a systematic review found that the general public has an incomplete understanding of antibiotic resistance and misperceptions about it and its causes (McCullough et al. 2016), while other studies with both UK and US samples have found that many people do not consider antibiotic resistance to be an important problem (Carter et al., 2016; McNulty et al. 2010). For instance, several studies report that participants identified resistance as a problem in hospitals, and crucially failed to identify a threat to themselves, nor a perceived ability to influence antimicrobial resistance by minimising their own consumption (Brooks et al., 2008; Hawkings et al., 2007). One of the most common misconceptions is that the human body becomes resistant to the antibiotic rather than the organism itself becoming resistant (Hawkings et al., 2007; Heid et al., 2016).

Finally, regarding the outcomes associated with the missed detection, participants ranked “Serious complications due to illness progression” as the worst outcome in both the Pre-test and Study 1. This is in line with past research findings that one of the main reasons driving people to expect antibiotics is because they want to avoid the cost and the associated negative consequences of missed illness (Spicer et al., 2020; Thorpe et al., 2021). Further systematic work is needed to identify which outcomes, and to what extent, have the biggest effect on participants’ antibiotic expectations (i.e., through communication intervention studies manipulating different factors of risk representation), while potential findings from such studies could provide causal evidence, as well as help improve the current patient communication leaflets.

Limitations

Several limitations of our research deserve more attention. First, our research used realistic and familiar medical situations, but our participants were not making decisions about antibiotics based on currently experiencing an actual illness. Future research could test the proposed mechanisms on patients currently experiencing respiratory tract infections to provide more robust evidence and ensure ecological validity. Second, even though we followed the NICE and NHS guidelines for constructing the antibiotic scenarios, we are not medical professionals so it is possible that some of the symptoms presented in the scenarios might not correspond fully to the intended diagnosis. However, given that previous studies employed similar symptomatic scenarios (i.e., Roope et al., 2020; Sirota et al., 2017, 2022; Thorpe et al., 2020a, 2020b, 2021), and that our participants were able to discriminate the different symptom categories and their antibiotic expectations in the four uncertainty conditions were all in the expected direction, we believe that this is not a substantial drawback. Third, even though we assessed perceived payoffs and base rate in Study 1 via the three rating questions, we do not believe this is the best way to do so. Future research could create different decision environments and manipulate the payoff parameter, such as by creating different cost environments either via the use of monetary incentives using a behavioural game paradigm (Böhm et al., 2022) or by stressing the cost of false alarms and missed detections verbally in the scenarios. Fourth, there were several methodological limitations identified that could account for the observed findings on participants' antibiotic expectations (*methodological artefact assumption*), such as the experiment length, the wording of the scenarios, and the response scale used. Future research should further test the model by creating different decision environments and systematically removing the methodological limitation identified to provide more conclusive evidence.

Summary

In summary, we found no evidence for a liberal bias in people's antibiotic expectations; participants expected antibiotics for uncertain cases where antibiotics were not clinically needed but also did not expect them for uncertain cases where antibiotics *were* clinically needed. We also found no evidence for a more liberal bias in the uncertain compared to the certain conditions. Finally, the results provide no evidence for an association between participants' antibiotic expectations and perceived payoffs and base rate. However, we believe that this might be due to the methodology employed. Overall, the findings do not indicate that people are liberally biased towards antibiotics but seem to suggest that expectations for antibiotics can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics (*uncertainty assumption*). Further work is needed to test the model by creating different decision environments and removing some of the limitations identified to rule out that the observed findings are not due to methodological limitations (*methodological artefacts assumption*) and provide more robust and conclusive evidence behind people's antibiotic expectations.

CHAPTER 3

Re-testing signal detection theory of people's antibiotic expectations across different methodological settings

Introduction

In Chapter 2, we found that participants did not display any liberally biased antibiotic expectations while using a utility-based signal detection theory approach and proposed two accounts that can explain the findings. The *uncertainty assumption* proposes that expectations for antibiotics can be explained by diagnostic uncertainty rather than a genuine bias towards antibiotics. This suggests that in cases of diagnostic uncertainty, people err on both sides: they might expect antibiotics for viral conditions that are not clinically warranted but they also might not expect them for bacterial illnesses where antibiotics are clinically needed, indicating that people are not actually biased towards antibiotics bur rather well-calibrated to their environment.

Indeed, patients' diagnostic uncertainty has gathered strong empirical and theoretical support as the main driver of people's antibiotic expectations. Many studies have reported that people experience conceptual confusion about whether antibiotics are needed or not (Braun & Fowles, 2000; McNulty et al., 2013, 2019; Welschen et al., 2004), while findings also show that people expect antibiotics for conditions that do not require them, such as viral infections (McNulty et al., 2019; Kong et al., 2022). Diagnostic uncertainty can also concern the clinical symptoms and whether they manifest a viral or bacterial infection. For example, uncertainty regarding the nature of their illness predicted people's expectations for antibiotics for their recently experienced symptoms of a cold (Thorpe et al., 2021). Moreover, recent robust experimental evidence showed that reducing diagnostic uncertainty by providing a clinician's judgement about the illness aetiology of the symptoms, and in some cases including a diagnostic test, significantly decreased people's antibiotic expectations in hypothetical consultations (Thorpe et al., 2020a, 2020b, 2021). Moreover, a recent study employing a signal detection theory framework and manipulating uncertainty found that in high-uncertainty environments, participants often adopted a more liberal decision strategy and displayed higher antibiotic expectations (Sirota et al., 2022). However, tests of quantitative model predictions are missing, and no study has yet manipulated the uncertainty in a systematic manner to provide cognitive and computationally testable predictions for its effect on people's antibiotic expectations.

On the other hand, the *methodological artefacts assumption* proposes that the observed findings in Chapter 2 are due to methodological limitations. Some of the potential methodological limitations identified in Chapter 2 included: the number of scenarios and the survey length, the wording of the antibiotic scenarios, and the 4-point response scale used. It is important to address those limitations systematically to provide more robust and conclusive evidence behind people's antibiotic expectations. This chapter, therefore, focuses on further testing the two accounts by exploring some of the potential methodological limitations identified and manipulating the uncertainty to provide a better understanding behind the factors that drive people to expect antibiotics.

In three pre-registered studies, we tested the two accounts by removing some of the methodological limitations identified while using a utility-based signal detection theory approach. Specifically, in Study 2, we reduced the number of scenarios by half while we also reduced the survey length. Furthermore, we reworded the antibiotic scenarios to remove any ambiguous information and avoid any negations as these are harder to process. In Study 3, we invited back participants who took part in Study 2 and took the experimental design to its bare minimum by only presenting people with one antibiotic scenario with the aim to match their antibiotic expectations across the two studies. Finally, in Study 4, we used a binary response scale with an explicit (yes or no) response.

Assuming that the results observed are due to the *uncertainty assumption*, we expect to find similar antibiotic expectations to those observed in Chapter 2 by removing the methodological limitations. Specifically, we do not expect to find evidence for any liberally biased antibiotic expectations. However, assuming that the results are due to the *methodological artefacts assumption*, then we expect to find different antibiotic expectations to those observed in Chapter 2 by removing the methodological limitations. Specifically, we expect to find evidence for liberally biased antibiotic expectations.

Study 2

The Present Research

In the present research, we aimed to test the *methodological artefacts* versus the *uncertainty* account by removing two of the potential methodological limitations identified in Chapter 2 while using a utility-based signal detection theory approach. Specifically, we reduced the number of scenarios by half (12 in total) while we also reworded the scenarios to remove any ambiguous information and avoid any negations as these are harder to process (i.e., "You do not have a high temperature" = "You have a normal temperature"). Participants were randomly presented with 12 hypothetical medical antibiotic scenarios of varying uncertainty (4 conditions: certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and were asked to report their need for antibiotics as a treatment.

Assuming that the *methodological artefacts account* is correct, we derived one main hypothesis. We expect that by removing the two methodological limitations identified, participants will display a liberal bias for judging whether antibiotics are needed or not (i.e., resulting in increased antibiotic expectations relative to the optimal criterion location that maximizes accuracy; Hypothesis 1).

Methods

Participants

Participants were recruited online via the participant research platform Prolific. Based on power simulations for detecting an effect size of $d = 0.2$ for the deviation from the optimal criterion, the 95% Bayesian credible interval did not include 0 in 261 out of 300 simulated datasets with $N = 200$ giving an estimated statistical power of 87%. We, therefore, aimed to recruit a minimum of 200 valid responses. Panel members were eligible to participate only when they fulfilled two conditions: (i) their approval rate in previous studies was above 90%, and (ii) they resided in the UK. A balanced sample in terms of sex was also selected in the pre-screening criteria. A total of 220 responses was recorded. Based on pre-registered exclusion criteria, one participant was excluded from the final sample size due to failing the attention check question.

In the final sample size of 219 participants, 108 identified as male, and 111 as female. The sample age ranged from 18 to 78 years old ($M = 37.8$, $SD = 13.8$ years). Most participants (93.2%) were native English speakers. Participants' occupation varied as follows: management, professional, and related (33.8%), service (5.0%), sales and office (8.2%), construction, extraction, and maintenance (1.8%), production, transportation and material moving (3.2%), government (5.9%), retired (5.9%), unemployed (9.6%), student (10.0%) and other (16.4%). Their level of education varied as follows: less than high school (0.5%), high school degree (13.7%), some college (22.4%), undergraduate degree (43.8%), master's degree (16.9%), and doctoral or professional degree (2.7%).

Design

This was a within-subjects design with uncertainty condition being the independent variable and expectations for antibiotics being the dependent variable. Participants read 12 (randomly selected out of a total 24) hypothetical medical scenarios in the four within-subjects uncertainty conditions (certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and were asked to report their need for antibiotics as a treatment via a rating on a 4-point discrete scale ranging from 1 (Definitely no) to 4 (Definitely yes) with an explicit cut-off between "yes" and "no" responses (necessary for the analyses based on signal detection theory). From the responses to the antibiotic expectations variable, we calculated the bias and sensitivity with the bias being the main dependent variable.

Materials and Procedure

After participants provided informed consent, they were able to start the study, which took around 8 minutes to complete. They then moved on to the introductory page of the antibiotic scenarios task. Importantly, due to the COVID-19 pandemic, all participants were told that COVID-19 cannot account for their symptoms and were asked to indicate "yes" to the following question showing that they have read and understood the above information. All participants were then presented with the 12 antibiotic scenarios (randomly presented out of a total of 24 with a fixed attention check question halfway through the task), followed by the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 12 hypothetical medical scenarios describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines (see Appendix Study 2). There were four main conditions: certain antibiotics are not needed (3 scenarios presented out of a total 6) uncertain antibiotics are needed (3 scenarios presented out of a total 6), uncertain antibiotics are not needed (3 scenarios presented out of a total 6), certain antibiotics are needed (3 scenarios presented out of a total 6). In the scenarios, all participants received a description of the symptoms and illness duration and a description of the physical chest examination. Specifically, all the scenarios had the following set of symptoms that stayed constant: sore throat, runny nose, muscle aches and general fatigue. Moreover, the following pieces of clinical information were present in all scenarios but varied depending on the condition: *illness duration, cough, phlegm, temperature, breathlessness, and physical chest examination*. After each scenario, participants were asked to report their perceived need for antibiotics as a treatment (i.e., "I need antibiotics") on a four-item Likert scale ranging from 1 to 4 (1 = *Definitely no*, 2 = *Probably no*, 3 = *Probably yes*, 4 = *Definitely yes*) with an explicit cut-off between "yes" and "no" responses. An average score of antibiotics expectations (0-4) was computed for each participant in the four conditions. Higher scores indicate higher antibiotic expectations. The antibiotic expectations responses were also coded in a binary "yes" or "no" response according to the explicit cut-off value between the responses on the scale (necessary for the analyses based on signal detection theory).

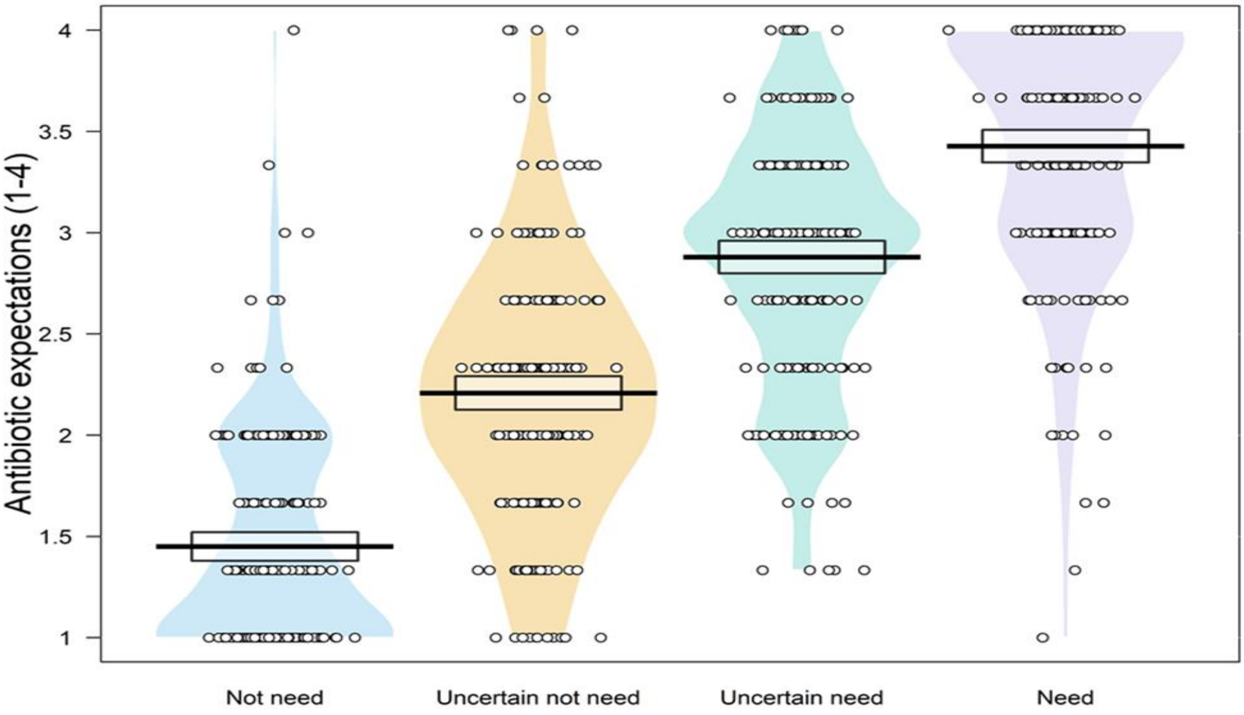
Lastly, participants were given the chance to comment on the study prior to being asked to answer some socio-demographic questions (i.e., age, gender, education, occupation and language) and were finally debriefed.

Results and Discussion

Participants reported the lowest antibiotic expectations in the “certain antibiotics are not needed” condition, whereas they reported the highest expectations in the “certain antibiotics are needed” condition (see Figure 20). Similarly to Study 1, in the two uncertain conditions participants’ antibiotic expectations responses fell around the middle of the scale but there was much greater response variation compared to the two certain conditions (see Figure 20). Overall, participants’ antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories and conditions.

Figure 20

Effect of Uncertainty on Antibiotic Expectations

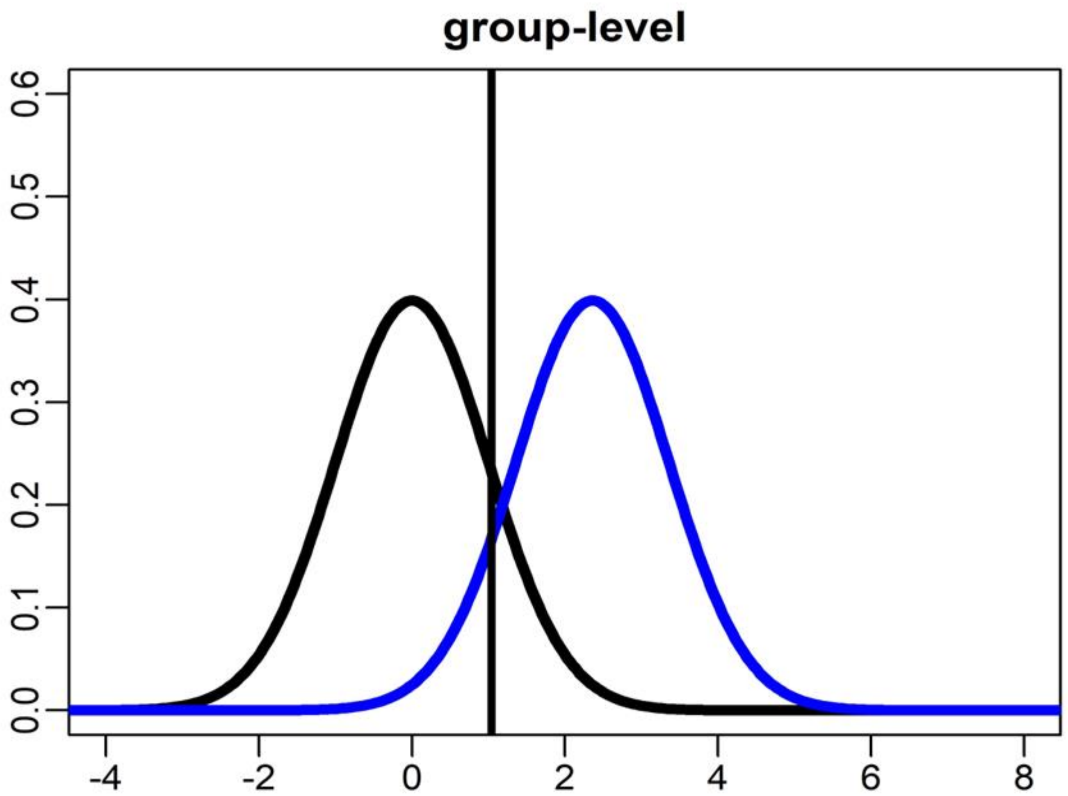


Note. The figure shows the effect of uncertainty condition (certain antibiotics are not needed vs uncertain antibiotics are not needed vs uncertain antibiotics are needed vs certain antibiotics are needed) on antibiotic expectations. The middle bold line represents the arithmetic mean and the box borders represent 95% confidence intervals.

We also calculated the utility-based signal detection model parameters, bias and sensitivity, using the coded "yes – antibiotics are needed", and "no – antibiotics are not needed" responses and participants' rate of false alarms and correct detections. Generally, the proportion of false alarms and missed detections was very similar (33.6 and 28.8 respectively). The model was estimated using a pre-registered multilevel approach (thus comprising both group-level "fixed" effects and subject-specific "random" effects). Although there was a shift in the expected direction towards higher antibiotic expectations (false alarms), it was not significant. Overall, participants' responses did not deviate systematically from the optimal strategy (as indicated by the mean deviation from the optimal criterion and its associated 95% Bayesian credible interval) and they did not display any liberally biased antibiotic expectations, mean deviation from optimal criterion = -.013, 95%CI [-0.27,0.02], (see Figure 21). Thus, Hypothesis 1, that by removing the two potential methodological limitations identified participants would display a liberal antibiotic bias, was not confirmed.

Figure 21

The Signal Detection Model Parameters



Note. The figure shows the signal detection model parameters, bias (c) and sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in black), calculated by people's antibiotic expectations in the scenarios. The vertical black bold line represents the criterion location.

In summary, contrary to our study prediction and the *methodological artefacts assumption*, participants did not display any liberally biased antibiotic expectations. Thus, the lack of antibiotic bias observed in study 1 and in this study does not seem to be due to methodological limitations. The results lend further support for the *uncertainty assumption*, that expectations for antibiotics can be explained by diagnostic uncertainty rather than a genuine bias towards antibiotics. However, even though we reduced the number of scenarios presented, it is possible that the lack of observed bias is driven by completing several scenarios. Therefore, in the next study, we wanted to take the experimental design to its bare minimum and present participants with only one antibiotic scenario.

Study 3

Present Research

In the present study, we aimed to further test the *uncertainty* vs the *methodological artefacts* account by exploring some additional methodological limitations identified in Chapter 2. Specifically, we invited back participants who took part in Study 2 and presented them with only one hypothetical medical antibiotic scenario (out of ones they had already seen before) with the aim to match their antibiotic expectations across the two studies.

We set up three main aims. First, we aimed to remove two potential methodological limitations (number of scenarios and survey length) by taking the study to its bare minimum and presenting participants with only one antibiotic scenario. Second, we aimed to test whether participants would display similar responses overall to the antibiotic scenario in this study to that of Study 2. So, we invited back participants who took part in Study 2 and presented them with one of the antibiotic scenarios from the “uncertain antibiotics are not needed” condition (i.e., the condition that gives rise to false alarms) that they read in the previous study so that their scenario was matched. Third, we aimed to explore whether the wording of the antibiotic expectations question (i.e., need for antibiotics) could have an effect on participants' responses. We therefore also included a follow-up question regarding desire for antibiotics.

We derived two main hypotheses based on the *uncertainty* vs the *methodological artefacts* assumptions. Assuming that the results observed in our previous study are due to methodological artefacts (*methodological artefacts assumption*), we expect that participants will display different responses overall in the antibiotics expectations question to the scenario in this study compared to the previous study (i.e., their antibiotic expectations will not be matched; Hypothesis 2a). Assuming that the results observed in our previous study are due to the uncertainty and not the bias (*uncertainty assumption*), we expect that participants will display similar responses overall to the antibiotics expectations question to the scenario in this study as in the previous study (i.e., their antibiotic expectations will be matched; Hypothesis 2b).

Methods

Participants

Participants who took part in study 2 and had valid responses ($N = 219$) were invited to take part in our study via the participant research platform Prolific in exchange for monetary payment and a chance to receive a bonus payment of £10. We had estimated that we would have a turnout rate of around 90% ($N = 197$).

In the final sample size of 187 participants, 93 identified as male and 94 as female. The sample age ranged from 18 to 78 years old ($M = 39.2$, $SD = 14.1$ years). Most participants (92.5%) were native English speakers. Participants' occupation varied as follows:

management, professional, and related (36.4%), service (5.3%), sales and office (9.1%), construction, extraction, and maintenance (2.1%), production, transportation and material moving (2.7%), government (5.3%), retired (8.6%), unemployed (9.1%), student (8.6%) and other (12.8%). Their level of education varied as follows: less than high school (0.5%), high school degree (15.0%), some college (23.5%), undergraduate degree (39.0%), master's degree (17.6%), and doctoral or professional degree (4.3%).

Design

Expectations for antibiotics were the main dependent variable. Participants were randomly presented with one hypothetical medical scenario from the "uncertain antibiotics are not needed" condition (out of the three that they saw in the previous study) so that participants' scenarios in the two studies were matched. They were then asked to report their need for antibiotics as a treatment, and their desire for antibiotics as a treatment, followed by some socio-demographic questions.

Materials and Procedure

After participants provided informed consent, they were able to start the study, which took around 2 minutes to complete. They then moved on to the introductory page of the antibiotic scenarios task. Importantly, due to the COVID-19 pandemic, all participants were told that COVID-19 cannot account for their symptoms. They were also informed that they have the chance to receive an extra payment of £10. This was done mainly to increase participant turnout on Prolific, and it was made clear to all participants that the selection of the bonus payment would be entirely random, and that after all data for the study had been collected one participant would be randomly selected to receive the bonus payment. They were then asked to indicate "yes" to the following question showing that they have read and understood all the above information. All participants were then presented twice with 1 antibiotic scenario (out of the three that they saw in the previous study) from the "uncertain antibiotics are not needed condition", followed by the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 1 hypothetical medical scenario describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines. The scenario was from the " uncertain antibiotics are not needed" condition used in the previous study, modelled after cases where antibiotics should not be prescribed. Participants were randomly presented with one scenario (out of the three that they saw in the previous study) so that participants' scenarios were matched in the two studies. In the scenario, all participants received a description of the symptoms and illness duration and a description of the physical chest examination. Specifically, all scenarios had the following set of symptoms that stayed constant: sore throat, runny nose, muscle aches and general fatigue. Moreover, the following pieces of clinical information were present in all scenarios but varied: *illness duration, cough, phlegm, temperature, breathlessness, and physical chest examination*. After reading the scenario, participants were asked to report their perceived need for antibiotics as a treatment (i.e., "I need antibiotics") on a four-item Likert scale ranging from 1 to 4 (1 = *Definitely no*, 2 = *Probably no*, 3 = *Probably yes*, 4 = *Definitely yes*) with an explicit cut-off between "yes" and "no" responses. Participants were then presented with the same scenario again and were asked to report their desire for antibiotics as a treatment (i.e., "I would want my doctor to prescribe me antibiotics") via a rating on a 4-point discrete scale ranging from 1 (Definitely no) to 4 (Definitely yes)

Lastly, participants were asked to answer some socio-demographic questions (i.e., age, gender, education, occupation and language) and were finally debriefed.

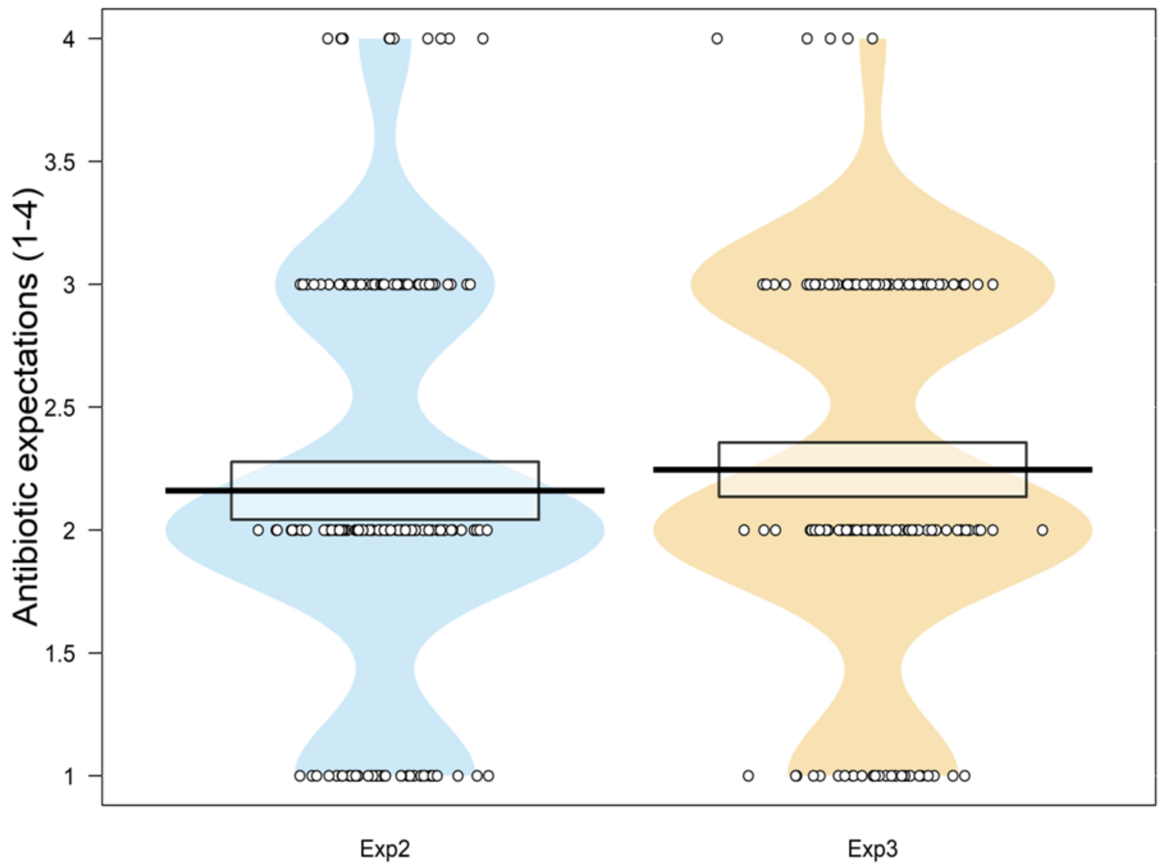
Results and Discussion

Antibiotic expectations

Overall, participants displayed similar responses to the antibiotic expectations question in this study as in Study 2 (see Figure 22). We run a pre-registered multilevel ordinal regression Bayesian model to compare participants' distributions of ratings in the antibiotic expectations question in the two antibiotic scenarios (i.e., the scenario used in this study vs the previous study). We found no significant within-subjects difference in the antibiotic expectations, b = 0.25, 95%CI [-0.12, 0.62]. Thus, participants' expectations were matched at the group-level, therefore confirming hypothesis 1a (*the uncertainty assumption*), that people's antibiotic expectations can be better explained by diagnostic uncertainty.

Figure 22

Effect of Experiment on Antibiotic Expectations

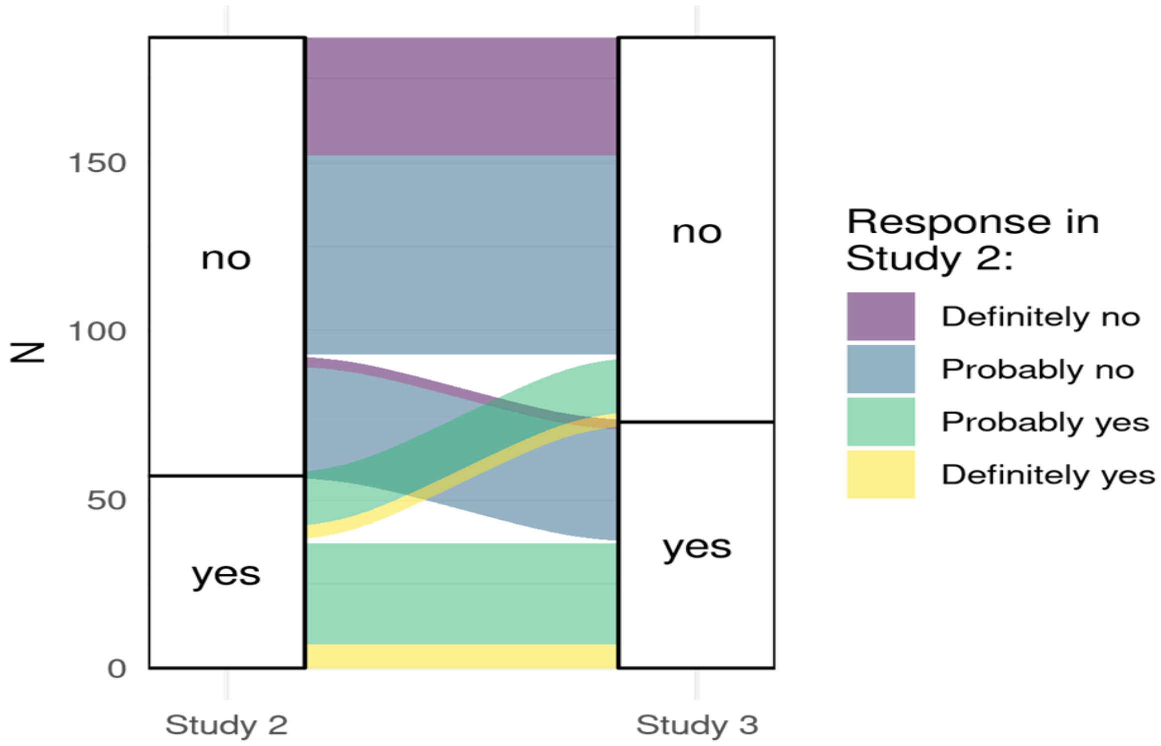


Note. The figure shows the effect of experiment (Exp2 vs Exp3) on the antibiotic expectations response in the antibiotic scenario across the two studies. The middle bold line represents the arithmetic mean and the box borders represent 95% confidence intervals.

We also looked at the within-subject response variation of participants' antibiotic expectations. We found that participants' within-subjects responses varied at the individual level (see Figure 23) meaning that some participants gave different responses to the antibiotic scenario in Study 2 compared to the same scenario in our study and vice versa, which provides further evidence for the *uncertainty account*, as it indicates that people are uncertain.

Figure 23

Antibiotics Expectations Response Variation



Note. The figure shows the antibiotics expectations within-subjects response variation (Study 2 versus Study 3).

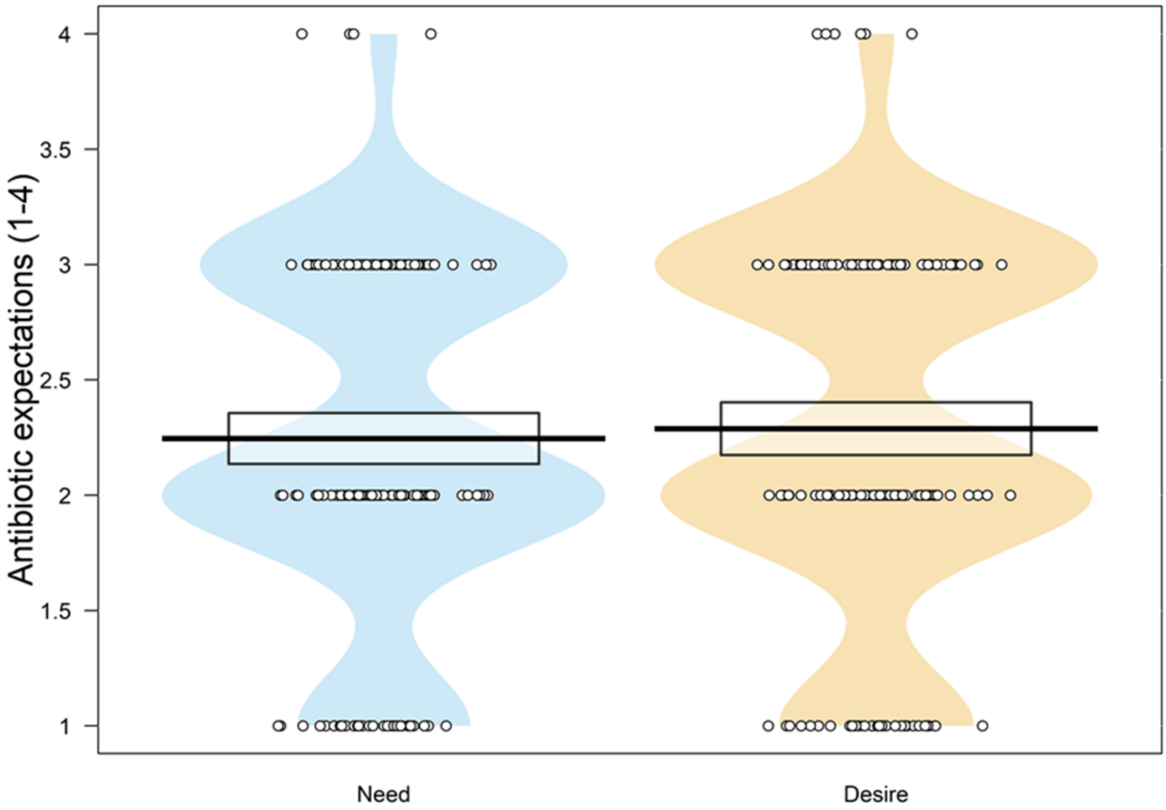
Need vs desire for antibiotics

Overall, participants gave similar responses to the *need for antibiotics* versus *desire for antibiotics* question (see Figure 24). We also run a pre-registered multilevel ordinal regression Bayesian model to test whether participants' distributions of ratings in our study differ in the two different antibiotic questions (need for antibiotics vs desire for antibiotics). We found no significant difference in participants' responses between the two questions, b =

0.11, 95% CI[-0.25, 0.49], (see Figure 24). Thus, the wording of the question did not have an effect on participants' antibiotic expectations.

Figure 24

The Effect of the Response Wording on Antibiotic Expectations



Note. The figure shows the effect of the response wording (need vs desire) on antibiotic expectations. The middle bold line represents the arithmetic mean and the box borders represent 95% confidence intervals.

Summary

In summary, participants displayed similar responses to the antibiotic expectations question in this study as in the previous study (expectations were matched at the group level).

Participants also responded similarly to the need versus desire for antibiotics question. Overall, the findings suggest that results observed in the previous studies are not due to methodological limitations (*methodological artefacts assumption*). Thus, the results give further support to the *uncertainty assumption*, that antibiotic expectations can better be explained by diagnostic uncertainty rather than a genuine bias towards antibiotics. However, even though we matched people's antibiotic expectations across the two studies at the group-level and provided further evidence for the *uncertainty assumption,* it is possible that the lack of observed bias is driven by another methodological limitation, namely, the response scale used. Therefore, in the next study, we wanted to test the effect of the response scale and used a binary response scale instead of a discrete scale.

Study 4

The Present Research

In the present research, we aimed to further explore the methodological artefacts vs the uncertainty account by removing the final methodological limitation identified. Specifically, we used a binary (yes or no) response scale instead of the 4-point discrete response scale used in the previous studies. Participants, similarly to Study 2, were randomly presented with 12 hypothetical medical antibiotic scenarios of varying uncertainty (4 conditions: certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and asked to report their antibiotic expectations in a binary (yes or no response scale).

We derived two main hypotheses based on the *uncertainty* vs the *methodological artefacts* assumptions. Assuming that the results observed in our previous studies are due to methodological artefacts, we expect that participants in this study will display a liberal bias for judging whether antibiotics are needed or not due to the binary response scale (i.e., resulting in increased antibiotic expectations relative to the optimal criterion location that maximises accuracy; Hypothesis 3a). Assuming that the results observed in our previous studies are due to the uncertainty and not the bias, we expect that participants in this study will not display any liberal bias for judging whether antibiotics are needed or not due to the binary response scale (i.e., resulting in optimal antibiotic expectations; Hypothesis 3b).

Methods

Participants

Participants were recruited online via the participant research platform Prolific. Based on the same power simulations used in Study 2, for detecting an effect size of d = 0.2 for the deviation from the optimal criterion, the 95% Bayesian credible interval did not include 0 in 261 out of 300 simulated datasets with *N* = 200 giving an estimated statistical power of 87%. We, therefore, aimed to recruit a minimum of 200 valid responses. Panel members were eligible to participate only when they fulfilled three conditions: (i) their approval rate in previous studies was above 90%, (ii) they resided in the UK, and (iii) they had not taken part in any of our previous studies. A balanced sample in terms of sex was also selected in the pre-screening criteria. A total of 221 responses were recorded. Based on pre-registered exclusion criteria, three participants were excluded from the final sample size due to failing the attention check question.

In the final sample size of 218 participants, 107 identified as male, 107 as female and 4 as other. The sample age ranged from 19 to 81 years old *(M* = 38.95, *SD* = 13.46 years). Most participants (88.1%) were native English speakers. Participants' occupation varied as follows: management, professional, and related (27.1%), service (3.7%), sales and office

(9.2%), construction, extraction, and maintenance (2.3%), production, transportation and material moving (1.8%), government (7.3%), retired (8.7%), unemployed (9.6%), student (11.9%) and other (18.3%). Their level of education varied as follows: less than high school (0.9%), high school degree (13.8%), some college (29.8%), undergraduate degree (38.1%), master's degree (13.3%), and doctoral or professional degree (4.1%).

Design

This was a within-subjects design with uncertainty condition being the independent variable and expectations for antibiotics being the dependent variable. Participants read 12 (randomly selected out of a total of 24) hypothetical medical scenarios in the four within-subjects uncertainty conditions (certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and were asked to report their need for antibiotics as a treatment via a binary (yes or no) response scale. From the responses to the antibiotic expectations variable, we calculated the bias and sensitivity with the bias being the main dependent variable.

Materials and Procedure

After participants provided informed consent form, they were able to start the study, which took around 8 minutes to complete. They then moved on to the introductory page of the antibiotic scenarios task. Importantly, due to the COVID-19 pandemic, all participants were told that COVID-19 cannot account for their symptoms and were asked to indicate "yes" to the following question showing that they have read and understood the above information. All participants were then presented with the 12 antibiotic scenarios (randomly presented out of a total of 24 with a fixed attention check question halfway through the task), followed by the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 12 hypothetical medical scenarios describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines. There were four main conditions: certain antibiotics are not needed (3 scenarios presented out of a total 6) uncertain antibiotics are needed (3 scenarios presented out of a total 6), uncertain antibiotics are not needed (3 scenarios presented out of a total 6), certain antibiotics are needed (3 scenarios presented out of a total 6). In the scenarios, all participants received a description of the symptoms and illness duration and a description of the physical chest examination. Specifically, all the scenarios had the following set of symptoms that stayed constant: sore throat, runny nose, muscle aches and general fatigue. Moreover, the following pieces of clinical information were present in all scenarios but varied depending on the condition: *illness duration, cough, phlegm, temperature, breathlessness, and physical chest examination*. After each scenario, participants were asked to report their perceived need for antibiotics as a treatment (i.e., "I need antibiotics") on a binary (yes or no) response scale. An average score of antibiotics expectations (1-2) was computed for each participant in the four conditions. Higher scores indicate higher antibiotic expectations.

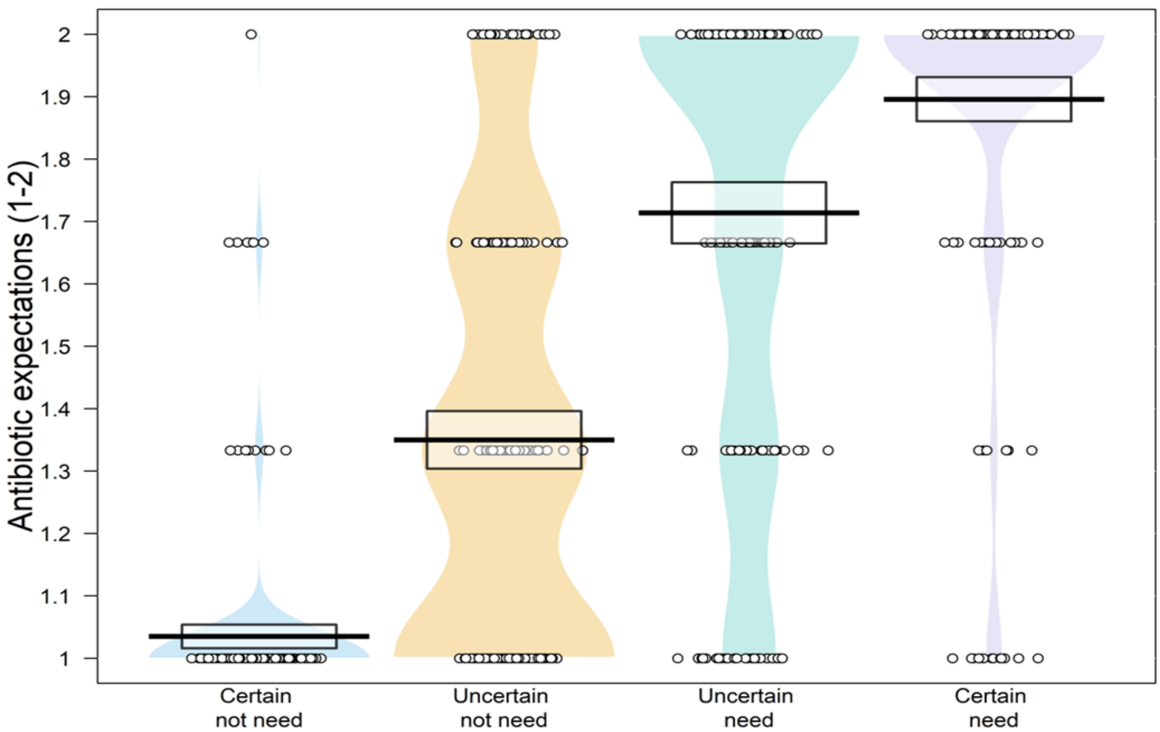
Lastly, participants were given the chance to comment on the study prior to being asked to answer some socio-demographic questions (i.e., age, gender, education, occupation and language) and were finally debriefed.

Results and Discussion

Similarly to the previous studies, participants reported the lowest antibiotic expectations in the "certain antibiotics are not needed" condition, whereas they reported the highest expectations in the "certain antibiotics are needed" condition (see Figure 25). In the two uncertain conditions, participants' antibiotic expectations responses similarly fell around the middle of the scale but there was greater response variation compared to the two certain conditions (see Figure 25). Overall, participants' antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories.

Figure 25

Effect of Uncertainty on Antibiotic Expectations

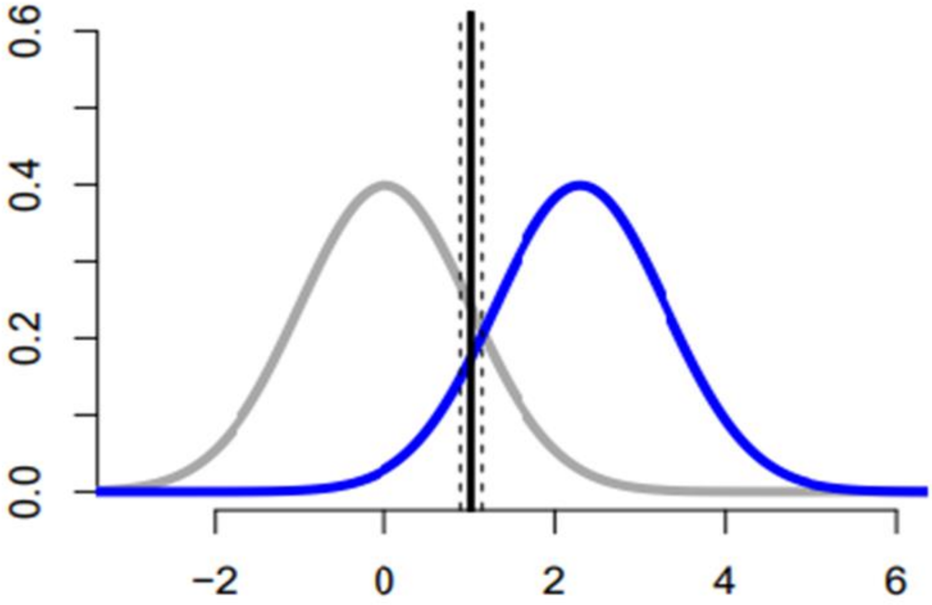


Note. The figure shows the effect of uncertainty condition (certain antibiotics are not needed vs uncertain antibiotics are not needed vs uncertain antibiotics are needed vs certain antibiotics are needed) on antibiotic expectations. The middle bold line represents the arithmetic mean and the box borders represent 95% confidence intervals.

We also calculated the utility-based signal detection model parameters, bias and sensitivity, using the coded "yes – antibiotics are needed", and "no – antibiotics are not needed" responses and participants' rate of false alarms and correct detections. Generally, the proportion of false alarms was slightly higher than that of missed detections (35 and 29 respectively). We run a pre-registered multilevel Bayesian generalized linear model (with a probit link function, thus equivalent to a signal detection theory analysis) to estimate the group-level signal detection model parameters (bias and sensitivity). We also estimated the 95% credible interval of the group-level bias, and used it to compare it to the optimal criterion, to assess objectively whether participants over or underestimate the need for antibiotics in each scenario. There was a small shift towards more liberal antibiotic expectations (false alarms) and in this case, it was significant. Overall, participants' responses deviated from the optimal strategy, and they displayed liberally biased antibiotic expectations, mean deviation from the optimal criterion = -0.15, 95CI [-0.29, -0.01], (see Figure 26). Thus, hypothesis 3a (*the methodological artefacts assumption*), that by including a binary (yes or no) response scale participants would display a liberal bias towards antibiotics, was confirmed. However, the credible interval just barely did not contain 0 and is very close to being a null effect, so the evidence is not strong.

Figure 26

The Signal Detection Model Parameters



Note. The figure shows the signal detection model parameters, bias (c) and sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in black), calculated by people's antibiotic expectations in the scenarios. The vertical black bold line represents the criterion location. The dashed grey lines represent the 95% Bayesian credible interval.

In summary, in this study we found evidence for a slightly liberal bias towards antibiotics; including a binary (yes or no) response scale resulted in participants displaying more liberal antibiotic expectations. However, the shift was very small, and the credible interval just about did not contain 0 and was close to a null effect, so the evidence is not very strong.

General Discussion

Gaining a better understanding of the behavioural determinants behind people's antibiotic expectations is crucial in strengthening antibiotic stewardship efforts and enabling us to reduce antibiotic overprescribing. The present studies aimed to test the *uncertainty assumption*, that antibiotic expectations can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics, versus the *methodological artefacts assumption*, that the lack of an antibiotic bias can be explained by methodological limitations, to provide more robust and conclusive evidence behind people's antibiotic expectations. In three pre-registered studies, we tested the two accounts by designing different decision environments and removing some of the methodological limitations identified in Chapter 2 while using a utility-based signal detection theory approach to measure participants' optimality of decision-making in terms of their antibiotic expectations and provide cognitive and computationally testable model predictions. Specifically, in Study 2, we halved the number of scenarios and reduced the survey length, while we also reworded the vignettes to remove any ambiguous information and avoid any negations as these are harder to process. In Study 3, we invited back participants who took part in Study 2 and took the experimental design to its bare minimum by only presenting people with one antibiotic scenario with the aim to match their antibiotic expectations across the two studies. Finally, in Study 4, we used a binary response scale with an explicit (yes or no) response. Based on participants' responses, we then calculated the signal detection model parameters underlying behaviour: bias and sensitivity

Overall, we found that people were optimal in their antibiotic expectations and did not display any liberal bias towards antibiotics. The findings provide evidence for the *uncertainty assumption* and seem to indicate that expectations for antibiotics can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics; participants expected antibiotics for uncertain conditions where antibiotics were not clinically needed but also did not expect antibiotics for uncertain conditions where antibiotics *were* clinically appropriate. The findings are also aligned with our model prediction, positing that diagnostic uncertainty can account for people's antibiotic expectations.

Past studies looking at people's antibiotic expectations and finding evidence for inappropriate expectations have typically only used one or two hypothetical medical scenarios (Roope et al., 2020; Sirota et al., 2017, 2022; Thorpe et al., 2020a, 2020b, 2021). Moreover, most of those scenarios were usually modelled after cases where antibiotics should not be prescribed, such as for viral ear infections (Sirota et al., 2022), cold symptoms (Thorpe et al., 2021), or flu-like symptoms (Roope et al., 2020), while others were modelled after cases where antibiotics should not be prescribed, such as for bacterial kidney infections (Sirota et al., 2022). While this approach approximates the real-world patient-clinician interaction, in that people typically visit their doctors while experiencing a specific illness and set of symptoms, the caveat is that it does not take into account how different levels of diagnostic uncertainty might influence participants' antibiotic expectations or if those inappropriate expectations identified in prior research actually extend to both directions.

In our studies, when looking in isolation at the uncertain cases where antibiotics should not be prescribed, we also found evidence for higher inappropriate antibiotic expectations similar to those of past research (Sirota et al., 2022; Thorpe et al., 2020a, 2020b, 2021). However, we also found that participants do not expect antibiotics for uncertain cases that do warrant them, thus showing that participants display inappropriate antibiotic expectations in both directions. Our findings, therefore, provide novel evidence for the effect of uncertainty as they suggest that when taking into context the different uncertainty levels, people tend to err on both sides (i.e., expect antibiotics for uncertain cases where antibiotics are not clinically warranted but also do not expect them for uncertain cases where antibiotics *are* clinically warranted), indicating that participants are not actually biased but rather well-calibrated. This adds to the substantive body of evidence reporting that lay uncertainty is one of the main drivers of people's antibiotic expectations (Broniatowski et al., 2018; Kong et al., 2022; McNulty et al., 2019; Sirota et al., 2020; Thorpe et al., 2020a, 2020b, 2021).

Furthermore, past studies examining people's antibiotic expectations usually used Likert-type response scales with several statements, after which an average score of people's antibiotic expectations was calculated (Roope et al., 2020; Sirota et al., 2017, 2022; Thorpe et al., 2020a, 2020b, 2021). In studies 1-3, we also used a 4-point Likert scale to measure people's antibiotic expectations. However, it is possible that the Likert-type response scales used might have influenced participants' responses, as it can be argued that the scale itself has inherent uncertainty as it contains statements in probability terms. Moreover, such scales do not reliably reflect the patient-doctor interaction as most people visiting their clinicians for their symptoms usually think in dichotomous decision terms and either expect antibiotics or not for their symptoms. The effect of the response scale used was partially shown in Study 4 where we used a binary response scale instead with an explicit (yes or no) response similar to that of prior research using a signal detection theory framework to measure GPs' referral decision-making (Kostopoulou et al., 2019). We found that the use of a binary response scale shifted participants' decision criterion, therefore, resulting in higher antibiotic expectations. This is also consistent with findings using the fuzzy trace theory and showing that when people are faced with two options, they are much more likely to subscribe to the categorical gist of "why not take a risk" and choose the risky option on the possibility of improvement (i.e., take antibiotics) as opposed to preferring the option without an antibiotic treatment even if they understand that probability of improvement is low (Reyna et al., 2021, 2022). Future studies should further examine the effect of using a Likert scale versus a binary response scale on people's antibiotic expectations.

Moreover, it is worth noting that the specific illnesses after which the scenarios were modelled in our studies might similarly have influenced participants' responses. Bronchitis, in particular, is an illness that often divides the clinical community. Even though around 90% of acute bronchitis infections are caused by viruses (Gonzales et al., 2001; Worrall, 2008), around 65 to 80% of patients with acute bronchitis are prescribed antibiotics (Gonzalez et al., 1997; Linder et al., 2002), indicating that clinicians themselves are often also uncertain. Specifically, despite no evidence that sputum reliably differentiates between bacterial and viral lower respiratory tract infections (Little et al., 2005), discoloured sputum has been cited as one of the main symptoms driving clinicians' prescribing behaviours in patients presenting with symptoms of bronchitis (Butler et al., 2011). It is possible then that the specific symptoms used in the scenarios might partially explain the findings and why people err on both sides, while past antibiotic prescribing from their clinician might similarly have influenced people's responses. Future research should aim to corroborate the findings by including a wider range of illnesses and symptoms. For instance, future studies could focus on other respiratory tract infections, such as sinusitis or pharyngitis, to see whether similar findings will be observed, or even on non-respiratory tract infections, such as urinary tract or skin infections, which usually also receive far less media coverage compared to respiratory tract infections (Huttner et al., 2010).

Overall, our findings have important implications for the theory as they provide novel evidence for the effect of uncertainty of both viral and bacterial illnesses on people's antibiotic expectations. They challenge the assumption that in cases of diagnostic uncertainty people only display inappropriately high antibiotic expectations for viral conditions that do not require them, such as bronchitis, as the findings also show the opposite: in cases of diagnostic uncertainty, people also display inappropriately low antibiotic expectations for conditions that do require antibiotics, such as pneumonia. The findings, therefore, suggest that people's inappropriately high antibiotic expectations identified in previous research can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics. Future research should focus on further testing this account by also including another predictor of people's antibiotic expectations that could better account for the observed findings in conjunction with the uncertainty. For instance, future studies employing a signal detection theory approach could focus on designing decision environments closer to the real-world rate of viral and bacterial illnesses and test their effect on people's antibiotic expectations.

Limitations

Several limitations of our research deserve more attention. First, even though we removed the methodological limitations identified in Chapter 2 (i.e., the number of scenarios and the survey length, the wording of the antibiotic scenarios, and the 4-point response scale), the list was not exhaustive and other methodological artefacts could account for the findings. Future research employing a signal detection theory approach should focus on designing different decision environments and exploring additional methodological limitations to test their effect on people's antibiotic expectations and provide more conclusive evidence. Second, even though we reworded the antibiotic scenarios to reduce ambiguity and remove any negations which are harder to process, and constructed similar symptomatic scenarios to those validated in previous research following clinical guidelines (i.e., Roope et al., 2020; Sirota et al., 2017, 2022; Thorpe et al., 2020a, 2020b, 2021), we are not medical professionals so it is possible that some of the symptoms presented in the scenarios might not correspond fully to the intended diagnosis and that some ambiguity might still remain. However, given that participants were able to discriminate between the different symptom categories in all our studies, and that their antibiotic expectations in the four uncertainty conditions were all in the expected direction, we do not believe that this is a substantial drawback. Third, we used a fixed base rate in all our studies (besides Study 3 which only tested one scenario), such that half of the scenarios presented were modelled after cases where antibiotics should not be prescribed, which might have similarly influenced participants' performance. Future research should attempt to test the base rate parameter of the model, such as by manipulating the base rates of viral versus bacterial illnesses via the number of scenarios presented to test its effect on people's antibiotic expectations.

Summary

In summary, we found that people did not display any liberal bias towards antibiotics and that their antibiotic expectations can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics; people expected antibiotics for uncertain cases where antibiotics were not clinically needed but also did not expect them for uncertain cases where antibiotics *were* clinically needed, thus erring on both sides and indicating that they are not actually biased but rather well-calibrated to the decision environment. We believe that the findings have important implications for the theory as they provide novel cognitive and computationally testable evidence for the effect of uncertainty on people's antibiotic expectations and extend our understanding of the factors that drive people to expect antibiotics.

CHAPTER 4

The effect of base rate on people's antibiotic expectations

Introduction

Findings from our previous studies using a utility-based signal detection theory approach revealed that people expected antibiotics for cases that were not clinically needed while they also did not expect antibiotics for cases that were clinically needed, suggesting that people are well-calibrated and that their inappropriate antibiotic expectations can better be explained by diagnostic uncertainty rather than a genuine bias towards antibiotics. However, in conjunction with the uncertainty, another important but understudied determinant of people's antibiotic expectations, and of the main environmental parameters of the model, that could also account for the observed findings is the base rate.

Even though research on the effect of the base rate on people's antibiotic expectations is limited, one aspect of base rate which has gathered some evidence as a determinant of people's antibiotic expectations is prior experience. Several studies have found that past consultation behaviours and previous antibiotic treatment for viral infections are associated with greater expectations for antibiotics (Thorpe et al., 2021; Vinker et al., 2003).

Another important aspect of the base rate concerns the real-world rates of viral versus bacterial illnesses. People typically encounter many more cases of viral rather than bacterial illnesses in their daily lives (i.e., Creer et al., 2016). According to the NICE clinical summaries, adults typically experience an average of 2-3 colds per year (NICE, 2022), while the annual incidence of acute bronchitis is 44 per 1000 adult population (Wark, 2011). In contrast, the annual incidence of community-acquired pneumonia is 5-10 per 1000 adult population (NICE, 2014, 2024). Furthermore, a study aiming to detect common upper respiratory tract pathogens among patients with fever and flu-like symptoms showed that around 82% of the pathogens identified were viruses, while only 12% of them were bacteria (Tang et al., 2019). However, most studies measuring people's antibiotic expectations have typically measured them in the currently high viral environment (i.e., McNulty et al., 2019) without controlling for the real-world rates of viral versus bacterial illnesses, and no study has yet directly manipulated the base rate to provide causal evidence for its effect on people's antibiotic expectations.

According to the utility-based approach, the base rate parameter describes the perceiver's probability of encountering targets (i.e., cases where antibiotics are needed) vs foils (i.e., cases where antibiotics are not needed) and is an estimate of the criterion location. In all our previous studies, we have used a fixed base rate so that all the scenarios presented were set up such that half of them would require antibiotic treatment. However, this differs greatly from the real-world rates as people typically tend to encounter many more cases of viral compared to bacterial illnesses in their daily lives (i.e., Creer et al., 2016). Moreover, it also raises the question of whether the results observed in our previous studies are due to the decision environment employed or due to participants maintaining a fixed prior belief that antibiotics are equally likely to be needed as not needed. One way to overcome this limitation and test the effect of base rate is to create decision environments that approximate the real-world rates of encountering viral versus bacterial illnesses, while also employing an experimental design to provide causal evidence for its effect on people's antibiotic expectations.

Study 5

The Present Research

In the present research, we aimed to test the effect of base rate on people's antibiotic expectations while using a utility-based signal detection theory approach. We manipulated the base rate to approximate the real-world higher rates of viral versus bacterial infections by presenting participants with 16 antibiotic scenarios and setting the base rate at 0.2 (i.e., 80% of the scenarios were modelled after viral illnesses and did not require antibiotic treatment).

Assuming that the results of our previous studies are due to participants maintaining a fixed prior belief that antibiotics are equally likely to be needed as not needed, then participants might fail to adapt their decision strategy to the more realistic distribution of scenarios used in this study. Thus, by increasing the number of antibiotics not needed scenarios, we hypothesised that participants would display a liberal bias resulting in an asymmetrical pattern of errors, with fewer missed detections (responding that antibiotics are not needed when they actually are) and more false alarms (responding that antibiotics are needed when they are not) than the optimal error-minimising strategy (Hypothesis 1).

Methods

Ethics

The research complied with all relevant ethical regulations. It received ethical approval from the Ethics Committee at the University of Essex (ref: ETH2021-0608). Informed consent was also obtained from all participants prior to starting the study online. Participants were also remunerated for their time at a standard Prolific rate.

Participants

Participants were recruited online via the participant research platform Prolific in exchange for monetary payment. Panel members were eligible to participate only when they fulfilled all three conditions: (i) their approval rate in previous studies was above 90%, (ii) they resided in the UK, and (iii) they had not taken part in any of our previous studies. A balanced sample in terms of sex was also selected in the pre-screening criteria. Based on pre-registered exclusion criteria, participants who failed the attention check question were excluded from the final sample size.

In order to estimate the sample sizes required to test our hypotheses, we used a simulation approach. The parameters of the simulations (comprising both group-level "fixed" effects coefficients and variance-covariance matrix for subject-specific "random" effects) were set to values estimated in our prior studies that used the same method. Specifically, based on power simulations for detecting an effect size of Cohen's $d = 0.2$ for the deviation from the optimal criterion assuming $\alpha = .05$, the 95% Bayesian credible interval did not include 0 in 261 out of 300 simulated datasets with a sample size of $N = 200$ giving an estimated statistical power of 87%. We, therefore, aimed to recruit a minimum of 200 valid responses. A total of 211 responses was recorded.

In the final sample size of 211 participants, 104 identified as male, 106 as female, and 1 as other. The sample age ranged from 18 to 79 years old ($M = 40.1$, $SD = 13.2$ years). Most participants (92.4%) were native English speakers. Participants' occupation varied as follows: management, professional, and related (32.2%), service (8.1%), sales and office (12.8%), construction, extraction, and maintenance (1.9%), production, transportation and material moving (1.4%), government (6.2%), retired (6.6%), unemployed (6.6%), student (8.5%) and other (15.6%). Their level of education varied as follows: less than high school (0.5%), high school degree (17.1%), some college (23.7%), undergraduate degree (41.7%), master's degree (12.8%), and doctoral or professional degree (4.3%).

Design

This was a within-subjects design with uncertainty condition being the independent variable and expectations for antibiotics being the dependent variable, while the base rate was manipulated to approximate the real-world base rates of viral versus bacterial illnesses. Participants read 16 hypothetical medical scenarios (i.e., the base rate was set at 0.2 so that only 20% of the scenarios presented required an antibiotic treatment) from the four within-subjects uncertainty conditions (certain antibiotics are needed, uncertain antibiotics are needed, uncertain antibiotics are not needed, certain antibiotics are not needed) and were asked to report their need for antibiotics as a treatment via a binary (yes or no) response scale. From the responses to the antibiotic expectations variable, we calculated the bias and sensitivity with the bias being the main dependent variable.

Materials and Procedure

After participants provided informed consent, they were able to start the study, which took around 8 minutes to complete. They then moved on to the introductory page of the antibiotic scenarios task. Importantly, due to the COVID-19 pandemic, all participants were told that COVID-19 cannot account for their symptoms and were asked to indicate "yes" to the following question showing that they have read and understood the above information. All participants were then presented with the 16 antibiotic scenarios (randomly presented with a fixed attention check question halfway through the task), followed by the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 16 hypothetical medical scenarios describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines (see Appendix Study 5). There were four main conditions: certain antibiotics are not needed (6 scenarios) uncertain antibiotics are needed (6 scenarios), uncertain antibiotics are not needed (2 scenarios), and certain antibiotics are needed (2 scenarios). The base rate was set such that 80% of the scenarios presented were modelled after cases that did not require an antibiotic treatment. In the scenarios, all participants received a description of the symptoms and illness duration and a description of the physical chest examination. Specifically, all the scenarios had the following set of symptoms that stayed constant: sore throat, runny nose, muscle aches and general fatigue. Moreover, the following pieces of clinical information were present in all scenarios but varied depending on the condition: *illness duration, cough, phlegm, temperature, breathlessness, and physical chest examination*. After each scenario, participants were asked to report their perceived need for antibiotics as a treatment (i.e., "I need antibiotics") via a binary (yes or no) response scale. An average score of antibiotics expectations (1-2) was computed for each participant in the four conditions. Higher scores indicate higher antibiotic expectations. From the responses to the antibiotic expectations variable, we then calculated the bias and sensitivity with the bias being the main dependent variable.

Lastly, participants were given the chance to comment on the study prior to being asked to answer some socio-demographic questions (i.e., age, gender, education, occupation and language) and were finally debriefed.

Results and Discussion

Participants reported the lowest antibiotic expectations in the “certain antibiotics are not needed” condition, whereas they reported the highest expectations in the “certain antibiotics are needed” condition similar to our previous studies (see Figure 27). However, contrary to our previous studies, participants’ antibiotic expectations in the two uncertain conditions here did not fall around the middle of the scale. Specifically, participants displayed markedly higher antibiotic expectations in the “uncertain antibiotics are needed condition” and a much lower count of missed detections compared to the “uncertain antibiotics are not needed condition” (see Figure 27). Overall, participants’ antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories and conditions.

Figure 27

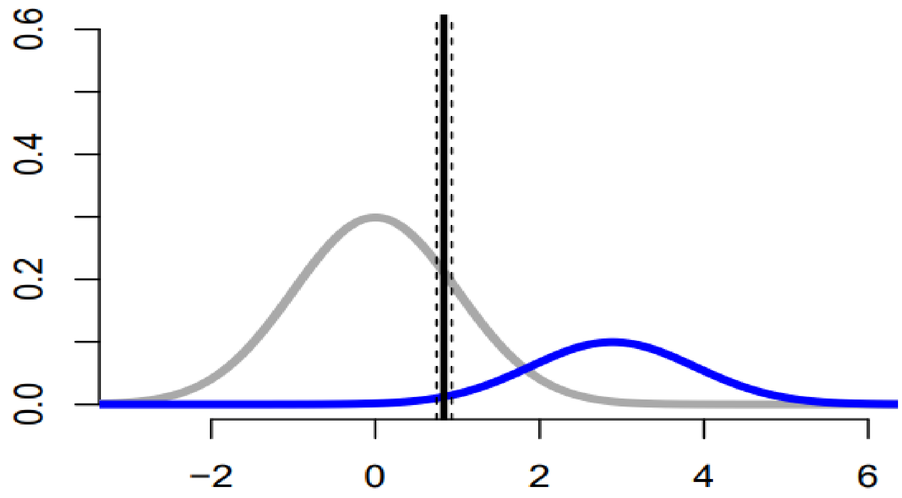
Effect of Uncertainty on Antibiotic Expectations

Note. The figure shows the distribution of the need for antibiotics responses (1 = "no", 2 = "yes") in the four uncertainty conditions: certain antibiotics are not needed (NN) vs uncertain antibiotics are not needed (UN) vs uncertain antibiotics are needed (UY) vs certain antibiotics are needed (YY). The black error bars represent the standard error of the mean.

Participants displayed increased antibiotic expectations when the base rate was set to approximate the real-world base rates of viral versus bacterial illnesses. We run a pre-registered multilevel Bayesian generalized linear model (with a probit link function, thus equivalent to a signal detection theory model with a Gaussian-distributed latent decision variable) to estimate the group-level signal detection model parameters: bias and sensitivity. Overall, participants' responses deviated significantly from the optimal strategy, and they displayed liberally biased antibiotic expectations, mean deviation from the optimal criterion = -1.00, 95%CI [-1.26, -0.79] (see Figure 28). Thus, hypothesis 1, that by setting the base rate to approximate the real-world base rates of viral vs bacterial illnesses participants would display a liberal antibiotic bias, was confirmed.

Figure 28

The Signal Detection Model Parameters



Note. The figure shows the signal detection model parameters, bias (c, that is the extent to which the decision criterion deviates from the statistically optimal criterion) and sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in black), calculated by people's antibiotic expectations in the scenarios. The vertical black bold line represents the criterion location. The dashed grey lines represent the 95% Bayesian credible interval.

Study 6

The Present Research

In the present study, we aimed to provide causal evidence for the role of base rate on peoples' antibiotic expectations. We thus employed a between-subjects design while manipulating the base rate so that participants were randomly allocated to one of the two conditions: control condition (50% of the scenarios require antibiotic treatment) vs viral base rate condition (20% of the scenarios require antibiotic treatment).

We hypothesised that participants would display a more liberal antibiotic bias (i.e., resulting in increased antibiotic expectations relative to the optimal criterion location that maximises accuracy) when antibiotics would be needed for 20% of scenarios (viral base rate condition) compared to when antibiotics would be needed for 50% of scenarios (control condition; Hypothesis 2).

Methods

Ethics

The research complied with all relevant ethical regulations. It received ethical approval from the Ethics Committee at the University of Essex (ref: ETH2021-0608). Informed consent was also obtained from all participants prior to starting the study online. Participants were also remunerated for their time at a standard Prolific rate.

Participants

Participants were recruited online via the participant research platform Prolific in exchange for monetary payment. Panel members were eligible to participate only when they fulfilled all three conditions: (i) their approval rate in previous studies was above 90%, (ii) they resided in the UK, and (iii) they had not taken part in any of our previous studies. A balanced sample in terms of sex was also selected in the pre-screening criteria. Based on pre-registered exclusion criteria, participants who failed the attention check question were excluded from the final sample size.

In order to estimate the sample sizes required to test our hypotheses, we used a simulation approach. The parameters of the simulations (comprising both group-level "fixed" effects coefficients and variance-covariance matrix for subject-specific "random" effects) were set to values estimated in our prior studies that used the same method. Specifically, based on power simulations for detecting an effect size of Cohen's $d = 0.2$ for the deviation from the optimal criterion assuming $\alpha = .05$, the 95% Bayesian credible interval did not include 0 in 261 out of 300 simulated datasets with a sample size of $N = 200$ giving an estimated statistical power of 87%. We, therefore, aimed to recruit around 400 valid responses (200 per condition). A total of 401 responses was recorded. Based on the pre-registered exclusion criteria, four participants were excluded from the final sample size due to failing the attention check question.

In the final sample size of 397 participants, 199 identified as male, 196 as female, and 2 as other. The sample age ranged from 18 to 80 years old ($M = 39.7$, $SD = 12.8$ years). Most participants (94.0%) were native English speakers. Participants' occupation varied as follows: management, professional, and related (32.7%), service (6.3%), sales and office (10.6%), farming, fishing, and forestry (0.3%), construction, extraction, and maintenance (2.3%), production, transportation and material moving (2.8%), government (7.1%), retired (5.0%), unemployed (8.8%), student (6.8%) and other (17.4%). Their level of education varied as follows: less than high school (0.5%), high school degree (13.1%), some college (23.4%), undergraduate degree (41.8%), master's degree (18.1%), and doctoral or professional degree (3.0%).

Design

This was a mixed design with base rate and uncertainty being the independent variables and expectations for antibiotics being the dependent variable. Participants were randomly allocated to one of the two conditions: control condition (50% of the scenarios require antibiotic treatment) vs high viral base rate condition (20% of the scenarios require antibiotic treatment). Participants read 16 (randomly presented with a fixed attention check question) hypothetical medical scenarios in the four within-subjects uncertainty conditions and were asked to report their need for antibiotics as a treatment via a binary (yes or no) response. From the responses to the antibiotic expectations variable, we calculated the bias and sensitivity with the bias being the main dependent variable.

Materials and Procedure

After participants provided informed consent, they were able to start the study, which took around 8 minutes to complete. Participants were then allocated to either the high viral base rate condition (20% of the scenarios require an antibiotic treatment) or the control condition (50% of the scenarios require an antibiotic treatment). All participants were then presented with 16 antibiotic scenarios (randomly presented with a fixed attention check question halfway through the task), followed by the socio-demographic questions.

Antibiotic scenarios. Participants had to provide their antibiotic expectations after reading 16 hypothetical medical scenarios describing a consultation with a physician for symptoms of respiratory tract infections modelled after the NHS and NICE clinical guidelines (see Appendix Study 6). In the high viral base rate condition, 80% of the scenarios presented were modelled after cases of viral illness that did not require an antibiotic treatment, while 20% were modelled after cases of bacterial illness that required antibiotic treatment; their distribution was as follows: certain antibiotics are not needed (6 scenarios) uncertain antibiotics are needed (6 scenarios), uncertain antibiotics are not needed (2 scenarios), certain antibiotics are needed (2 scenarios). In the control condition, 50% of the scenarios were modelled after cases of viral illness not requiring antibiotics and 50% were modelled after cases of bacterial illness requiring antibiotics; their distribution was as follows: certain antibiotics are not needed (4 scenarios) uncertain antibiotics are needed (4 scenarios), uncertain antibiotics are not needed (4 scenarios), certain antibiotics are needed (4 scenarios). Participants were also presented with one attention check question embedded halfway through the task in both conditions. In the scenarios, all participants received a description of the symptoms and illness duration and a description of the physical chest examination (see Study 5 Antibiotic scenarios for exact details). After each scenario, participants were asked to report their perceived need for antibiotics as a treatment (i.e., "I need antibiotics") via a binary (yes or no) response scale. An average score of antibiotics expectations (1-2) was computed for each participant in the four conditions. Higher scores indicate higher antibiotic expectations. From the responses to the antibiotic expectations variable, we then calculated the bias and sensitivity with the bias being the main dependent variable.

Lastly, participants were given the chance to comment on the study prior to being asked to answer some socio-demographic questions (i.e., age, gender, education, occupation and language) and were finally debriefed.

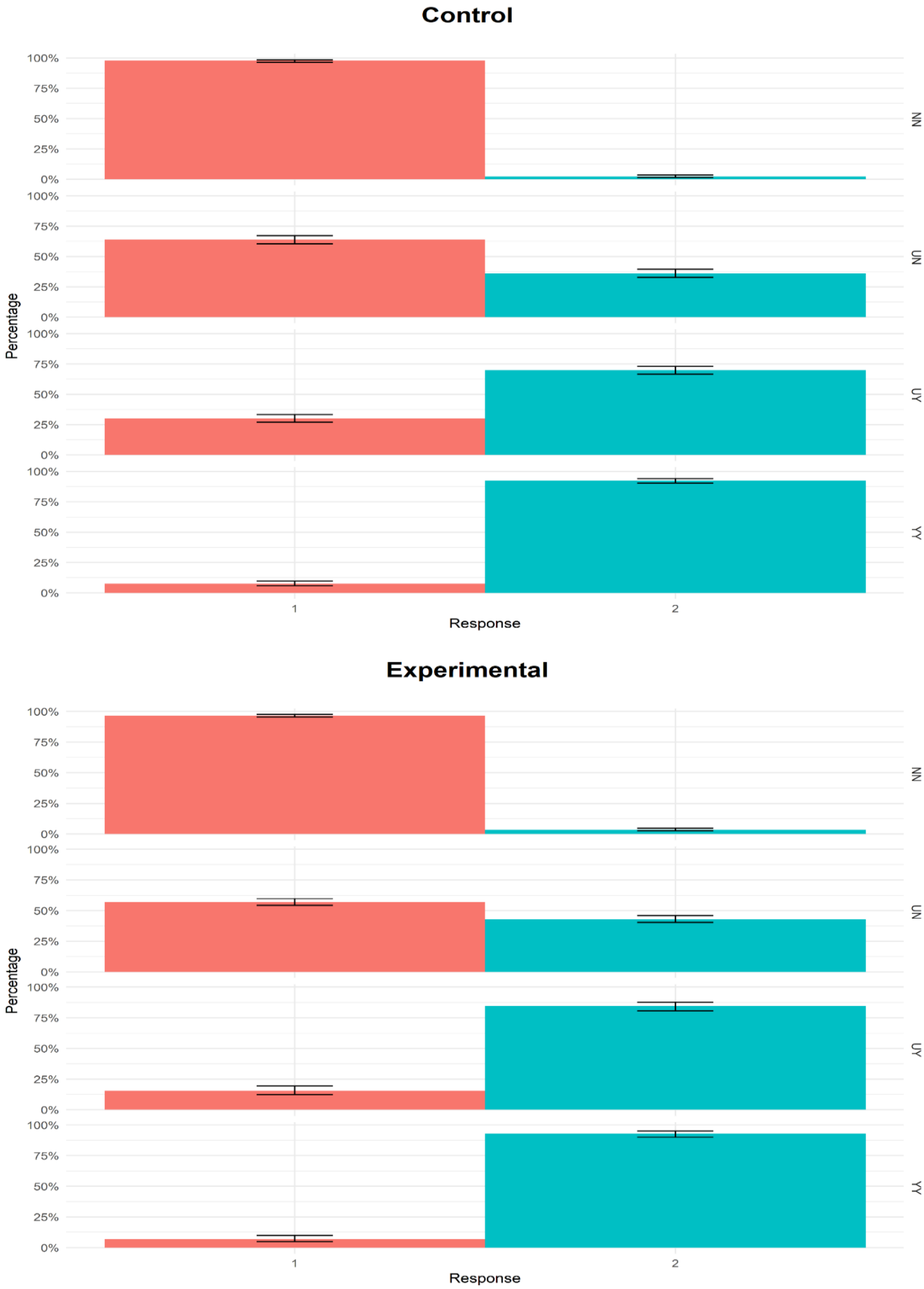
Results and Discussion

In the control condition, participants reported the lowest antibiotic expectations in the "certain antibiotics are not needed" condition, whereas they reported the highest expectations in the "certain antibiotics are needed" condition (see Figure 29). As expected and similar to our previous studies with a fixed base rate, in the two uncertain conditions participants' antibiotic expectations responses fell around the middle of the scale (see Figure 29). Overall, participants' antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories and conditions.

In the high viral base rate condition, participants reported the lowest antibiotic expectations in the "certain antibiotics are not needed" condition, whereas they reported the highest expectations in the "certain antibiotics are needed" condition (see Figure 30). Similar to Study 5, which also had a high viral base rate environment, participants' antibiotic expectations in the two uncertain conditions did not fall around the middle of the scale. Specifically, participants displayed markedly higher antibiotic expectations in the "uncertain antibiotics are needed condition" and a much lower count of missed detections compared to the "uncertain antibiotics are not needed condition" (see Figure 30). Overall, participants' antibiotic expectations in the different uncertainty conditions were all in the expected direction and they were able to discriminate between the different symptom categories and conditions.

Figure 29

Effect of Uncertainty on Antibiotic Expectations in the Control and Experimental Condition

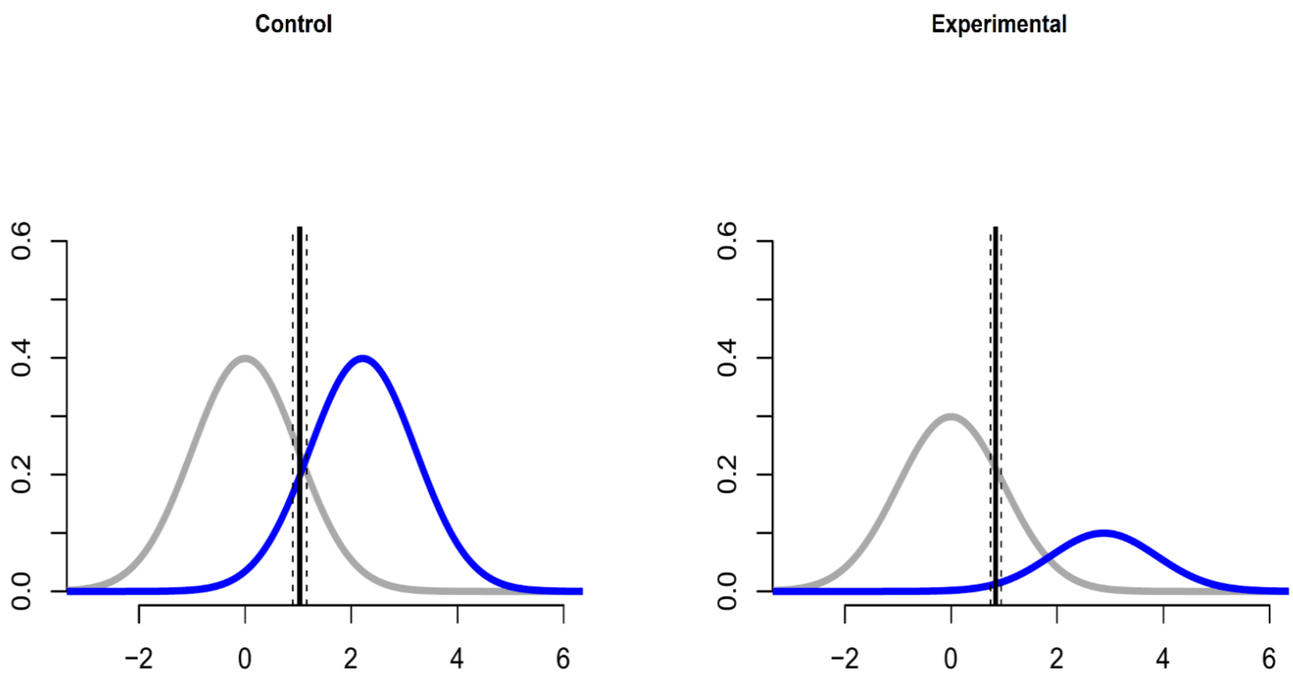


Note. The figure shows the distribution of the need for antibiotics responses (1 = "no", 2 = "yes") in the four uncertainty conditions: certain antibiotics are not needed (NN) vs uncertain antibiotics are not needed (UN) vs uncertain antibiotics are needed (UY) vs certain antibiotics are needed (YY) in the control (upper graph) and experimental (lower graph) conditions. The black error bars represent the standard error of the mean.

Overall, participants expected antibiotics for conditions which were not clinically appropriate when the decision environment approximated the real-world base rates of viral versus bacterial infections. We run a pre-registered multilevel Bayesian generalized linear model (with a probit link function, thus equivalent to a signal detection theory model with Gaussian-distributed latent decision variable) to estimate the group-level signal detection model parameters: bias and sensitivity. We estimated the signal detection theory parameters for the two base rate conditions (control vs high viral base rate) to test whether antibiotics expectations (i.e., the criterion location of the bias) change as a function of the base rate. In the high viral base rate condition, participants' responses deviated systematically from the optimal criterion, and they displayed liberally biased antibiotic expectations, mean deviation = -0.88, 95% Bayesian CI [-1.01, -0.76] compared with the control condition where participants did not display any liberally biased antibiotic expectations, mean deviation = -0.11, 95% Bayesian CI [-0.23, 0.02], (see Figure 30). Thus, hypothesis 2, that participants would display a more liberal antibiotic bias in the high viral base rate condition compared to the control condition, was confirmed.

Figure 30

The Signal Detection Model Parameters



Note. The figure shows the signal detection model parameters, sensitivity (d', that is the distance between the signal distribution, shown in blue, and the noise distribution, shown in grey) and bias (c, that is the extent to which the decision criterion deviates from the statistically optimal criterion), calculated by people's antibiotic expectations in the control condition (left plot) and the high viral base rate experimental condition (right plot). The vertical black bold lines represent the criterion location. The dashed grey lines represent the 95% Bayesian credible interval.

Discussion

The present two studies aimed to understand the effect of the base rate on people's antibiotic expectations using a utility-based signal detection theory approach to provide causal evidence and exact cognitive and computationally testable mechanisms behind people's antibiotic expectations. Specifically, in Study 5 we manipulated the base rate to approximate the real-world higher rates of viral vs bacterial illnesses such that 80% of the scenarios presented were modelled after viral illness not requiring antibiotic treatment. In Study 6, we aimed to provide evidence for the causal role of base rate by assigning people to either the high viral base rate condition (80% of scenarios do not require antibiotic treatment) or the control condition (50% of scenarios require an antibiotic treatment). Participants were presented with hypothetical medical scenarios modelled after the NICE and NHS clinical guidelines with varying symptoms and illness duration, and were asked to report their need for antibiotics as a treatment. Based on participants' responses, we then calculated the signal detection model parameters: bias and sensitivity.

Overall, in both studies, we found evidence for higher inappropriate antibiotic expectations when the decision environments approximated the real-world base rates of viral versus bacterial illnesses in line with our main hypotheses. Crucially, in Study 6, we also provided causal evidence for the effect of base rate on people's antibiotic expectations; participants expected antibiotics for conditions which were not clinically appropriate, thus displaying higher inappropriate antibiotic expectations in environments with higher rates of viral illnesses (high viral base rate condition) compared with environments with the same rates of viral and bacterial illnesses (control condition). The findings are also aligned with our model predictions, positing that people's higher inappropriate antibiotic expectations are due to an interplay between the diagnostic uncertainty and the environmental base rate of viral versus bacterial illnesses.

Our findings are also aligned with previous studies looking at different aspects of the base rate, such as prior experience, and finding evidence that past consultation behaviours and previous antibiotic treatment for viral infections are associated with greater expectations for antibiotics (Thorpe et al., 2021; Vinker et al., 2003). For instance, two studies show that between 74.40 and 81.80% of people who have received an antibiotic prescription for upper respiratory tract infections expect antibiotic treatment for them in the future (Emslie & Bond, 2003; Osborne & Sinclair, 2006). Moreover, our findings are also consistent with accounts of fluency suggesting that people use their fluency of processing information as an indicator of accuracy (Reber & Unkelbach, 2010), with prior exposure increasing the ease of processing the relevant information (Gawronski et al., 2023; Lewandowsky et al., 2012; Schwarz et al., 2007; Unkelbach et al., 2019). For example, studies using a signal detection theory analysis framework found that prior exposure can influence the identification of fake news in two functionally distinct ways: via response biases and discrimination sensitivity; participants' ability to discriminate between real and fake news decreased as a function of prior exposure, while their tendency to judge news regardless of their veracity increased as a function of prior exposure (Batailler et al., 2022; Pennycook et al., 2018).

Applied to our research question and findings, fluency accounts from the perspective of signal detection theory suggest that prior experience with antibiotic treatment for viral illnesses could influence the identification of clinical situations needing or not antibiotic treatment via response biases and discrimination sensitivity. First, prior experience with antibiotic treatment for viral illness might induce a tendency to judge similar illnesses or symptoms as needing antibiotics irrespective of whether they are actually needed or not.

Second, prior experience with antibiotic treatment for viral illnesses might reduce people's ability to discriminate between clinical cases of whether antibiotics are needed or not.

Future research could focus on testing the fluency account and the effect of prior exposure by controlling for participants' past antibiotic treatment and past consultation history to look at another aspect of the base rate while employing a signal detection theory approach. Another avenue going forward could be to train people on specific viral illnesses and symptoms accompanied by information that antibiotics are not needed for such illnesses to test whether prior exposure to such information would result in lower antibiotic expectations for viral illnesses and symptoms compared to participants who receive no such information.

Most studies finding evidence for inappropriate antibiotic expectations and requests for antibiotics have typically used the real-world environments where people tend to encounter many more cases of viral versus bacterial illnesses (i.e., McNulty et al., 2019), while others employing a vignettes approach have typically focused on specific illnesses (i.e., common cold or urinary tract infection; Sirota et al., 2022; Thorpe et al., 2020a, 2020b, 2021) without manipulating or controlling for the real-world rates of viral versus bacterial illnesses. Thus, our findings provide novel causal evidence for the effect of base rate and raise some important questions as they suggest that those inappropriate antibiotic expectations evidenced in prior research might not, in fact, be inappropriate or liberally biased, but rather a by-product of people's uncertainty in conjunction with the real-world high viral environment we all live in. The public's inappropriate expectations for antibiotics can then be seen as manifestations of diagnostic uncertainty in environments with high base rates of viral infections.

The findings have important implications for the theory as they provide novel causal evidence for the effect of base rate on people's antibiotic expectations, therefore, extending our understanding of the factors that drive people to expect antibiotics. They also clearly show that an interplay of uncertainty and base can account for peoples' antibiotic expectations and provide cognitive and computationally testable model predictions. The findings have also important implications for the practice as they can help tailor effective interventions to better communicate the diagnostic uncertainty to reduce it and by extension to reduce people's antibiotic expectations, and consequently the spread of antibiotic resistance.

Limitations

Several limitations of our research deserve more attention. First, even though we tried to manipulate the base rates of viral versus bacterial illnesses via the number of scenarios presented, we believe there are better ways of doing so to ensure ecological validity. Future research could assess and control for base rate by asking participants about their prior experiences regarding certain symptoms or illnesses and their antibiotic prescription history or even manipulate the base rate through training participants with certain symptoms and illnesses prior to the antibiotic scenarios. Second, even though we tried to approximate the real-world rates of viral versus bacterial illnesses based on published research (i.e., Creer et al., 2016), the actual percentage is not as clear-cut as there is a lot of variation in the data, especially when it comes to viral illnesses that can also develop bacterial complications. Future research could focus on other specific illnesses and manipulate the base rate for each illness based on the real-world available data to further test the effect of the base rate on people's antibiotic expectations and better approximate the real-world rates. Third, our studies focused on specific aspects of the decision environment, namely, base rate and uncertainty, but there might be a more complex interplay of factors besides the model parameters that can account for participants' decision-making. Future research could include and control for other important factors besides the cognitive mechanisms that could also account for participants' performance, such as cultural norms (Ventola, 2015), language (McNulty et al., 2022), knowledge (McNulty et al., 2022), and access to antibiotics and healthcare (Willis & Chandler, 2019).

Conclusion

To summarise, we found that people displayed higher inappropriate antibiotic expectations when the decision environments approximated the real-world higher rates of viral versus bacterial illnesses. Thus, the public's inappropriate expectations for antibiotics can be seen as manifestations of diagnostic uncertainty in environments with high base rates of viral infections, such as the real-world environment we all live in. We believe that the findings have important implications both for the theory, by providing cognitive and computationally testable mechanisms behind people's antibiotic expectations and extending our understanding of the factors that drive people to expect antibiotics, but also for the practice, by helping to tailor effective interventions to reduce people's inappropriate expectations, which will, in turn, reduce the spread of antibiotic resistance

CHAPTER 5

General Discussion

Overview

Antibiotic resistance is currently one of the biggest global health threats (Centers for Disease Control and Prevention, 2019) and is predicted to result in 10 million deaths per annum by 2050 if no action is taken to curtail its spread (Department of Health and Social Care, 2019; The Review on Antimicrobial Resistance, 2016). Even though antibiotic resistance is a natural process, human overuse and misuse accelerates this process (Public Health England, 2015). One of the main factors that contributes to the promotion and emergence of antibiotic resistance is the overuse of antibiotics within healthcare (Chatterjee et al., 2018; Goossens et al., 2005; Levy & Marshall, 2004; Ventola, 2015). Addressing the inappropriate use of antibiotics in health care is therefore one of the top priorities in the fight to tackle the spread of antibiotic resistance (Davies, 2018).

Antimicrobial use is fundamentally a human behaviour (Sirota et al., 2023). Thus, a better understanding of the behavioural and cognitive factors that drive or impede the inappropriate use of antibiotics in health care is crucial (Sirota et al., 2023). The public's expectations for antibiotics are critical in this effort as findings consistently indicate that people's antibiotic expectations contribute to antibiotic overuse within healthcare (Public Health England, 2015), and have been found among the strongest predictors of clinicians' decisions to prescribe antibiotics (Macfarlane et al., 1997; McNulty et al., 2013; Sirota et al., 2017; Welschen et al., 2004). However, despite the well-established link between patients' antibiotic expectations and antibiotic overprescribing, the factors underlying these expectations still remain unclear and a theoretical understanding is lacking (Donald, 2015).

In this thesis, to tackle the overuse of antibiotics in healthcare, we aimed to understand what drives people to expect antibiotics by employing a signal detection theory framework (Lynn & Barrett, 2014; Lynn et al., 2015) to provide causal evidence and exact cognitive and computationally testable mechanisms behind people's antibiotic expectations by disentangling the two distinct aspects underlying behaviour: sensitivity (the ability to accurately distinguish between clinical situations whether antibiotics are needed or not) and bias (the propensity to judge certain clinical situations as needing or not antibiotics). In a series of six pre-registered studies, we designed different decision environments by manipulating or eliciting the three important drivers of antibiotic expectations that map into the three main utility-based signal detection model parameters – payoffs (cost-benefit considerations), similarity (diagnostic uncertainty), and base rate (viral versus bacterial illnesses) - and presented participants with hypothetical medical scenarios for symptoms of respiratory tract infections and asked them to report their need for antibiotics as a treatment. From the responses to the antibiotic expectations variable, we then calculated utility-based signal detection theory model parameters underlying behaviour: bias and sensitivity.

Overall, we found that participants did not display any liberal bias towards antibiotics and that their antibiotic expectations can be better explained by diagnostic uncertainty; participants expected antibiotics for uncertain viral conditions where they were not clinically needed, but they also did not expect antibiotics for bacterial conditions where antibiotics were clinically required, thus erring equally on both sides. Moreover, we found that people displayed higher inappropriate antibiotic expectations when the decision environments approximated the real-world higher rates of viral versus bacterial illnesses. Thus, the public's inappropriate expectations for antibiotics can be seen as manifestations of diagnostic uncertainty in environments with high base rates of viral infections, such as the real-world environment we all live in.

The role of bias on antibiotic expectations

In Chapter 2, the main aim was to test the antibiotic scenarios that we created and the utility-based signal detection theory model. Participants were presented with 24 hypothetical medical scenarios modelled after the NICE clinical guidelines with varying symptoms and illness duration in four within-subjects uncertainty conditions (certain antibiotics are not needed, uncertain antibiotics are not needed, uncertain antibiotics are needed, certain antibiotics are needed) and were asked to report their need for antibiotics as a treatment. Based on participants' responses, we then calculated the signal detection model parameters underlying behaviour: bias and sensitivity.

Overall, the antibiotic scenarios worked as intended and participants were able to discriminate between the different symptom categories, with the two uncertain conditions displaying the greatest response variation. The function of the scenarios was further supported by an additional exploratory analysis which revealed that all the symptoms in the scenarios seemed to have a reliable influence on participants' decisions. However, contrary to our predictions, we found no evidence for a liberal antibiotic bias; participants' antibiotic expectations were not increased relative to the optimal strategy. Moreover, we similarly found no evidence for a more liberal bias in the uncertain versus certain conditions; participants' overall criterion location did not differ between the certain and uncertain conditions. We offered two possible explanations as to why this might be the case.

First, the findings seem to indicate that antibiotic expectations can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics (*uncertainty assumption*). Participants expected antibiotics for uncertain conditions where antibiotics are not needed but they also did not expect antibiotics for uncertain conditions where antibiotics *are* clinically appropriate. This is in line with our model prediction, positing that antibiotic expectations can be explained by diagnostic uncertainty, as well as with a significant body of evidence reporting that diagnostic uncertainty is one of the main drivers behind people's antibiotic expectations (Roberts et al., 2015; Simon et al., 2008; Sirota et al., 2022; Spicer et al., 2020; Szymczak et al., 2018; Thorpe et al., 2021).

Second, the observed findings might be due to methodological limitations (*methodological artefacts assumption*). Some of the potential methodological limitations identified include the number of scenarios and the length of the experiment, the wording of the scenarios, and the response scale used. It is important to further test the two accounts by removing the methodological limitations identified in a systematic manner to draw more robust and conclusive evidence.

Antibiotic decision outcomes: perceived payoffs and base rate

In Chapter 2, we were also interested in the association between participants' antibiotic expectations and their perceived payoffs and base rate so participants also completed a set of rating tasks of the four antibiotic decision outcomes (taking antibiotics when they are not needed, not taking antibiotics when they are needed, taking antibiotics when they are needed, and not taking antibiotics when they are not needed) to elicit their utility. Contrary to our prediction, the findings overall provide no evidence for an association between participants' antibiotic expectations (their bias and sensitivity) and their perceived payoffs and base rate in the four decision outcomes.

Regarding the payoffs, there is well-documented evidence in the literature that cost-benefit considerations are one of the key drivers of people's antibiotic expectations. For instance, people tend to overestimate the benefits of antibiotics to avoid the cost and the potential negative effects of missed illnesses (Roberts et al., 2015; Simon et al., 1996; Spicer et al., 2020; Thorpe et al., 2021), while they tend to underestimate the risks of side effects of antibiotics and the risks associated with antibiotic resistance (Finkelstein et al., 2014; Fletcher-Miles & Gammon, 2020; Halfvarsson et al., 2000; Roberts et al., 2015; Simon et al., 1996; Spicer et al., 2020; Szymczak et al., 2018; Thorpe et al., 2021). More recently, a study employing a signal detection theory framework found that increasing the saliency of the costs of antibiotic overuse decreased antibiotic expectations and requests in hypothetical consultations (Sirota et al., 2022).

Thus, it is important to note here that the lack of an observed association between participants' antibiotic expectations and their perceived payoffs and base rate is more likely due to the methodology employed for eliciting the utility for the payoffs and base rate in the four rating questions. The wording of the questions in this task was not optimal as it contained double negatives and was confusing at times, which was further corroborated by participants' comments at the end of the study. We believe that there are much better methods for manipulating the payoffs and base rate model parameters that future research could employ. For instance, one such method could be to manipulate the base rates of viral versus bacterial illnesses via the number of scenarios presented. Future research could also create different decision environments and manipulate the payoff parameter, such as by creating different cost environments via the use of monetary incentives. Another avenue for going forward would be to employ a behavioural game paradigm (Böhm et al., 2022) and model the payoff parameter and the costs associated with taking and not taking antibiotics via health points. This approach has been successfully used in a similar context to model the underlying social dilemma of antibiotic intake (Böhm et al., 2022; Santana et al., 2023a) and the diagnostic uncertainty in the context of delayed prescriptions (Santana et al., 2023b).

Antibiotic-related outcomes associated with false alarms and missed detections

In Chapter 2, we were also interested in how participants perceive several antibiotic-related outcomes associated with false alarms (taking antibiotics when they are not needed) and missed detections (not taking antibiotics when they are needed) so participants also had to rank eight outcomes associated with false alarms and eight outcomes associated with missed detections from best to worst. Even though we did not have any concrete hypotheses here as this was more of an exploratory task, some of the findings are still important and worth mentioning.

Interestingly, we found that the false alarm outcome "Getting an antibiotic-resistant infection" was only rated as the fourth-worst outcome in Study 1. This lower ranking might be due to participants' incomplete knowledge regarding antibiotic resistance. This is consistent with a systematic review that found that the general public often lack sufficient knowledge of antibiotic resistance and have misperceptions about it and its causes (McCullough et al. 2016). Moreover, several other studies report that participants identified resistance as a problem in hospitals, but they did not consider it an important problem (Carter et al., 2016; McNulty et al. 2010) and crucially failed to identify a threat to themselves, nor a perceived ability to influence antimicrobial resistance by minimising their own consumption (Brooks et al., 2008; Hawkings et al, 2007; McNulty, 2022). One of the most common misconceptions is that the human body becomes resistant to the antibiotic rather than the organism itself becoming resistant (Hawkings et al., 2007; Heid et al., 2016).

Even though public health campaigns increasingly include information about antibiotic resistance (Huttner et al., 2010), it is unclear whether the observed effects on antibiotic use are due to changes in the behaviour of physicians, patients, or both, or due to other confounding variables, while causal scientific evidence is limited (Huttner et al., 2010).

Moreover, a recent study looking at existing terminology associated with antimicrobial resistance found that existing antimicrobial resistance-related health terms, such as “AMR” and “Antimicrobial resistance”, are unsuitable for public health communication due to their low scores on both memorability and risk association (Krockow et al., 2023). Further work is needed to develop effective interventions for communicating the risks of antibiotic resistance and provide causal evidence for their effect on reducing people's antibiotic expectations and antibiotic overuse. For instance, future studies could extend the predictions of the signal detection theory model and focus on testing how the representation of the risks associated with antibiotic resistance affects people’s antibiotic expectations by manipulating different factors of risk representation (e.g. narrative evidence vs statistics, risk proximity in time and space, personal vs societal impact, different language framing terms for antibiotic resistance; Betsch et al., 2011; Krockow et al., 2023; Lewandowsky, 2021; Lewandowsky et al., 2021 Slovik, 1987;), with the goal to find the optimal framing format that will reduce inappropriate expectations. Furthermore, the findings from the ranking task here could similarly be used in a future study focusing on manipulating the payoffs parameter of the model. For example, the overall worst-ranked outcomes associated with false alarms and missed detections could be used to stress the cost of the false alarms and the missed detections verbally in the scenarios. Such studies could help identify which outcomes and factors related to antibiotic resistance have the biggest effect on participants’ antibiotic expectations by providing causal evidence, while potential findings from such studies could help tailor effective public health communication campaigns, as well as help improve the current patient communication leaflets.

The effect of uncertainty on antibiotic expectations

In Chapter 3, the main aim was to further test the *uncertainty assumption*, that antibiotic expectations can be better explained by diagnostic uncertainty, versus the *methodological artefacts assumption*, that the observed findings are due to methodological limitations, by designing different decision environments and removing some of the potential methodological limitation identified in Chapter 2. Specifically, in Study 2, we reduced the number of scenarios by half and reduced the survey length, while we also reworded the antibiotic scenarios to remove any ambiguous information and avoid any negations as these are harder to process. In Study 3, we invited back participants who took part in Study 2 and took the experimental design to its bare minimum by only presenting people with one antibiotic scenario with the aim to match their antibiotic expectations across the two studies. Finally, in Study 4, we used a binary response scale with an explicit (yes or no) response. Participants were presented with hypothetical medical scenarios modelled after the NICE clinical guidelines with varying symptoms and illness duration and were asked to report their need for antibiotics as a treatment. Based on participants' responses, we then calculated the signal detection model parameters underlying behaviour: bias and sensitivity.

Overall, participants did not display any liberally biased antibiotic expectations and the findings provide evidence for the *uncertainty assumption* and seem to indicate that expectations for antibiotics can be better explained by diagnostic uncertainty rather than a genuine bias towards antibiotics: participants expected antibiotics for uncertain conditions where antibiotics are not clinically needed but also did not expect antibiotics for uncertain conditions where antibiotics *were* clinically appropriate. This is in line with our model prediction, positing that diagnostic uncertainty can account for people's antibiotic expectations.

The findings are also consistent with past research finding that diagnostic uncertainty is one of the main drivers of people's antibiotic expectations (Braun & Fowles, 2000; Kong et al., 2022; McNulty et al., 2013, 2019; Thorpe et al., 2021; Welschen et al., 2004). Several studies have reported that people are often confused about the nature of their illness and whether their symptoms are due to a viral or bacterial aetiology (Heikkinen & Järvinen, 2003; Tan et al., 2008; Thorpe et al., 2021; Turner, 2010). For instance, uncertainty regarding the nature of their illness predicted people's expectations for antibiotics for their recent cold-like symptoms (Thorpe et al., 2021), while past findings showed that uncertainty might induce a "better to be safe than sorry" thinking and prompt people to expect antibiotics even when the disease is not caused by bacteria (Broniatowski et al., 2015). Moreover, people are often uncertain regarding antibiotic use (Braun & Fowles, 2000; McNulty et al., 2013, 2019; 2022; Welschen et al., 2004). For example, past studies show that people often inappropriately expect antibiotics for viral infections (McNulty et al., 2019; Kong et al., 2022), and often think that antibiotics can kill viruses, and are effective against most colds and coughs (McNulty et al., 2007). More recently, a public survey in England found that about one-third of respondents incorrectly stated that antibiotics can effectively treat viral or fungal infections (McNulty et al., 2022), while many respondents did not know that antibiotics work for 'the majority of urine infections' (McNulty et al., 2022). Such erroneous misconceptions and beliefs have been found to reliably predict people's inappropriate expectations for antibiotics (Broniatowski et al., 2018; Sirota et al., 2022; Thorpe et al., 2021).

Past research using similar symptomatic vignettes found evidence for higher inappropriate antibiotic expectations that are not clinically warranted (Thorpe et al., 2020a, 2020b), while a more recent study employing a signal detection theory framework and manipulating uncertainty found that in high uncertainty environments, participants often displayed higher antibiotic expectations and a more liberal decision strategy (Sirota et al., 2022). However, most of these studies have typically focused on uncertain clinical cases where antibiotics are not clinically warranted, such as for cold-like symptoms and acute ear infections (Thorpe et al., 2020a, 2020b; Sirota et al., 2022), or for certain cases where antibiotics are clinically needed, such as for kidney bacterial infections (Sirota et al., 2022), without controlling for or taking into account all the possible uncertainty levels. Thus, our findings building on those of past research provide novel evidence for the effect of uncertainty as they suggest that when taking into context the different uncertainty levels, people tend to err on both sides (they expect antibiotics for uncertain viral conditions where antibiotics are not clinically needed but they also do not expect antibiotics for uncertain bacterial conditions where antibiotics *are* clinically appropriate), thus indicating that participants are not actually biased but rather well-calibrated. Indeed, aligned with the findings, studies looking at people's knowledge regarding antibiotics efficacy have found that people similarly err on both sides: they inappropriately think that antibiotics are effective for viral conditions, such as the common cold, but they also inappropriately think that antibiotics are *not* effective for bacterial conditions, such as urinary tract infections (McNulty et al., 2022).

Future research could build on our findings about the effects of diagnostic uncertainty on antibiotic expectations using a signal detection theory approach and aim to extend them to a more applied setting by helping to develop effective applied interventions to best communicate the diagnostic uncertainty. This is also in line with past research calling for more studies on communication intervention methods to help manage uncertainty (Tarrant & Krockow, 2021), as well as the recent policy brief on an antimicrobial resistant agenda calling for developing (cost-) effective behavioural change interventions to mitigate the spread of antimicrobial resistance emergence by targeting and engaging the general public, health-care providers, mass media and policymakers across socioeconomic settings (World

Health Organisation, 2023). For example, future research could experimentally investigate the communication strategies that family physicians can use to reduce patients' diagnostic uncertainty, and consequently their expectations for antibiotics, while using a signal detection theory framework and assigning people to experimental conditions with different levels of clinical information provided. Such a study would not only be cost-effective as it could easily be administered online targeting the general public, but it would also have significant practical relevance and help the clinical community to improve antibiotic stewardship efforts and develop effective interventions to reduce people's diagnostic uncertainty and their antibiotic expectations, and consequently the spread of antibiotic resistance (Theodoropoulou et al., 2024).

It is also possible that in addition to the uncertainty, people may not be able to take into account the base rate – the prior probability of bacterial and viral infections - in their decisions about antibiotics. In all the above studies, we used a fixed base rate such that half of the scenarios presented required an antibiotic treatment. However, this base-rate differs greatly from the real-world rates of viral versus bacterial illnesses as people tend to encounter many more cases of viral illnesses in their daily lives (i.e., Creer et al., 2016). It is, therefore, important to also test the effect of base rate on people's antibiotic expectations by designing decision environments closer to the real-world base rates of viral versus bacterial illnesses.

The effect of base rate on antibiotic expectations

In Chapter 4, the main aim was to test the effect of the base rate on people's antibiotic expectations while employing a utility-based signal detection theory framework. Specifically, in Study 5, we manipulated the base rate to approximate the real-world higher rates of viral vs bacterial illnesses by presenting participants with 16 antibiotic scenarios and setting the base rate at 0.2 (i.e., 80% of scenarios were modelled after viral illnesses and did not require antibiotic treatment). In Study 6, we aimed to provide causal evidence for the effect of base rate, or lack thereof, on people's antibiotic expectations; participants were assigned to either the high viral base rate condition (80% of scenarios do not require antibiotic treatment) or the control condition (50% of scenarios require an antibiotic treatment). Participants were presented with hypothetical medical scenarios modelled after the NICE and NHS clinical guidelines with varying symptoms and illness duration and were asked to report their need for antibiotics as a treatment. Based on participants' responses, we then calculated the signal detection model parameters underlying behaviour: bias and sensitivity.

Aligned with our predictions, in both studies, we found evidence for higher inappropriate antibiotic expectations when the decision environments approximated the real-world base rates of viral versus bacterial illnesses; participants displayed a liberal antibiotic bias in the decision environments with higher rates of viral illnesses. Crucially, in Study 6, we also provided causal evidence for the effect of base rate on people's antibiotic expectations; participants displayed higher inappropriate antibiotic expectations in environments with higher rates of viral illnesses (viral base rate condition) compared with environments with the same rates of viral and bacterial illnesses (control condition). Thus, the public's inappropriate expectations for antibiotics can be seen as manifestations of diagnostic uncertainty in environments with high base rates of viral infections. The findings are aligned with our model prediction, positing that the base rate in conjunction with the diagnostic uncertainty, can account for people's antibiotic expectations.

The findings are also aligned with previous studies looking at different aspects of base rate, such as prior experience, and finding evidence for an association between past consultation behaviours and previous antibiotic treatment for viral infections with greater expectations for antibiotics (Thorpe et al., 2021; Vinker et al., 2003), while several studies have reported that the majority of people receiving an antibiotic prescription for upper respiratory tract infections expect antibiotics for them in the future (Emslie & Bond, 2003; Osborne & Sinclair, 2006). Similarly, participants in England who reported receiving antibiotics in the last year were much more likely to say, ‘antibiotics will always speed up my recovery’ (McNulty et al., 2022).

Moreover, past studies reporting higher inappropriate antibiotic expectations for viral illnesses have typically used the real-world environments where people tend to encounter many more cases of viral versus bacterial illnesses (i.e., McNulty et al., 2019), while others employing a similar hypothetical symptomatic vignette approach have typically focused on specific illnesses, such as the common cold and kidney infections ear infections (Sirota et al., 2022; Thorpe et al., 2020a, 2020b, 2021) without manipulating or controlling for the real-world rates of viral versus bacterial illnesses. Our findings, therefore, provide novel experimental evidence and computationally testable model predictions for the effect of base rate on people’s antibiotic expectations. They also raise some important questions as they suggest that those inappropriate antibiotic expectations evidenced in prior research might not, in fact, be inappropriate or liberally biased, but rather a by-product of people’s diagnostic uncertainty in conjunction with the high real-world viral environment we all live in.

It is worth noting here that even though we tried to manipulate the base rates of viral versus bacterial illnesses via the number of scenarios presented, we believe there are better ways of doing so to ensure ecological validity. For instance, future research could assess and control for the base rate by asking participants about their prior experiences regarding certain symptoms or illnesses and their antibiotic prescription history or even manipulate the base rate by training participants with certain symptoms and illnesses prior to the antibiotic scenarios. Moreover, even though we found evidence for the effects of base rate and uncertainty on people’s antibiotic expectations, there might be a more complex interplay of factors besides the cognitive model parameters that can account for participants’ decision-making. For instance, several other important social and structural factors might similarly influence participants' decision-making, such as cultural norms, access to antibiotics and healthcare, prosociality, language, insufficient knowledge of antibiotic efficacy and illness aetiology, and barriers to obtaining antibiotics (Ancillotti et al., 2023; Krockow et al., 2022; McNulty et al., 2019; Santana et al., 2023a; Ventola, 2015; Willis & Chandler, 2019). Future work could attempt to incorporate all relevant factors related to people's antibiotic expectations-related behaviour with the aim to develop a complete theoretical framework and identify suitable intervention strategies for reducing people's antibiotic expectations. For instance, the COM-B model (Michie et al., 2011) is an excellent such framework as it includes a range of both internal determinants and external factors forming a "behaviour system" of three main conditions – capacity, opportunity, and motivation – which are then mapped into nine intervention functions aimed at addressing deficits in said conditions and guide the identification of suitable interventions and policies, forming a "behaviour change wheel" (BCW; Michie et al., 2011, 2014). For example, interventions aiming to reduce people's antibiotic expectations by promoting their decision capability could focus on improving communication about abstract base rates of viral and bacterial illnesses. Another way going forward could be to focus on increasing their decision capability by reducing their diagnostic uncertainty by communicating the results of clinical point-of-care tests, such as CRP (Tonkin-Crine et al., 2017; Theodoropoulou et al., 2024).

Implications

Theoretical

Our findings have important theoretical implications as they advance the current literature on people's antibiotic expectations and extend our understanding of the factors that drive people to expect antibiotics. They successfully corroborate the utility-based signal detection account of antibiotic expectations (Lynn & Barrett, 2014; Lynn et al., 2015; Sirota et al., 2022) while leveraging the computational nature of the theory to provide exact cognitive and computationally testable model predictions behind people's antibiotic expectations. Specifically, our findings provide novel causal and computationally testable evidence for the effects of uncertainty and base rate on people's antibiotic expectations; they show that the public's inappropriate antibiotic expectations can be explained by diagnostic uncertainty in environments with high base rates of viral illnesses. The findings extend our theoretical understanding of the drivers behind people's antibiotic expectations and can help inform national efforts to reduce people's antibiotic expectations, and consequently, antibiotic over-prescribing.

Methodological

Our findings also have significant methodological implications as they extend prior research findings of using the signal detection theory approach and they provide the first evidence of leveraging the computational nature of the theory to provide exact quantitative and computationally testable model predictions. Moreover, they extend the methods used in prior research for measuring people's antibiotic expectations by including a much bigger number of hypothetical medial scenarios modelled after illnesses not usually featured in prior research, such as bronchitis and pneumonia, and by crucially manipulating the diagnostic uncertainty in the scenarios to take into account its effect on people's antibiotic expectations. Finally, our studies are the first to directly manipulate the bare rate of viral versus bacterial illnesses by modelling the decision environments to approximate the real-world higher rate of encountering viral illnesses, and they provide the first causal evidence for the effect of base rate on people's antibiotic expectations.

Clinical

Our findings also have important practical implications as they can help the clinical community to improve antibiotic stewardship efforts and develop effective interventions to best communicate the risks associated with antibiotic resistance, as well as help tailor effective communication interventions aimed at reducing the diagnostic uncertainty of patients and at improving their understanding of disease base rates. For example, future studies could focus on testing different communication methods aimed at reducing people's diagnostic uncertainty by providing them with different levels of clinical information, such as information regarding the nature of their illness and the efficacy of antibiotics, as well as the results of point-of-care tests (Tonkin-Crine et al., 2017) to see their effect on people's antibiotic expectations. Such cost-effective intervention studies aimed at reducing the antibiotic expectations of the general public would have important implications for health risk communication for healthcare providers, media outlets, and national and international health organisations, while they could also help improve the current patient information leaflets, and consequently help reduce the overuse of antibiotics and the spread of antibiotic resistance.

General limitations and future directions

There are several limitations that deserve readers' attention. First, even though we followed the NICE and NHS guidelines for constructing the antibiotic scenarios and used realistic and familiar medical situations and similar symptomatic scenarios to those used in prior research (i.e., Roope et al., 2020; Sirota et al., 2017, 2022; Thorpe et al., 2020a, 2020b, 2021), our participants were not making decisions about antibiotics based on currently experiencing an actual illness, which limits the ecological validity of the findings. However, given that our main focus was to test the cognitive mechanisms underlying people's antibiotic expectations, we believe that this is not a substantial drawback. Nevertheless, future research could test the proposed mechanisms on patients currently experiencing symptoms of respiratory tract infections to provide more robust evidence and ensure ecological validity, as well as to validate the vignettes and observe whether participants' judgements will differ when they are the ones experiencing the symptoms. This would substantially advance our understanding of how patients suffering from respiratory tract infections think about antibiotics and make decisions about their health, and how these differ from hypothetical medical situations.

Second, we used a nonrepresentative and non-random sample drawn from a general adult population of UK residents. Future research could use a more representative sample randomly drawn from the general adult population to further establish the robustness of the studies. It is also possible that participants' prior beliefs and prescription practices of their country of origin might play a role in their reported antibiotic expectations and result in different findings to those observed with the UK samples used here. In many other countries, antibiotics are unregulated and available over the counter without a prescription, which promotes overuse and leads to an increase in antibiotic expectations (Laxminarayan, & Heymann, 2012; Morgan et al., 2011; Torres et al., 2019; Ventola, 2015). Future research could therefore look at cultural differences by collecting data from various countries with differing antibiotic practices to test the effect of culture on antibiotic expectations and extend the generalisation of the findings.

Third, our scenarios were modelled after respiratory tract infections. Future research could use a wider range of illnesses, particularly those receiving less media coverage. For instance, a high number of people incorrectly believe that antibiotics work for most ear infections, while around one-fourth of respondents incorrectly believe that antibiotics do not work for most urinary tract infections (McNulty et al., 2022). However, these receive far less media coverage as the majority of public health communication campaigns have focused on respiratory tract infections (Haynes & McLeod, 2015; Huttner et al., 2010; Thoolen et al., 2012) with calls for more qualitative and quantitative research needed to explore the public's understanding and antibiotic preferences regarding other illnesses to inform effective interventions (McNulty et al., 2022). Future research could, thus, focus on hypothetical scenarios for symptoms of ear infections and urinary tract infections to extend the generalisation of the findings and extend our understanding of how people view and understand different illnesses.

Final summary

The inappropriate prescribing of antibiotics in healthcare fuels the spread of antibiotic resistance, while people's antibiotic expectations have been found among the strongest predictors of clinicians' decisions to prescribe antibiotics. However, the factors underlying these expectations still remain unclear and a theoretical understanding is lacking. The main focus of this thesis was to test the utility-based signal detection theory and its main parameters mapping into the antibiotic drivers of people's antibiotic expectations - diagnostic uncertainty, base rate, and payoffs - to better understand the factors driving people to expect antibiotics and provide exact cognitive and computationally testable model predictions.

In summary, we found that people's inappropriate antibiotic expectations can be better explained by diagnostic uncertainty rather than a genuine bias toward antibiotics; participants expected antibiotics for uncertain conditions where antibiotics are not needed but they also did not expect antibiotics for uncertain conditions where antibiotics *are* clinically appropriate, thus erring on both sides and indicating that they are not biased bur rather well-calibrated. Moreover, we found that people displayed higher inappropriate antibiotic expectations when the decision environments approximated the real-world higher rates of viral illnesses compared to environments with the same rates of viral and bacterial illnesses.

Taken together, our findings imply that the public's inappropriate expectations for antibiotics can be seen as manifestations of diagnostic uncertainty in environments with high base rates of viral infections, such as the real-world environment we all live in.

The findings have important implications both for the theory and the practice. They provide novel causal, cognitive, and computationally testable evidence for the effects of uncertainty and base rate on people's antibiotic expectations, and extend the current literature on the factors that drive people to expect antibiotics. Moreover, the findings offer many clear directions for future work to build on and they can help tailor effective interventions to best communicate the diagnostic uncertainty and the risks associated with antibiotic resistance to reduce people's inappropriate antibiotic expectations, which will in turn reduce the spread of antibiotic resistance.

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APPENDIX

Pre-test

Antibiotic Scenarios

Certain (antibiotics not needed)

1) For the past **three days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough with no phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

2) For the past **five days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough with no phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

3) For the past **seven days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough with no phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

4) For the past **three days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **clear phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

5) For the past **five days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **clear phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

6) For the past **seven days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **clear phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

Uncertain (antibiotics not needed)

1) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

2) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

3) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm** and a **raised temperature of around 37.5C.** However, you have **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

4) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **green phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

5) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **green phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

6) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **green phlegm** and a **raised temperature of around 37.5C.** However, you have **no breathlessness**. Upon examination, your GP tells you that they do not hear **any crackling or wheezing** in your lungs.

Uncertain (antibiotics needed)

1) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough with no phlegm**. Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C**. However, you have **no breathlessness**. Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

2) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm**. Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C**. However, you have **no breathlessness**. Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

3) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **green phlegm**. Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C**. However, you have **no breathlessness**. Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

4) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough with no phlegm**. Moreover, you have been feeling **breathless**. However, you have **no high temperature.** Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

5) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.**

You have also developed a **hacking cough** which brings up **yellow phlegm**. Moreover, you have been feeling **breathless**. However, you have **no high temperature.** Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

6) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **green phlegm**. Moreover, you have been feeling **breathless**. However, you have **no high temperature.** Upon examination, your GP tells you that they hear **some wheezing** in your lungs.

Certain (antibiotics needed)

1) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue**. You have also developed a **severe hacking cough** which brings up **yellow phlegm**. Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C**. However, you have **no increased breathlessness**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

2) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue**. You have also developed a **severe hacking cough** which brings up **green phlegm.** Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C**. However, you have **no increased breathlessness**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

3) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **severe hacking cough** which brings up **phlegm stained with blood.** Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C**. However, you have **no increased breathlessness**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

4) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **severe hacking cough** which brings up **yellow phlegm.** Moreover, for the past **four days** you have been experiencing a **high**

temperature of around 38.5C and you have been feeling **increasingly breathless**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

5) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **severe hacking cough** which brings up **green phlegm.** Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C** and you have been feeling **increasingly breathless**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

6) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **severe hacking cough** which brings up **phlegm stained with blood.** Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C** and you have been feeling **increasingly breathless**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

Study 1

Rating task of the four antibiotic decision outcomes

Instructions: Below are four potential decision situations associated with taking or not taking antibiotics. Please imagine that the below situations apply to you.

Consequences of not taking antibiotics when they are needed

Now try to think about the situation when you do not take antibiotics when they are needed and its possible consequences

How bad or good are the consequences of not taking antibiotics when they are needed?

Give your rating on the scale below from 0 (extremely bad) to 100 (extremely good).

How likely is the situation of not taking antibiotics when they are needed to happen to you?

Give your rating on the scale below from 0 (certain it will **NOT** happen) to 100 (certain it **will** happen).

Now, assume that you did not take antibiotics when they are needed.
How likely are the consequences of not taking antibiotics when they are needed to happen?

Give your rating on the scale below from 0 (certain they will **NOT** happen) to 100 (certain they **will** happen).

What are the consequences of not taking antibiotics when they are needed?

Give your answer by writing on the box below.

Consequences of taking antibiotics when they are not needed

Now try to think about the situation when you take antibiotics when they are not needed and its possible consequences

How bad or good are the consequences of taking antibiotics when they are not needed?

Give your rating on the scale below from 0 (extremely bad) to 100 (extremely good)

How likely is the situation of taking antibiotics when they are not needed to happen to you?

Give your rating on the scale below from 0 (certain it will **NOT** happen) to 100 (certain it **will** happen).

Now, assume that you took antibiotics when they are not needed.
How likely are the consequences of taking antibiotics when they are not needed to happen?

Give your rating on the scale below from 0 (certain they will **NOT** happen) to 100 (certain they **will** happen).

What are the consequences of taking antibiotics when they are not needed?

Give your answer by writing on the box below.

Consequences of taking antibiotics when they are needed

Now try to think about the situation when you take antibiotics when they are needed and its possible consequences

How bad or good are the consequences of taking antibiotics when they are needed?

Give your rating on the scale below from 0 (extremely bad) to 100 (extremely good)

How likely is the situation of taking antibiotics when they are needed to happen to you?

Give your rating on the scale below from 0 (certain it will **NOT** happen) to 100 (certain it **will** happen).

Now, assume that you took antibiotics when they are needed.
How likely are the consequences of taking antibiotics when they are needed to happen?

Give your rating on the scale below from 0 (certain they will **NOT** happen) to 100 (certain they **will** happen).

What are the consequences of taking antibiotics when they are needed?

Give your answer by writing on the box below.

Consequences of not taking antibiotics when they are not needed

Now try to think about the situation when you do not take antibiotics when they are not needed and its possible consequences

How bad or good are the consequences of not taking antibiotics when they are not needed?

Give your rating on the scale below from 0 (extremely bad) to 100 (extremely good)

How likely is the situation of not taking antibiotics when they are not needed to happen to you?

Give your rating on the scale below from 0 (certain it will **NOT** happen) to 100 (certain it **will** happen).

Now, assume that you did not take antibiotics when they are not needed.
How likely are the consequences of not taking antibiotics when they are not needed to happen?

Give your rating on the scale below from 0 (certain they will **NOT** happen) to 100 (certain they **will** happen).

What are the consequences of not taking antibiotics when they are not needed?

Give your answer by writing on the box below.

Study 2

Antibiotic scenarios

Certain (antibiotics not needed)

1) For the past **three days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **dry hacking cough**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

2) For the past **five days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **dry hacking cough**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

3) For the past **seven days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **dry hacking cough**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

4) For the past **three days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **clear phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

5) For the past **five days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **clear phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

6) For the past **seven days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **clear phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

Uncertain (antibiotics not needed)

1) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

2) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that they hear **wheezing** in your lungs.

3) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **yellow phlegm** and a **raised temperature of around 37.5C.** However, you have **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

4) For the past **fourteen days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **hacking cough** which brings up **green phlegm**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.

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Uncertain (antibiotics needed)

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no breathlessness. Upon examination, your GP tells you that they hear **wheezing** in your lungs.

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Certain (antibiotics needed)

1) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue**. You have also developed a **severe hacking cough** which brings up **yellow phlegm**. Moreover, for the past **four days** you have been experiencing a **high**

temperature of around 38.5C and you have been feeling **moderately breathless**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

2) For the past **twenty-one days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue**. You have also developed a **severe hacking cough** which brings up **green phlegm.** Moreover, for the past **four days** you have been experiencing a **high temperature of around 38.5C** and you have been feeling **moderately breathless**. Upon examination, your GP tells you that they hear **crackling** in your lungs.

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Study 5

Antibiotic scenarios

High viral base rate condition

NOT NEED

1) For the past **three days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **dry hacking cough**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.
2) For the past **five days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **dry hacking cough**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.
3) For the past **seven days** you have been feeling ill. You have had a **sore throat** and a **runny nose**, and you have been experiencing **muscle aches** and **general fatigue.** You have also developed a **dry hacking cough**. However, you have a **normal temperature** and **no breathlessness**. Upon examination, your GP tells you that your lungs sound **clear**.
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Study 6

Antibiotic scenarios

High viral base rate condition

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Control condition

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